AL-MG AND MN-CR AGES OF NORTHWEST AFRICA 011 ACHONDRITE.
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Introduction: Origin and distribution of extinct nuclides in the early solar system are not well known. Hence, it is important to examine isotope systematics due to decay of extinct nuclides in various meteorite parent bodies. Also, it is important to understand magmatic activities on achondrite parent bodies.

Northwest Africa 011 (NWA 011) is a basaltic achondrite which is petrologically similar to eucrites but is distinct from them based on the oxygen isotopic composition [1]. According to the Cr isotopic composition [2], it is expected to be very old. But Mn-Cr isochron ages have not been reported. The Sm-Nd age of NWA 011 was reported to be 4.46 +/- 0.04 Ga [3] which is not quite as old as expected from the Cr isotopic composition. Here we report Al-Mg and Mn-Cr ages of this meteorite. Thermal history of NWA 011 is discussed based on the chronological data.

Experimental: The Al-Mg and Mn-Cr measurements were made by secondary ion mass spectrometry. Al-Mg measurements were made on plagioclase and pyroxene, whereas Mn-Cr measurements were made on olivine and pyroxene. A strong O^- primary beam (~5nA, 40 μm in diameter) was used for sputtering. The mass resolving power for both Al-Mg and Mn-Cr measurements was ~4000. For the Mn-Cr chronology, ^{52}Cr, ^{53}Cr and ^{55}Mn were measured. ^{50}Cr could not be measured accurately due to severe interference of ^{50}Ti. Hence variation in instrumental mass fractionation of the $^{53}Cr/^{52}Cr$ ratio was estimated from deviation of the ratio during repeated measurements of a running standard sample and propagated to errors of the ratios. Details on the Mn-Cr measurements of olivine have been reported in [4,5].

Results: The Mn-Cr and Al-Mg systematics are shown in Fig.1 and Fig.2, respectively. The error bars are 1σ. Both Mn-Cr and Al-Mg diagrams show significantly positive slopes which are interpreted as isochrons. The inferred Mn initial ratio estimated from the isochron is, within the error, identical with that [2] estimated from the bulk Cr isotopic composition, suggesting that NWA 011 became a closed system soon after the generation of the parental magma. Using the absolute age and the inferred Mn initial ratio of Lewis Cliff 86016 [6], the absolute age of NWA 011 is calculated to be 4562.3 ± 2.6 Ma. Similarly, using the absolute age and the inferred Al initial ratio of CAIs in Efremovka [7], the absolute age is calculated to be 4562.7 ± 0.3 Ma. (The uncertainties of the respective anchors are not included in the errors.) Thus, the Mn-Cr age and Al-Mg age are consistent with each other.

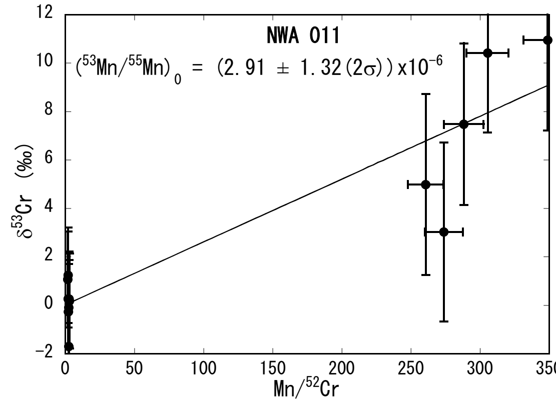

Fig.1

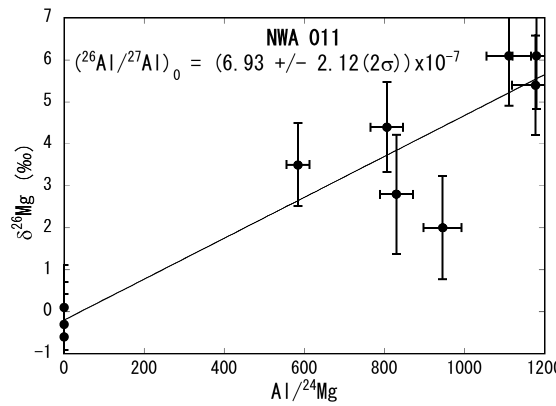

Fig.2

Discussion: Based on these Mn-Cr and Al-Mg systematics, NWA 011 is slightly younger than the oldest eucrite Asuka 881394 (4563.4~4563.9 Ma [8]), and is contemporaneous with quenched angrites like Sahara 99555 (4562.4~4562.9 Ma [8]). These data suggest that both ^{26}Al and ^{53}Mn had been homogeneously distributed in the solar nebula where 3 groups of achondrites formed. We note, however, that in the cases of Asuka-881394 and Sahara 99555, there is discordance between the ^{207}Pb-^{206}Pb ages, on the one hand, and the Mn-Cr and Al-Mg ages, on the other [9]. Therefore, it is important to obtain the ^{207}Pb-^{206}Pb age of NWA 011. The oldest ages from three achondrite groups (i.e. ages of Asuka-881394 from eucrites, quenched angrites and NWA 011) are nearly identical. This suggests that accretion of achondrite parent bodies is nearly simultaneous, and also suggests that ^{26}Al is the main heat source.

The Sm-Nd age of NWA 011 reported by [3] is significantly younger than the absolute ages reported here. A similarly young Sm-Nd age compared with the Mn-Cr and Al-Mg ages has been reported for Asuka-

881394. REE data for NWA 011 [10] may be interpreted that REE abundances in pyroxene were partially reset during metamorphism. If this interpretation is correct, then the young Sm-Nd age may be due to late metamorphic events.

The olivine grain size in NWA 011 is typically ~70 μm, whereas the size of plagioclase grains used for the chronological measurements is 400~1000 μm. The diffusion coefficients of Cr in olivine are given in [11] and those of Mg in plagioclase are given in [12]. Mg diffusion in plagioclase is faster than Cr diffusion in olivine. In other words, the Al-Mg system in plagioclase should close at lower temperatures than the Mn-Cr system in olivine if the grain size is the same. Due to the large grain size of plagioclase in NWA 011, however, plagioclase closes at higher temperatures than olivine. Since the Al-Mg age is very close to the age of magma source fractionation [2], it is probably the crystallization age of this achondrite. The high closure temperature of plagioclase in NWA 011 is also consistent with trace elements concentrations in plagioclase [10].

However, the above interpretation does not include metamorphic effects. Bulk compositions of relict augites suggest equilibrium at ~1100C [1]. Since Ca diffusion in pyroxene is much slower than Mg diffusions in plagioclase, if pyroxene is equilibrated at ~1100C by metamorphism, then the Al-Mg age of plagioclase should be reset. There are some uncertainties (up to ~0.1 Ma) in the time interval (Δt) between the magma source fractionation [2] and the closure of Al-Mg system. It seems marginally possible to equilibrate pyroxenes within 0.1 Ma at 1100C. If it turns out that the time interval (Δt) is not sufficient for pyroxene equilibration, then the interpretation of the relict augite compositions has to be reconsidered.

Olivine grains in NWA 011 are suggested to be produced by reheating [1]. Since the uncertainty of the Mn-Cr age of olivine is relatively large, and since the closure temperature is somewhat lower than that of plagioclase, if the reheating event occurred within 3 Ma of crystallization, it is consistent with the chronological constraints. Since olivine and associated opaque minerals are not in equilibrium with the rest of the achondrite, quick cooling (probably due to impact excavation) after the olivine formation is suggested [1].

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