CONSTRAINTS ON THE FORMATION AGE, HIGHLY SIDEROPHILE ELEMENT BUDGET AND NOBLE GAS ISOTOPE COMPOSITIONS OF NORTHWEST AFRICA 5400: AN ULTRAMAFIC ACHONDRITE WITH TERRESTRIAL ISOTOPIC CHARACTERISTICS.

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Introduction: Northwest Africa 5400 is a brachinite-like achondrite meteorite that is remarkable for having an oxygen isotopic composition indistinguishable from that of the Earth and Moon [1]. Continued studies of this specimen have focused on attempts to assess its formation age utilizing various short-lived extinct radionuclides, determination of the abundances and isotopic composition of highly siderophile elements, and noble gas isotope compositions. Here we report the results of these ongoing studies, as well as new measurements of oxygen isotopic composition.

Mn-Cr Isotope Systematics and ^{54}Cr/^{52}Cr Ratio: This work is a continuation of our effort to improve our understanding of the early evolutionary period of the Solar System by applying ^{53}Mn-^{53}Cr systematics to NWA 5400. The other important goal of this work was to determine a characteristic ^{54}Cr/^{52}Cr ratio for this specimen in an attempt to establish a genetic link between this meteorite and other meteorite classes.

It was shown recently that the bulk samples of various meteorite classes (such as eucrites, mesosiderites, angrites, ordinary chondrites and ureilites) have small but resolvable deficits of ^{54}Cr (e.g., [2]), whereas different types of the carbonaceous chondrites are characterized by variable excesses of ^{54}Cr [3]. The relative abundances of ^{54}Cr in enstatite chondrites [4] are the same as in terrestrial samples.

In order to obtain phases with different Mn/Cr ratios we applied our usual differential dissolution procedure that allows for separation of chromite from silicates. We have measured ^{53}Cr/^{52}Cr ratios and Mn and Cr abundances in chromite (Chr), silicates (Sil), and the total rock (TR). Although the Mn/Cr ratios reveal a relatively large range, up to ~6 (Figure 1), the measured ^{53}Cr excesses in Chr, Sil, and TR are essentially the same: 0.44±0.03 ε, 0.43±0.03 ε, 0.45±0.03 ε, respectively. For Sil, a small correction of 3 ppm for a spallation component was applied based on the Fe/Cr ratio and the 29 Ma cosmic ray exposure age (see below).

This indicates that ^{53}Mn had practically fully decayed at the time of isotopic closure. Thus, only an upper limit for the ^{53}Mn/^{55}Mn ratio at that time can be obtained: 4.23×10^{-8}. Using the angrite NWA 4801 as our new absolute time marker [5] (^{53}Mn/^{55}Mn = 0.96×10^{-6} at 4558 Ma ago), we calculate that the Cr isotopes in NWA 5400 equilibrated no earlier than 4541 Ma ago. Analyses in progress of the systematics of the longer half-life ^{182}Hf-^{182}W and ^{129}I-^{129}Xe isotopic systems should be able to more closely constrain the age of this specimen.

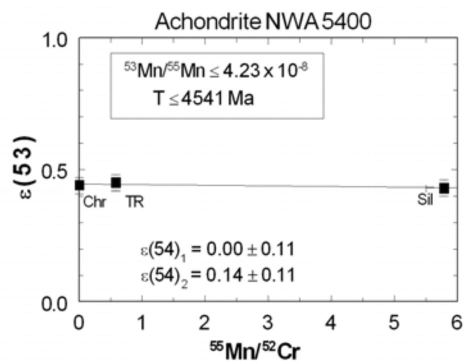

Figure 1. *^{53}Mn-^{53}Cr systematics in NWA 5400 and the relative abundance of ^{54}Cr.*

We conducted two series of measurements of the relative abundance of ^{54}Cr in NWA 5400. The results show (see Figure 1) that within the uncertainties the relative abundance of ^{54}Cr is indistinguishable from the terrestrial value (ε(54) = 0), in contrast to all studied meteorites, with the exception of enstatite chondrites.

Confirming Oxygen Isotope Analyses: Additional laser fusion measurements on different subsamples of NWA 5400 with more stringent acid-washing protocols than applied previously confirm the previous results [1]. Careful assessment of all the separate analyses leads us to accept the following four results:

	Δ^{17}O	δ^{17}O	δ^{18}O
	+0.019	2.681	5.061
	-0.006	2.741	5.223
	-0.017	2.446	4.683
	+0.026	2.632	4.953
mean	***+0.005***	***2.643***	***5.024 per mil***

The mean of these measurements is almost identical in ***all*** parameters to the average of two measurements in the same laboratory of lunar meteorite Northwest Africa 5000 [6].

Highly Siderophile Element Abundances and Osmium Isotopic Composition: A portion of the same bulk rock powder utilized for major and lithophile trace element analyses by [1] was analyzed multiple times for Os concentrations and isotopic composition by N-TIMS, and for highly siderophile element abundances by ICP-MS. NWA 5400 has approximately 2 to 7 times higher Re, Os, Ir, Ru and Pt contents than CI-chondrites, but 3 times lower concentrations of the moderately volatile element, Pd (Figure 2). These abundances are significantly higher than Earth's primitive upper mantle estimated from analyses of peridotite xenoliths [7, 8].

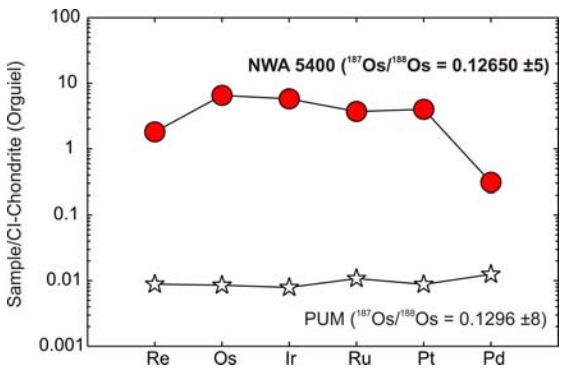

Figure 2. *Highly siderophile element pattern and Os isotope composition of NWA 5400 versus terrestrial primitive upper mantle (from [8]).*

NWA 5400 has a sub-chondritic $^{187}Re/^{188}Os$ ratio (0.11), but $^{187}Os/^{188}Os$ (0.1265) within the range of chondrite meteorite groups. LA-ICP-MS analyses reveal that the main carrier phase for the HSE are metals with relatively unfractionated chondrite-normalized Re/Os ratios, implying that the relatively low Re/Os of the bulk sample is likely a consequence of terrestrial alteration and mobilization of rhenium.

Noble Gases: Noble gases in two samples of NWA 5400 were analyzed by total melting and stepwise heating. The cosmic ray exposure age based on spallogenic ^{3}He and ^{21}Ne is ~29 Ma, which is within the range of exposure ages of brachinites (3-57 Ma; [9]). The meteorite shows a large ^{129}Xe excess (~3×10^{-10} cm^3/g) derived from ^{129}I decay ($T_{1/2}$ = 16 Ma), indicative of its formation very early in Solar System history. Other Xe isotopes show Xe to be dominated by chondritic trapped Xe, but fission Xe from ^{244}Pu ($T_{1/2}$ = 82 Myr) is not observed. Chondritic Xe is characteristic for brachinites and seems to be associated with trapped noble gases with $^{36}Ar/^{132}Xe$ of >200, which were detected in the high temperature fractions (>1000°C) [9]. The $^{36}Ar/^{132}Xe$ ratio of NWA 5400 at 1200-1850°C is ~140 in total, which is slightly lower than in brachinites.

Discussion: Although the chromium isotope results do not provide more than a maximum formation age for NWA 5400, they do show that this specimen is significantly younger than brachinites like Brachina [10]. Discrimination from brachinites is also clear on the basis of oxygen isotopic composition [11]. This, together with the presence of abundant radiogenic ^{129}Xe, leaves us with the conclusion at this stage of our studies that NWA 5400 appears to be a moderately ancient ultramafic achondrite with terrestrial oxygen and ^{54}Cr isotopic compositions. These observations provide permissible evidence consistent with NWA 5400 representing a terrene-related meteorite [1]. However, the elevated abundances of highly siderophile elements imply limited metal-silicate fractionation, which might not be expected in a parent body that had already undergone significant core formation. The necessity for storage over the last 4.5 Ga, and more recent re-capture, also may pose difficulties for a proto-terrestrial origin, as does the high $^{53}Cr/^{52}Cr$ ratio. Alternatively, NWA 5400 may represent the ultramafic portion of an asteroidal parent body that witnessed similar processing to brachinites, but that evolved more slowly (larger?) and originated from a compositionally distinct reservoir, yet one with similarities to the planetary feeding zones of the Earth-Moon system. Further chemical and multi-isotopic analyses are in progress to elucidate the origin and significance of NWA 5400.

References: [1] Irving A. et al. (2009) *LPS* **XL**, Abstract #2332. [2] Trinquier A. et al. (2007) *ApJ* **655**, 1179-1185. [3] Shukolyukov A. and Lugmair G.W. (2006) *EPSL* **250**, 200-213. [4] Shukolyukov A. and Lugmair G.W. (2004) *GCA* **68**, 2875-2888. [5] Shukolyukov A. et al. (2009) *LPS* **XL**, Abstract #1381. [6] Irving A. et al. (2008) *LPS* **XXXIX**, Abstract #2168. [7] Meisel T. et al. (2001) *Nature* **238**, 517-520 [8] Becker H et al. (2006) *GCA* **70**, 4528-4550 [9] Swindle T. D. et al. (1998) *Meteoritics & Planet. Sci. 33*, 31-48. [10] Wadhwa M. et al. (1998) *LPS* **XXIX**, Abstract #1480. [11] Rumble D. et al. (2008) *LPS* **XXXIX**, Abstract #1974.