DISTURBANCES IN THE ISOTOPIC RECORD OF ASUKA 881394. L. E. Nyquist[1] and D. D. Bogard[2], [1]KR/NASA Johnson Space Center, Houston, TX 77058. E-mail: laurence.e.nyquist@nasa.gov, [2]Lunar and Planetary Institute (3600 Bay Area Blvd, Houston TX 77058, Bogard@lpi.usra.edu).

Introduction: Asuka 881394 is a unique achondrite with a granulitic texture, very calcic ~An_{98} plagioclase, and pigeonite that has not inverted to orthopyroxene [1]. First thought to be a eucrite, recent O-isotopic studies show it has a closer affinity to angrites [2]. Initial isotopic studies provided evidence for now extinct ^{26}Al, ^{53}Mn, and ^{146}Sm [3,4,5]. A recent study [6] confirmed an early chronology with an absolute ^{207}Pb-^{206}Pb age of 4566.5±0.2 Ma, a new measurement of the Al-Mg formation interval as 3.7±0.1 Ma since $^{26}Al/^{27}Al = \sim 4.63 \times 10^{-5}$ for the E60 CAI, and a Mn-Cr formation interval of -6.0±0.2 Ma relative to LEW86010 ("LEW"). Absolute ages relative to age anchors presented by [6] were 4563.4±0.2 Ma by Al-Mg and 4564.6±0.5 Ma by Mn-Cr. These ages are in good, but not perfect, agreement with the ^{207}Pb-^{206}Pb age. Perhaps the most direct comparison of the early chronology of A881394 as determined by various workers is provided by reported $^{26}Al/^{27}Al$ values of 1.18±0.14, 1.28±0.07, and $2.1\pm0.4 \times 10^{-6}$ [4,6,5]. Analyses of mineral separates by TIMS [4] and MC-ICP-MS [6] agree well, but the higher value obtained by *in situ* SIMS analysis [5] is significant in light of the slight inconsistency between absolute ages inferred from the short-lived chronometers and the ^{207}Pb-^{206}Pb age. We examine the possibility that inconsistencies in the earliest fine-scale chronology of Asuka 881394 may be related to isotopic "disturbances" observed in ^{39}Ar-^{40}Ar, ^{87}Rb-^{87}Sr, and ^{147}Sm-^{143}Nd chronometers.

Age Summary: Fig. 1 is a recently compiled summary of isotopic age data for Asuka 881394 [7].

Ar-Ar Age: The ^{39}Ar-^{40}Ar age spectrum for a plagioclase separate is shown in Fig. 2. The first few extractions releasing 0-11% of the ^{39}Ar gave higher K/Ca and $^{36}Ar/^{37}Ar$ ratios and much lower apparent ages (~3.0-4.0 Ga), all suggestive of terrestrial weathering, and are ignored here. Extractions releasing 11-100% of the ^{39}Ar gave a nearly constant K/Ca of ~0.00034. The nearly constant $^{36}Ar/^{38}Ar$ ratio of 0.67 for these extractions indicates pure cosmogenic ^{36}Ar and ^{38}Ar. The apparent Ar-Ar ages for these individual extractions range between 4.50 Ga and 4.64 Ga, and average 4576 Ma. The data seem to define two quasi age plateaus. The average age for six extractions releasing 11-49% of the ^{39}Ar is 4526±21 Ma, and the average age for nine extractions releasing 57-100% of the ^{39}Ar is 4617 ± 22 Ma (both 1σ). These two ages bracket the 4.56 Ga formation age of A881394 indicated by the dashed horizontal line in Fig. 2.

The younger Ar-Ar ages of ~4.53 Ga are about the same as the oldest Ar-Ar ages measured for some other meteorite types. Those ages >4.55 Ga observed for the last ~45% of the ^{39}Ar release seem impossibly old. However, ^{39}Ar for most extractions required a correction of ~55% for ^{39}Ar produced in the reactor from ^{42}Ca, which dominates the age uncertainties in Fig. 2. This correction factor can vary somewhat [9], and if the A881394 correction was too large, the Ar-Ar age would artificially increase.

The stair-step shape of the Ar-Ar age spectrum suggests a partial degassing event slightly lowered the ages for those extractions releasing 11-49% of the ^{39}Ar. ^{40}Ar may have been redistributed within the sample without significant loss. Alternatively, the higher temperature extractions may contain some ^{40}Ar acquired during crystallization.

Sm-Nd Age: The younger Ar-Ar plateau age (Fig.

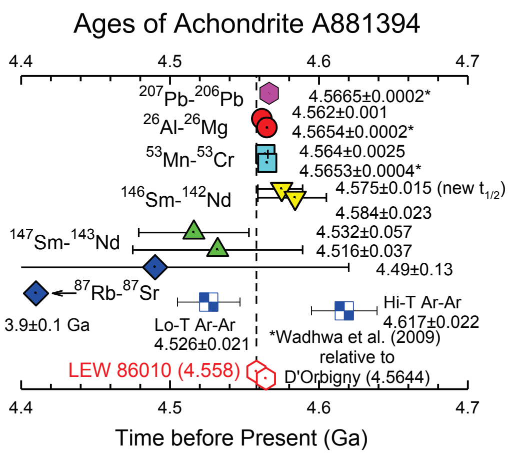

Figure 1. Summary of isotopic ages for Asuka 881394. "Absolute" ages for the short-lived chronometers are calculated relative to 4558 Ma for angrite LEW 86010. For ^{146}Sm-^{142}Nd, "new" $t_{1/2} = 0.68 \times 10^{8}$ yr [13].

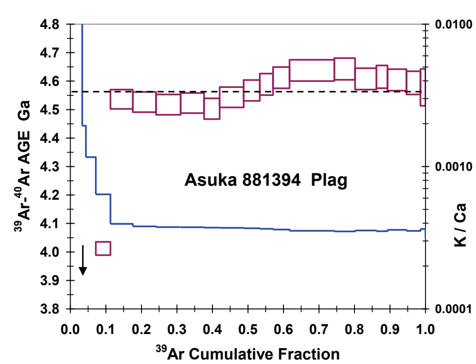

Figure 2. Ar-Ar age spectrum for A881394 plagioclase. ^{39}K decay constant and branching ratio from [10].

2) agrees within mutual error limits with the Sm-Nd age (Fig. 3). However, the Sm-Nd data show minor disturbances. Fig. 3 shows data obtained both in 2001 [3] and 2010 [7]. The Sm-Nd age obtained from these data is 4516±37 Ma (2σ) when data for handpicked tridymite and two leachates are omitted from the isochron (open symbols). A bulk sample (WR) and pyroxene separate analysed in 2001 plot below data for corresponding samples analysed in 2010. An isochron for only 2010 data gives a slightly older calculated age of 4532±57 Ma. Initial $\varepsilon_{Nd,\ HEDR}$ = 0.4±0.4 as calculated for either data set, and agrees within error limits with values of this parameter measured in the JSC lab for HED meteorites.

Rb-Sr Age: Fig. 4 shows Rb-Sr data obtained for Asuka 881394 in the 2001 and 2010 investigations. These data also show a probable isotopic disturbance. In this case, the most pronounced disturbance is for "Px1" a pyroxene-enriched sample with a density >3.32 g/cm^3 obtained as a heavy liquid separate. This sample and its leach residue align with handpicked tridymite from the 2001 investigation along an apparent 3.9±0.1 Ga isochron. Because the measured $^{87}Sr/^{86}Sr$ ratio for the residue Px1(r) is in agreement with that measured in the first investigation for handpicked Px, there is a strong suggestion that at ~3.9 Ga ago Rb was "sweated out" of pyroxene grain surfaces and migrated into late-stage tridymite, itself likely to have formed during granoblastic metamorphism of the rock. Plausibly this effect was minimal for the larger and purer handpicked pyroxene grains. Heating experiments for a eucrite showed that initial melting occurred along grain boundaries [12].

Discussion: The isotopic record in A881394 must be interpreted in the context of its granoblastic texture. The good concordance of the Al-Mg and Mn-Cr formation intervals suggests that the granoblastic texture formed before those isotopic systems closed. Later disturbance of the Sm-Nd and Rb-Sr systems appears to be limited to minor phases including tridymite and possibly Ca phosphate and ilmenite as well [12]. The Nd- and Sr-isotopic systems appear to have remained closed in the major mineral plagioclase. Thus, initial $^{87}Sr/^{86}Sr$ = 0.698989±14 is indistinguishable from that for eucrites or angrites, whereas initial ε_{Nd} agrees with values measured for HED meteorites. These observations are consistent with the primordial Pb isotopic composition (CDT) in plagioclase reported by [6]. The observations suggest that the (most radiogenic+CDT) regression [6] yielding an age of 4566.05±0.45 Ma should be preferred to one for which modern terrestrial Pb is included in the regression. However, the K-Ar system suggests that plagioclase was not closed to Ar-migration, and *in situ* SIMS analyses showed variations in $\delta^{26}Mg$ that were not well correlated with Al/Mg ratios in plagioclase [5]. Thus, caution in using Asuka 881394 data to evaluate the initial homogeneity of the distribution of short-lived nuclides in the early solar nebula is indicated.

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References: [1] Takeda H. et al. (1997) *Antarct. Meteorite Res. 10,* 401-413. [2] Scott E. R. D. et al. (2008) *LPS XXXIX,* Abstract #2344. [3] Nyquist L. E. et al. (2001) *MAPS 32,* A151. [4] Nyquist L. E. et al. (2003) *EPSL 214,* 11-25. [5] Srinivasan G. (2002) *LPS XXXIII,* Abstract #1489. [6] Wadhwa M. et al. (2009) *GCA*, *73,* 5189-5201. [7] Nyquist L. E. et al. (2011) *74th Ann. Mtg. Met. Soc.,* Greenwich, UK. [8] Bogard D. D. (2011) *Chemie Erde- Geochem. Doi:10.1016.* [9] Nyquist L. E. et al. (2006) *GCA 70*, 5990-6015. [10] Steiger R. H. and Jäger E. (1977) *EPSL 36,* 359-362. [11] Begemann F. et al. (2001) (2010) *GCA 65,* 111-121. [12] Yamaguchi A. and Mikouchi T. (2005) *LPS XXXI,* Abstract #1574. [13] Kinoshita N. et al. (2011) *Goldschmidt Conf. abs.,* p. 1191.

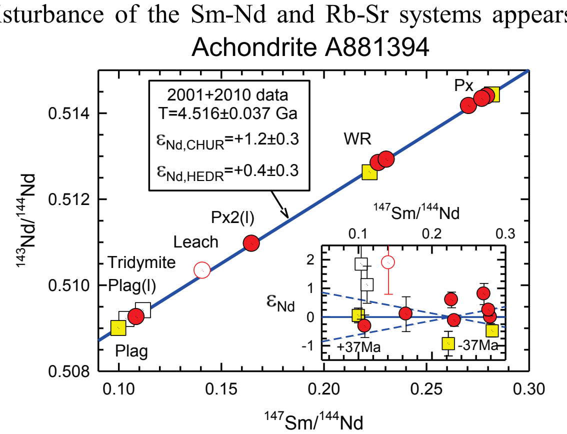

Figure 3. Sm-Nd data for Asuka 881394. Age calculated assuming $\lambda(^{147}Sm)$ = 0.00654 Ga^{-1}[11].

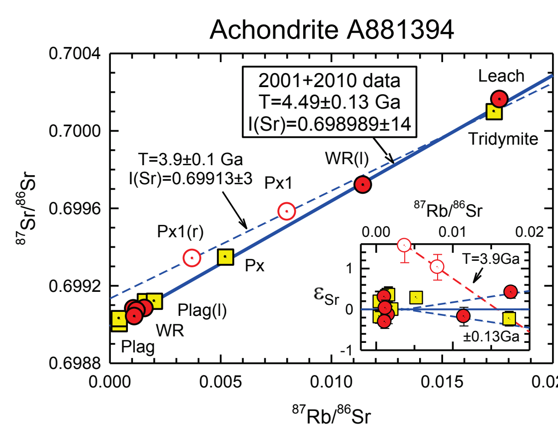

Figure 4. Rb-Sr data for Asuka 881394. Age calculated assuming λ (^{87}Rb) = 0.01402 Ga^{-1} [11].