MAJOR AND TRACE ELEMENT CHEMISTRY AND Ar-Ar AGE OF THE NWA 011 ACHONDRITE.
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Introduction: Northwest Africa (NWA) 011 was originally described as a non-cumulate eucrite with an anomalous Fe/Mn ratio [1]. However, it was demonstrated later [2] that this rock is different from eucrites in oxygen isotopic composition and represents a new type of basaltic meteorite. Furthermore, it has been suggested that the rock may have come from Mercury [3].

In this paper, we report new data on major- and trace-element compositions of this unique meteorite, in addition to the first results of ^{40}Ar-^{39}Ar dating. The mineralogy and petrology are reported in a companion paper [4]. These studies present new evidence showing that NWA 011 is significantly different from HED meteorites.

Results: The bulk composition of this rock was reconstructed from mineral modes and chemistry, which were measured in a polished thin-section of 2.9 cm^2. Trace elements were determined with INAA in two 10-20 mg chips. The whole-rock chemistry so obtained is significantly different from that given by [2] (Table 1). The bulk composition from our determination is distinctly higher in Si, P, and Fe/Mn and slightly lower in Al, Fe, and Ca. (Table 1). However, the MG# values are essentially the same. Using the bulk composition of [2], normative compositions as well as mineral modes from crystallization modeling do not correspond to the mineral modes measured by [1,4,5]. The composition of [2] models about 10% olivine, whereas olivine is almost absent in the rock [1,2,4]. It is also surprizing that P is very low in the bulk composition of [2]. Ca phosphate is not evenly distributed in this meteorite, but it is definitely a typical accessory phase of the rock [3,4]. It is also noteworthy that the Fe/Mn ratio from the composition of [2] is distinctly lower than that measured in the NWA 011 pyroxenes [1,2,4].

The REE patterns of the two analyzed chips are distinct from each other (Fig. 1). One pattern is similar to that reported by [2], with depleted LREEs and a positive Eu anomaly. The other chip is richer in LREEs. These differences are a function of the mineralogy of the analyzed chips, with the LREE-depleted chip also poor in Ca-phosphate. The REE pattern measured by [2] also reflects analysis of phosphate-poor material, a suggestion also supported by the low P content they obtained (Table 1). Other trace-element contents are similar. The INAA data confirm enrichments in siderophiles: Ni 50 (ppm), Co 28 (ppm), and Ir 40 (ppb), coupled with a depletion in Sc (15 ppm) [2]. The presence of low Ba and Sr concentrations (~100 ppm) are indicative of the low degree of weathering.

A whole-rock sample weighing 97 mg was used to carry out ^{40}Ar-^{39}Ar measurements. A high resolution ^{40}Ar-^{39}Ar age spectrum (34 extractions) was obtained (Fig. 2). The spectrum is characterized by stepwise increasing apparent ages reaching a maximum value of about 4 Ga.

Discussion: Based solely upon major-element chemistry, NWA 011 is in the range of eucritic compositions, except for the anomalous Fe/Mn ratio. However, similar Fe/Mn ratios were documented from the Ibitira eucrite and four Antarctic eucrites (Y-82082, A-881467, A-881388, Y-791195) [6]. The most prominent compositional characteristics of NWA011 are: 1) the high-P content, which is 2-3 times higher than that of other eucrites; 2) the low-Sc abundance, which is only 50% of the normal eucritic value; and 3) the high-siderophile-element concentrations, with highly fractionated. Ni/Ir and Ni/Co ratios, considerably lower than chondritic values. The high-siderophile contents, with such fractionated ratios have been explained by contamination of NWA 011 with a IVB iron component [2]. However, iron meteorites are rare in space, and Ni/Co ratios of IVB irons are higher than cosmic abundances. The Ir content of 20-40 ppb is probably too high to be attributed to a single impact. Comparable Ir contents are present in mature lunar soils and regolith breccias, which have resulted from an extended meteorite flux. NWA 011 is not a breccia [1,4]. We suggest that the siderophile contents are indigeneous to this meteorite – i.e., the apparent siderophile anomaly simply reflects a high content of such elements in the source region of the basalt. It is possible that this source had not completely equilibrated with Fe metal, perhaps because it was more oxidized, compared to the normal eucritic source. The high Fe/Mn ratio and P content of the basalt support this suggestion. In addition, the association of FeNi metal inclusions with troilite further suggests that the fractionated siderophile-element pattern can be related to the occurrence of sulfide mineralogy in the NWA 011 source. The low MG# indicates that NWA 011 resulted from fractional crystallization, whereas the low Sc suggests pyroxene fractionation, providing the source was not Sc depleted.

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While the ^{40}Ar-^{39}Ar age spectrum of NWA 011 shows some similarities with the eucrite age spectra [7], there are some interesting differences: An isochron analysis at low temperatures shows the presence of terrestrial argon contamination. The isochron plot (Fig. 3) of the first nine extractions yields an intercept of ^{36}Ar/^{40}Ar=0.00334±0.00003, exactly matching the Earth's atmospheric ratio. Correction for this component results in a low-temperature age plateau of 800± 60 Ma. Such a young isochron age has not been reported for eucrites before [7,8]. Apparent ages increase with increasing the extraction temperature, and reach values of 3.2-3.9 Ga in the high-temperature fractions. This indicates that the 800 Ma thermal event led to partial degassing and resetting of the ^{40}Ar- ^{39}Ar system of the basalt. It is possible that the 3.2-3.9 Ga date could represent the age of crystallization or impact metamorphism caused by the heavy meteorite bombardment, experienced by the Moon and HED parent body at about 3.7-4.2 Ga ago [7,8]. The NWA011 exposure age determined from cosmogenic ^{38}Ar agrees well with data by [2].

Summary: Compared to other eucrites, NWA 011 is enriched in Fe/Mn, P, siderophile elements and depleted in Sc. The siderophile-element proportions are highly fractionated, indicating that they are probably indigeneous – i.e., not meteoritic contamination. These characteristics suggest that the NWA 011 source region might be relatively oxidized and contain some sulfide phase. The ^{40}Ar- ^{39}Ar dating of this unique rock indicates a thermal event at 0.8 Ga and a crystallization age of >3.2 Ga.

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] Promprated P. et al. (2003) this volume; [5] Yamaguchi A. et al., (2001) *MAPS*, **36**, A228; [6] Wilkening L.L. and Anders E. (1975) *GCA*, **39**, 1205-1210; [7] Kunz J. et al. (1995) *Planet. Space Sci.*, **43**, 527-543. [8] Bogard D. (1995) *MAPS*, **30**, 244-268.

Table. Bulk composition (wt%) of NWA 011.

	This work	[2]
SiO_2	48.22	45.63
TiO_2	0.85	0.92
Al_2O_3	12.86	13.12
FeO	19.95	21.13
MnO	0.29	0.40
MgO	6.05	6.66
CaO	10.76	11.11
Na_2O	0.54	0.45
K_2O	0.03	0.03
P_2O_5	0.22	<0.02
Cr_2O_3	0.19	0.24
Total	99.96	99.71
MG#	0.35	0.36
Fe/Mn	70	53

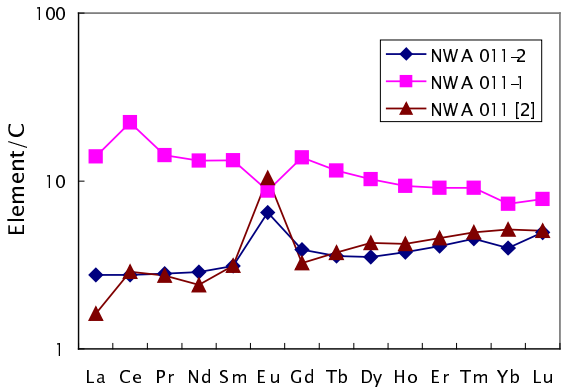

Fig. 1. *REEs of NWA 011. The data are from this work (1, 2) and from [2].*

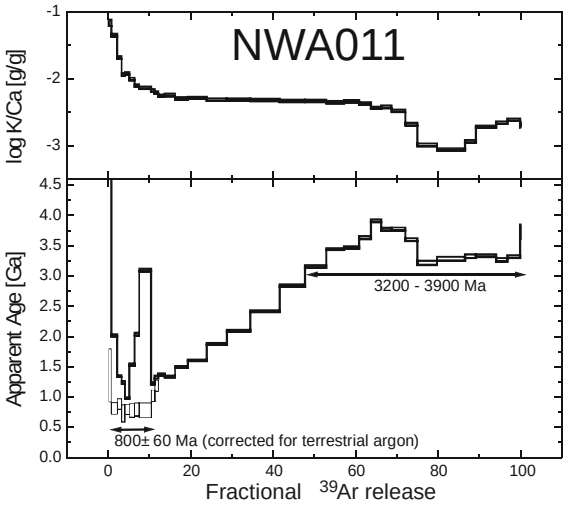

Fig. 2. *The high resolution ^{40}Ar-^{39}Ar age spectrum (34 extractions).*

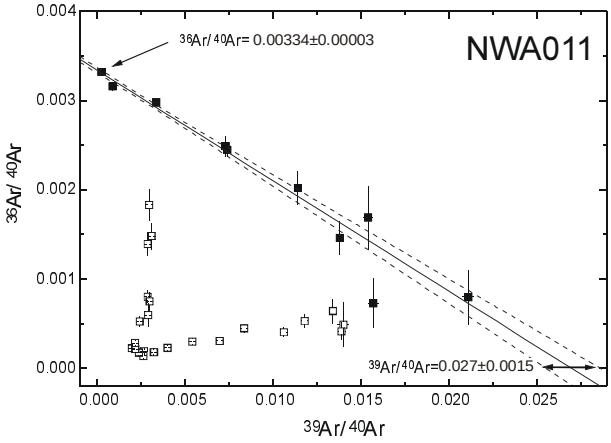

Fig. 3. *Isochron plot of NWA 011. Solid squares: low temperature extractions*