U-PB AGE, RE-OS ISOTOPES, AND HSE GEOCHEMISTRY OF NORTHWEST AFRICA 6704.

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Introduction: Northwest Africa (NWA) 6704 is a very unusual ungrouped fresh achondrite. It consists of abundant coarse-grained (up to 1.5 mm) low-Ca pyroxene, less abundant olivine, chromite, merrillite and interstitial sodic plagioclase. Minor minerals are awaruite, heazlewoodite, and pentlandite. Raman spectroscopy shows that a majority of the low-Ca pyroxene is orthopyroxene. Bulk major element abundances are nearly chondritic and distinct from those of howardite-eucrite-diogenites. Oxygen isotopic study [1] demonstrated that $^{18}O/^{16}O$ and $^{17}O/^{16}O$ of this meteorite plot within the acapulcoite-lodranite field, but these meteorites differ in mineralogy and geochemistry. These observations suggest that NWA 6704 originated on a distinct parent body from all other known meteorites.

Here we report U-Pb chronology and highly siderophile element (HSE) geochemistry, including Re-Os isotope systematics, of the unique achondrite NWA 6704. Our preliminary results show its remarkable antiquity and high HSE abundances with supra-chondritic $^{187}Os/^{188}Os$.

Methods: *U-Pb chronology.* U-Pb dating was performed on nine 10–20 mg fractions of pyroxene. All fractions were rinsed with distilled acetone. The fractions were then washed 4-5 times in ca. 0.5 ml of 0.5 M HNO_3 with ultrasonic agitation. Ultrasonic washes were combined as the first washes. Subsequently, the fractions were washed twice with hot 6 M HCl, followed by twice washing with hot 7 M HNO_3. Hot washes were combined as the second washes. All residues and leachates were spiked with mixed ^{202}Pb-^{205}Pb-^{229}Th-^{233}U-^{236}U tracer [2]. Spiked washes were evaporated to dryness, evaporated with 0.1 ml of 6 M HCl, 9 M HBr and re-dissolved in 0.3 M HBr. Spiked residues were digested in a HF+HNO_3 mixture, converted to a soluble form by repeated evaporation with 7 M HNO_3, 6 M HCl, 9 M HBr, and dissolved in 0.3 M HBr. The Pb separation was performed using 0.05 ml of anion exchange resin AG1x8 200–400 mesh. After the Pb separation, U and Th were separated using 0.05 ml of UTEVA resin. Pb isotopes were measured on a TRITON Plus TIMS at the ANU. U and Th isotopic analyses were carried out on a Neptune MC-ICPMS at the Australian National University.

HSE and Os isotopic measurement. HSE concentrations and $^{187}Os/^{188}Os$ were determined at the University of Maryland using standard high temperature acid digestion, chemical purification and mass spectrometry techniques [3]. The quantities of each of the HSE was at least 1000 times greater than the blanks measured at the same time. Thus, blanks had no impact on the measurements. Accuracy and precision of Ir, Ru, Pt and Pd concentrations are estimated to be <2%, of Re <0.4%, and of Os <0.1%. Reproducibility of $^{187}Os/^{188}Os$ for these quantities of Os is ≤0.05%.

Results: *U-Pb chronology.* The first washes yielded Pb with $^{206}Pb/^{204}Pb$ between 20 and 27, whereas the second washes gave Pb with variable $^{206}Pb/^{204}Pb$ ranging from 20 to 80. The Pb isotopic compositions of the residues are much more radiogenic. In detail, however, two residues yielded higher $^{206}Pb/^{204}Pb$ values (148 and 213) relative to the others (from 344 to 5494). Model $^{207}Pb^*/^{206}Pb^*$ dates (assuming primordial Pb [4] as initial Pb, and $^{238}U/^{235}U$=137.88) for seven most radiogenic residue analyses with $^{206}Pb/^{204}Pb$>500 yielded a weighted average of 4563.34±0.32 Ma. The U-Pb discordance of residue analyses range from -3% to -6% for more radiogenic data, and up to -10% for the two residues that contain less radiogenic Pb. A Pb-Pb isochron for the seven radiogenic residues (Fig. 1) yielded a radiogenic $^{207}Pb/^{206}Pb$ value (y-intercept of the regression line) of 0.62351±0.00017. This corresponds to a $^{207}Pb/^{206}Pb$ date of 4563.75±0.41 Ma, assuming a $^{238}U/^{235}U$=137.88.

Os isotopes and HSE abundances. The $^{187}Os/^{188}Os$ of 0.17538±8 is considerably more radiogenic than chondrites, as well as other primitive achondrites we have examined (brachinites, brachinite-like achondrites, GRA 06129) all of which have ratios of ~0.13 [5]. The abundances of HSE are generally much higher than in meteorites from the silicate portions of well-differentiated bodies (e.g., Earth, Vesta) [6,7], but are in the range of primitive achondrites (Fig. 2)[5]. As with other primitive achondrites, the relative abundances of the HSE are moderately fractionated, relative to bulk chondrites. The most noteworthy feature of the HSE pattern for NWA 6704 is the high Re/Os.

Discussion: For the calculation of $^{207}Pb/^{206}Pb$ dates, we have assumed the $^{238}U/^{235}U$ value of 137.88. Yet this assumption may be invalid likewise for Ca-Al-rich inclusions (CAIs) and basaltic achondrites [8-12].

Hence, to establish an assumption-free reliable $^{207}Pb/^{206}Pb$ date, precise $^{238}U/^{235}U$ needs to be determined for this meteorite. Using, instead, the $^{238}U/^{235}U$ value of 137.79±0.02 (an approximate estimate for most Solar System materials except CAIs, based on the data of [9-12]), yields the isochron age of 4562.80±0.46 Ma. This age estimate is valid unless $^{238}U/^{235}U$ in NWA 6704 is significantly lower than in the angrites and chondrites. Determination of the $^{238}U/^{235}U$ is in progress.

The estimated U-Pb age of NWA 6704 is substantially older than those of plutonic angrites, and only marginally younger than those of quenched angrites [11,13]. NWA 6704 is about 4-5 Ma younger than the CAIs [9,12]. The age of NWA 6704 (with our estimated $^{238}U/^{235}U$) is about 4-5 Ma younger than the ages of CAIs [9,12] and identical to the age of ungrouped achondrite NWA 2976 of 4562.89 ± 0.59 Ma [10], calculated with the measured $^{238}U/^{235}U$ = 137.751 ± 0.018. However, the O isotopic composition of NWA 6704 [1] and the meteorites paired with NWA 2976, i.e., NWA 011 [14] and NWA 2400 [15], does not plot on the same mass fractionation line, indicating that these meteorites originated from different asteroids.

Considering the old crystallization age, the expected simple geologic history (suggested by nearly concordant U-Pb systems), the mineral assemblage including pyroxene, plagioclase, olivine, chromite and metal, and the considerable sample size (8.4 kg in total), NWA 6704 has the potential to serve as a reliable reference point of various short-lived isotopic chronometers such as ^{26}Al-^{26}Mg, ^{53}Mn-^{53}Cr and ^{182}Hf-^{182}W chronometers. A new reliable reference point is essential for checking uniform distribution of the short-lived radionuclides and for building a consistent time scale of the early Solar System.

The HSE abundance data are broadly consistent with other primitive achondrites, but no similar HSE patterns have been previously observed. The fractionated pattern suggests the removal of some HSE, relative to bulk chondrites, via metal or sulfide extraction, as has been invoked for e.g., brachinites [7]. We currently have no explanation for the suprachondritic Re/Os, and resulting $^{187}Os/^{188}Os$.

Our data reinforce emerging evidence that multiple planetesimals – parent bodies of angrites, eucrite-like meteorites such as Asuka 881394 and Ibitira, and various achondrites that are currently called "ungrouped" – formed, experienced differentiation, and cooled down during the first 5 Ma of the Solar System, and remained relatively undisturbed since then. A more complex and prolonged geologic history of 4-Vesta – the presumed source of HED meteorites – appears an exception rather than the rule.

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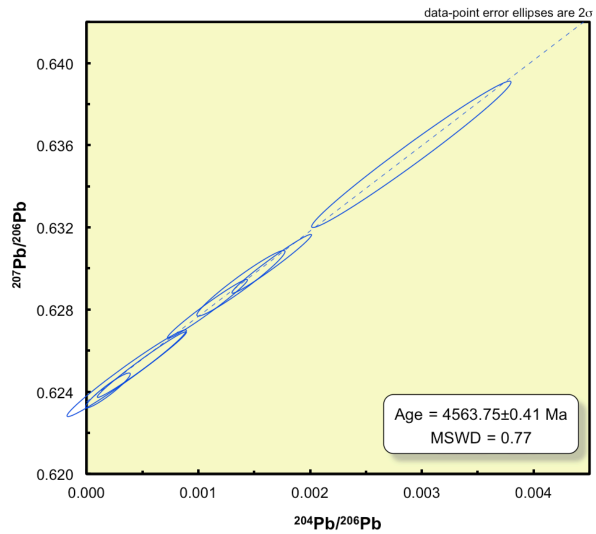

Fig. 1. Pb-Pb isochron for acid-washed pyroxenes from NWA 6704.

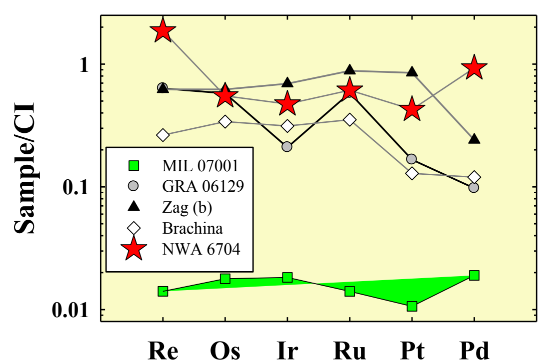

Fig. 2. CI normalized HSE pattern for NWA 6704, as compared with the diogenite MIL 07001, and other primitive achondrites: GRA 06129, the brachinite-like achondrite Zag (b), the brachinite Brachina.