AR-AR AND NOBLE GAS SYSTEMATICS OF THE UNGROUPED ACHONDRITE NORTHWEST AFRICA 6704. V. A. Fernandes[1], R. Burgess[2], S. A. Crowther[2], J. P. Fritz[1], J. D. Gilmour[2], A. Irving[3], M. M. M. Meier[4,5], M. Nottingham[2] and R. Wieler[5]; [1] Museum für Naturkunde, Leibniz-Institut für Evolutions- und Biodiversitätsforschung, Berlin, Germany; (veraafernandes@yahoo.com), [2]SEAES, University of Manchester, U.K., [3]Dept. of Earth & Space Sciences, University of Washington, Seattle, USA, [4]Department of Geology, Lund University, Sweden, [5]Department of Earth Sciences, ETH Zurich, Switzerland.

Introduction: Recent discoveries of "ungrouped" achondrites have extended the range of parent bodies and the primary bulk compositions that originated during planetary differentiation. The achondrite GRA06128/06129 is a good example as it shows a high temperature assemblage of sodic plagioclase, relatively Fe-rich pyroxenes and olivine, and abundant phosphates. It represents an episode of very early planetesimal melting (~4.566 Ga, [1]) superimposed by multiple events including subsolidus cooling (e.g., 4.460±0.028 Ga [2]), metamorphism, shock, and potentially interactions between fluid and the mineral assemblage (e.g., ≤2.673±0.038 Ga [2]). Similarly, Northwest Africa (NWA) 6704 (and paired materials NWA 6693 and NWA 6926) are samples of an achondrite with an igneous cumulate texture [3-5], which may provide information on geologic processes within another parent body.

Petrology and Bulk Composition: The rock is composed predominantly of low-Ca pyroxene (orthopyroxene; $Fs_{41.6-42.4}Wo_{2.8-3.6}$) as large oikocrysts enclosing smaller chadacrysts of olivine ($Fa_{51.6-53.2}$) and chromite, along with interstitial intercumulus very sodic plagioclase ($Ab_{92}An_4Or_4$) and tiny grains of Cr-spinel and awaruite [3-5]. Orthopyroxene grains contain curvilinear trains of small empty bubbles [3]. Our very preliminary Raman measurements revealed a small peak at 4330 cm^{-1}, however it is so far unclear if this bears any relevance. Although NWA 6704 was regarded as unshocked [3], in rare locations smaller grains of pigeonite with twin lamellae and the "cloudy" aspect of the extinction in crossed polarized light of the albite grains can in addition to chemical inhomogenities resemble weak undulatory extinction [5]. In our sample olivine and pyroxene display no signs of undulatory extinction, the whole pyroxene oikocryst shows cleavage and albite display a "cloudy" extinction. Thus the sample does not display diagnostic shock deformation effects and appears unshocked to very weakly shocked. Representative clean wire-saw cutting dust from NWA 6704 was analyzed for major elements by XRF spectrometry at Washington State University. The results (Table 1) differ somewhat from the results reported by [5] for ground chips of NWA 6693. We have used the NWA 6704 analysis to correct for noble gas production rates.

Table 1. Major element composition.

	NWA 6704	NWA 6693 [5]
SiO_2	44.29	50.52
TiO_2	0.07	[Ti] 384 ppm
Cr_2O_3	0.97	[Cr] 2990 ppm
Al_2O_3	2.11	1.94
FeO*	28.01	24.65
MnO	0.26	0.25
MgO	16.55	18.46
NiO	1.86	[Ni] 10400 ppm
CaO	1.41	1.47
Na_2O	0.97	1.02
K_2O	0.08	[K] 329 ppm
P_2O_5	0.21	[P] 378 ppm
Sum	96.80	~98.3

^{40}Ar-^{39}Ar Results: Two whole-rock aliquots (each ~22 mg) were step heated in a Ta-Furnace and Ar-isotopes measured in an attempt to determine the thermal history from crystallisation to the timing of any shock event(s) experienced by this differentiated planetary material.

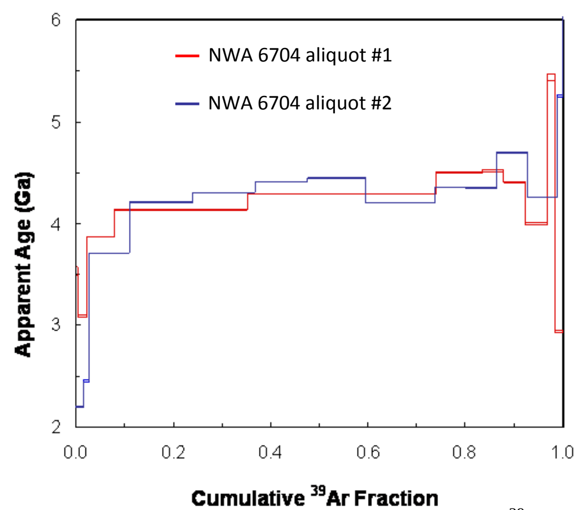

Figure 1 Apparent age spectra vs. Cumulative ^{39}Ar fraction for two bulk NWA 6704 aliquots.

The two ^{40}Ar-^{39}Ar spectra overlap and both indicate degassing of ^{40}Ar during a thermal event at ≤2.20±0.33 Ga (aliquot #2). The total age for aliquot #1 is 4.56±0.29 Ga and for aliquot #2 is 4.30±0.28 Ga. Suggesting either a heterogenous effect of a thermal event as evidenced by the different total ages or due to the heterogeneous effect given by different grain size in each of the aliquots, e.g., aliquot#2 possibly was composed by smaller mineral grains. Aliquot #1 at high temperature release suggests the preservation of a relic age ~4.52±0.01 Ga (equivalent to ~10% of the ^{39}Ar release), which is within error the same as the total age calculated for this aliquot. The trapped (i.e., non-radiogenic) ^{40}Ar content is very low for all step releases and therefore not affecting the age calculated. The measurements were performed long after the irradiation and therefore it is not possible to both calculate the Ca/K for each step heating and a reliable cosmic ray exposure age. Although voids/bubbles were observed in pyroxenes [3-5], there was no obvious release of trapped Ar gas by bubble decrepitation.

Xe Data: Xenon data were acquired from three ~1 mg samples by step heating using the RELAX mass spectrometer [6]. One of these had been neutron irradiated, allowing the release of xenon isotopes derived from iodine, barium and uranium to be investigated. Iodine-derived ^{128}Xe was released from the irradiated sample at low temperatures, possibly indicating terrestrial contamination. In contrast, the majority release of trapped xenon occurred alongside releases of ^{131}Xe (from barium) and ^{134}Xe (from uranium) at high temperature. The ^{136}Xe/^{132}Xe and ^{134}Xe/^{132}Xe ratios of the trapped component (1-3 x 10^{-11} cm^3 STP ^{132}Xe g^{-1}) released from both the unirradiated samples were lower than Q-Xe and consistent with solar xenon, lighter isotopes showed evidence of an ~4% contribution (at ^{132}Xe) from spallation of barium. There was at most marginal evidence for ^{129}Xe from ^{129}I decay, perhaps reflecting a low concentration of indigenous iodine.

Noble Gas Results: He, Ne and Ar were measured in a 79.6 mg piece of NWA 6704, extracted by pyrolysis in a single temperature step (1800 K), on a custom built mass spectrometer at ETH-Zurich, based on the method given by [7]. While interferrences of $H_2{}^{18}O$, CO_2 and $^{40}Ar^{++}$ on masses 20 and 22 were negligible, contribution of $H^{35}Cl$ and $H^{37}Cl$ on masses 36 and 38 (~66%) had to be corrected. The Ne isotopic composition of NWA 6704 is almost exclusively cosmogenic, while for Ar, a small amount of trapped, non-radiogenic gases is present based on the ^{36}Ar/^{38}Ar measured. The ^{22}Ne/^{21}Ne-ratio of 1.09 indicates a burial depth of a few decimeters within an object of at least 50 cm in radius. At this depth, a ^{3}He/^{21}Ne-ratio of ~5-5.5 would be expected. The measured ratio of 2.81 indicates however that a significant part of the He has been lost. This is confirmed by low $^{3}He_{cos}$ and low radiogenic ^{4}He, and can be explained by loss of He from plagioclase (e.g. [8]), which makes up ~40% of NWA 6704 [3]. Isotopic production rates for ^{3}He, ^{21}Ne and ^{38}Ar were calculated based on major/minor-element concentrations (Table 1) and the model by [9], yielding a CRE age of 30±3 Ma from both $^{21}Ne_{cos}$ and $^{38}Ar_{cos}$. The calculated K-Ar age of the sample (with ~600 ppm K) is ~4.0 Ga.

Table 2: He, Ne, Ar results and CRE ages All concentrations given in 10^{-8} ccSTP/g

	He	Ne	Ar
Measured ratios ($^3/_4$, $^{22}/_{21}$, $^{36}/_{38}$)	0.058	1.09	0.84
($^3/_{21}$, $^{40}/_{36}$)	2.81		12900
Concentration (^{4}He, ^{22}Ne, ^{36}Ar)	487	11.0	1.14
- Radiogenic (^{4}He, ^{40}Ar)	330	-	3900
- Cosmogenic (^{3}He, ^{21}Ne, ^{38}Ar)	28.4	10.1	1.29
Exposure age, in Ma (T3, T21, T38)	15	29	31

Discussion/Summary: Based on petrology, noble gas and Ar-Ar data, the achondrite NWA 6704 appears to have been in more than one thermal event after crystallization. [5] suggested that shock probably happened while the rock was still rather hot from igneous petrogenesis, and this may be the reason why shock features are subdued and the bubbles are devoid of fluid. That seems consistent with survival of relict old (igneous or very near igneous) ^{40}Ar-^{39}Ar age of for aliquot #1 of 4.56±0.29 Ga. Loss of cosmogenic He from plagioclase must have happened during the last few Ma, during irradiation while in transfer to Earth – i.e., in the very late history. It is interesting to note the similarity in the ^{40}Ar-^{39}Ar ages obtained for NWA 6704 and GRA06128/06129: both samples were thermally affected at ~4.5 and at ≤2. 7 Ga. probably suggesting impact or other thermal events that affected the parent body. The presence of a solar signature in trapped xenon is intriguing given the absence of significant trapped He, Ne and Ar and the observation that it is released alongside volume-correlated components produced during artificial neutron irradiation. The latter suggests inheritance from the source magma rather than implantation in the regolith.

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