NORTHWEST AFRICA 5400/6077: DECIPHERING THE ORIGIN OF THE MYSTERIOUS ACHONDRITE WITH A NEW LOOK AT THE ISOTOPIC COMPOSITION.

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Introduction: The achondrite Northwest Africa (NWA) 5400 and its paired stones NWA 6077/5363 have been puzzling meteorites since their first identification in 2008. NWA 5400 displays mineralogical and textural similarities to brachinites, resulting in an initial description of being a brachinite-like meteorite [1]. However, unlike brachinites, the oxygen isotopic composition of NWA 5400 and its paired stones are indistinguishable from that of terrestrial rocks [1-4]. Initial measurement of the Cr isotopic composition of NWA 5400 [2] indicated an ε^{54}Cr value similar to terrestrial samples within error. The similarity in O and Cr isotopic composition was used to suggest the reservoir from which NWA 5400 formed may have been isotopically similar to the Earth [2]. There are, however, some notable differences between NWA 5400 and Earth. Recent work [4] determining the isotopic composition for O, Ca, Ti, Ni, Mo, and Ru showed that the NWA 5400-Earth isotopic similarity is not seen for all elements. In particular, while [4] observed similarity in O and Ni between NWA 5400/5363, and Earth, other elements, such as Ca, Ti, Mo, and Ru are isotopically distinct from Earth. As such, the composition of the source reservoir of NWA 5400 is still an open question.

While a full understanding of the isotopic composition of the NWA 5400 source reservoir is still being established, the formation age of NWA 5400 is also not well constrained. Initial work investigating the Pb-Pb age [5] did not yield a crystallization age, a result of the input of terrestrial Pb due to weathering. Attempts to date by U-Pb with SIMS was also not successful due to high common Pb isotopic composition in the datable minerals, such as apatites (Yin et al., unpublished). The Mn-Cr systematics reported by [2] provided an isochron with a slope of zero and an upper limit age of ≤4541 Ma. In contrast, the Hf-W system provides an ancient model age of 1.2 ± 0.5 Ma after CAIs potentially indicating the timing of metal-silicate segregation [4] and the I-Xe system an age of 4568.9 ± 0.6 Ma [6]. As such, the chronology provides both evidence for disturbance and undisturbed I-Xe systematics.

Here, we take a new look at the Cr isotopic composition of NWA 5400/6077 and the ^{53}Mn-^{53}Cr age.

Analytical Methods: Two separate aliquots were analyzed: a whole-rock sample from NWA 5400 and chromite grains separated from NWA 6077. Sample digestion procedures, column chemistry, and mass spectrometry methods for the analysis of the Cr isotopic composition and ^{55}Mn/^{52}Cr ratios are described in [7].

Results and Discussion: Both the bulk NWA 5400 sample and chromite grains from NWA 6077 analyzed in this study have deficits in ε^{54}Cr of -0.26 ± 0.08 and -0.36 ± 0.09, respectively. These two values are well resolved from the terrestrial composition and from the previously reported ε^{54}Cr of 0.00 ± 0.11 and 0.14 ± 0.11 by [2].

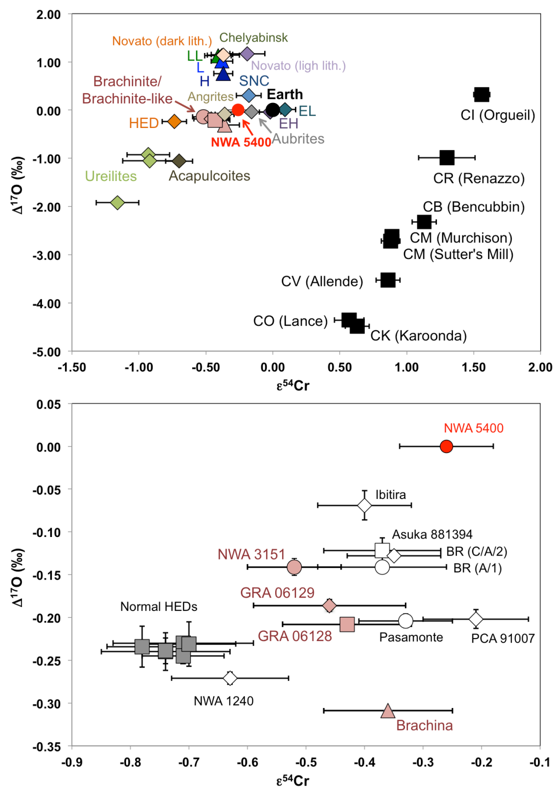

Figure 1. (top) NWA 5400 with other meteorite groups in Δ^{17}O-ε^{54}Cr isotope space. (bottom) Magnified view, where pink symbols are brachinites, grey filled symbols are normal HEDs, and open symbols are anomalous HEDs. Literature Δ^{17}O and ε^{54}Cr data from [7] and references therein.

As shown in Fig. 1, NWA 5400 plots in a region of Δ^{17}O-ε^{54}Cr isotope space that contains other meteorite groups, including the brachinites and anomalous eucrites. The initial petrographic descriptions of NWA 5400 [1] indicated a resemblance to brachinites. However, combined ε^{54}Cr–Δ^{17}O systematics appear to preclude such a connection ([7] and Fig. 1). It is likely

NWA 5400/6077 originated from a broadly similar geochemical and isotopic reservoir and possibly in close spatial proximity in the solar nebula. An increasing number of achondrites (brachinites, anomalous eucrites, and NWA 5400) have now been found to have a similar deficit in ε^{54}Cr. The diverse range of meteorite types encompassing a moderately narrow Cr compositional range is an indicator of the diversity of differentiation processes under variable physicochemical conditions occurring in the early Solar System within a close spatial range.

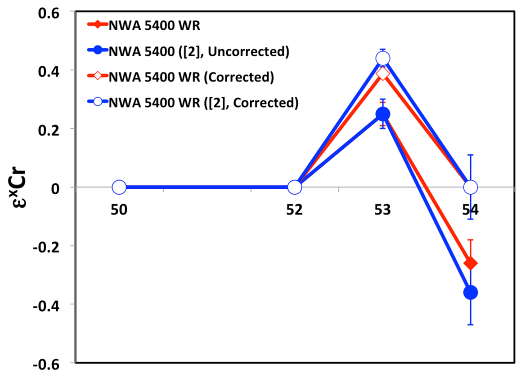

Figure 2. Effect of 2nd order correction. Filled red diamonds are the measured NWA 5400 WR in this study. Open red diamonds are the result of performing a 2nd order correction and setting ε^{54}Cr = 0. The open blue circles are the reported Cr composition in [2] and the filled blue circle are the uncorrected composition using the ε^{53}Cr reported here and in [2] to calculate the needed ε^{54}Cr to generate the observed difference.

The ε^{53}Cr values obtained for the NWA 5400 whole-rock (0.25 ± 0.04) and NWA 6077 chromite fractions (0.21 ± 0.04) are identical within error. These ε^{53}Cr values are resolvably different than the ε^{53}Cr reported by [2] of 0.44 ± 0.03, who also saw no variation among the whole-rock and mineral separates within errors. The significant difference (~20 ppm) between two studies requires further explanation. Although not explicitly stated by [2], it is possible that the ^{53}Cr data in [2] was corrected by a 2nd-order correction as in [8] using the ^{54}Cr/^{52}Cr ratio. As shown in Fig. 1 of [2], the ε^{54}Cr has two reported values in that study, one of them was 0.00 ± 0.11 and the other was 0.14±0.11. If there were a deficit in ε^{54}Cr, as determined here, and a second-order correction was applied as in [2,8] it would artificially raise the ε^{53}Cr. Fig. 2 shows the effect of applying a second order correction, setting ε^{54}Cr=0, to our data. Such a correction would increase the ε^{53}Cr to 0.39±0.04 and 0.40±0.04 for NWA 5400 and 6077, respectively. These values agree perfectly with 0.44±0.03 [2] within error. An isochron slope would remain unaffected so long as ε^{54}Cr is uniform among different phases (ε^{54}Cr = -0.26 ± 0.08 and -0.36 ± 0.09, respectively for the whole rock and chromite samples). Conversely, using the ε^{53}Cr and associated errors from both this study and [2], an ε^{54}Cr of -0.36 ± 0.05 and -0.43±0.05 are calculated following [9] (Fig. 2). These calculated ε^{54}Cr values are, within error, the same as that measured in the aliquot of NWA 5400 and the chromite fraction of NWA 6077 in this work.

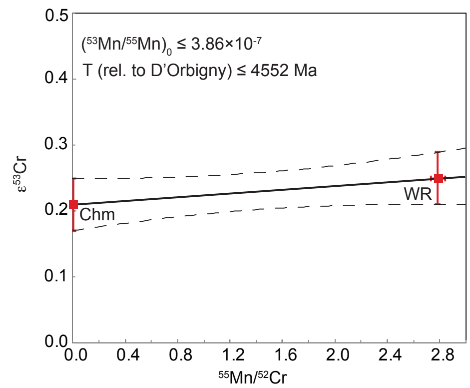

Figure 3. ^{53}Mn-^{53}Cr isochron tie line for NWA 5400 whole-rock (WR) and NWA 6077 chromite (Chm).

Using the whole-rock NWA 5400 sample and the chromite grains from NWA 6077, it is possible to calculate the slope of an isochron tie-line between the two points (Fig. 3). The chromite grains anchor the tie-line with a ^{55}Mn/^{52}Cr ratio of 0.004 and the NWA 5400 whole-rock has a moderately high ^{55}Mn/^{52}Cr ratio of 2.786. The resulting tie-line has a slope (initial ^{53}Mn/^{55}Mn) of 1.59(±2.27)×10^{-7}. Anchoring to the Pb-Pb corrected age of D'Orbigny [10,11] and its initial ^{53}Mn/^{55}Mn [12], this slope results in an upper limit age of ≤ 4552 Ma. In contrast, the upper limit obtained previously by [2] was an order of magnitude smaller at ≤4.23×10^{-8}. Consistent with the earlier study of NWA 5400 [2], the Mn-Cr systematics determined here do not provide a robust crystallization age, although the extreme upper limit obtained here is approximately 10 Ma earlier than that reported by [2], but younger than the measured Hf-W and I-Xe ages [4,6]. The lack of live ^{53}Mn at the time of last equilibration of the Cr isotopic composition indicates thermal activity on the parent body of NWA 5400/6077 occurred well after the formation ages of other achondrite groups (e.g., [10,11]).

References: [1] Irving A. J. et al. (2009) *LPS XL*, A#2332. [2] Shukolyukov A. et al. (2010) *LPS XLI*, A#1492. [3] Day J. M. D. et al. (2012) *GCA, 81*, 94. [4] Burkhardt C. et al. (2015) *LPS XLVI,* A#2737. [5] Amelin Y. & Irving A. J. (2011) *74th MetSoc*, A#5197. [6] Pravdivtseva O. et a. (2015) *78th MetSoc*, A#5387. [7] Sanborn M. E. & Yin Q.-Z. (2015) *LPS XLVI,* A2241. [8] Lugmair G. and Shukolyukov A. (1998) *GCA, 62,* 2863. [9] Trinquier A. et al. (2008) *JAAS, 23,* 1557. [10] Brennecka G. & Wadhwa M. (2012) *PNAS, 109,* 9299. [11] Amelin Y. (2008) *GCA, 72,* 221. [12] Glavin D. P. et al. (2004) *MAPS, 39,* 693.