U-PB CHRONOLOGY OF A NEWLY RECOVERED ANGRITE. A. Bouvier, G. A. Brennecka, M. E. Sanborn, and M. Wadhwa, Center for Meteorite Studies, School of Earth and Space Exploration, Arizona State University, PO Box 871404, Tempe AZ 85287-1404, USA (audrey.bouvier@asu.edu).

Introduction: The angrites are a small group of achondrites composed of pyroxene, olivine, plagioclase, metal and accessory phases (e.g., spinel, phosphates). They can be divided into two main textural subgroups: fine-grained 'quenched' angrites (e.g., D'Orbigny and SAH 99555) that were formed by rapid cooling of their parent melts and the coarser-grained 'plutonic' angrites (e.g., Angra dos Reis, LEW 86010), that record evidence of a more complex cooling history possibly involving some degree of thermal metamorphism. Northwest Africa (NWA) 6291 is recent meteorite find (250g, 2010) classified as an angrite. It has the unusual petrological characteritics of NWA 2999, such substantially larger modal abundances of metal and spinel in comparison to other angrites [1]. This suggests that these two angrites could be paired and may possibly represent a third subgroup. Thus, it is important to constrain the chronology and petrogenesis of this angrite to better understand the evolution of the angrite parent body and, more broadly, planetesimal differentiation processes in the inner Solar System.

Based on the U-Pb, Hf-W and Mn-Cr chronometers, the two main textural types of angrites correspond to two temporally well-resolved periods of igneous activity separated by ~7 Ma on the angrite parent body (e.g., [2-4]). The revised Pb-Pb age of quenched D'Orbigny is 4563.36 ± 0.34 Ma after correcting for its U isotopic composition [5-7] relative to normal $^{238}U/^{235}U$ ratio of 137.84 instead of 137.88 which was previously assumed [6,7]. There are no high-precision U isotopic data reported as yet for any of the coarse grained angrites, but their uncorrected Pb-Pb ages are significantly younger at 4557-4558 Ma [3]. We here report the trace element and high-precision Pb isotopic compositions for NWA 6291. This angrite contains coarse- as well as relatively fine-grained petrological domains; we report here data for whole-rock fractions from each of these domains and mineral separates from the coarse-grained domain. We are additionally in the process of measuring the U istopic composition of an unleached whole-rock sample, and of recombined fractions of leachates and residues collected after Pb extraction.

Analytical Techniques: Three interior fragments of NWA 6192 were processed for trace element and Pb isotopic analyses. One fragment each of the fine-grained (FG) and coarse-grained (CG) domains was washed in Milli-Q water before being processed for Pb isotopic measurements. A 438 mg fragment of the fine-grained domain was powdered, and two aliquots (102 and 132 mg) were obtained from this powder for whole-rock analyses (FG-WR1 and FG-WR2). A 837 mg fragment of the coarse-grained domain was split for whole-rock analyses, powdered and two aliquots (89 and 143 mg) were obtained (CG-WR1 and CG-WR2). The remainder of this coarse-grained fragment was subjected to mineral separation using a Frantz magnetic separator, followed by hand picking, to obtain two 48-65 mg pyroxene-rich separates (PX1 and PX2) and a 28 mg plagioclase-rich separate (PL). A third 613 mg fragment of the fine-grained domain (FG-WR3) was washed only in H_2O and prepared for trace element and U isotopic analyses.

The FG-WR2, CG-WR2, PX2 samples were acid-washed using a 8-step leaching protocol similar to that used by [3], including 3 steps in 0.5 M HNO_3 (ultrasonic), 1 step in 6M HCl (1h @ 100ºC), 3 steps in 7M HNO_3 (30mn, 1h cold, 1h @ 120ºC), and a final step in 1M HF (2h @ 120ºC). The FG-WR1, CG-WR1, PX1 and PL samples were only subjected to the first 7 steps of this leaching protocol, i.e., omitting the final (hot 1M HF) leach step for these samples. The first 3 leachates in each case dissolved mostly iron hydroxides (formed during the residence of the meteorite in the Saharan desert) and were not processed any further. The leachates from step 4 to step 6 (denoted as L_4-L_6) for each sample were recombined and saved for future U isotopic work. The L_7 and L_8 leachates were each processed separately for Pb chemistry and analysis. All residues (denoted as R) and leachates were dissolved in a concentrated HF-HNO_3 (5:1) mixture and converted to the chloride form before Pb extraction, as described in [8]. The loading, rinsing (1.5M HBr) and column washing (6M HCl) solutions were collected during the Pb column chemical procedures and saved for future U extraction. We analyzed the isotopic composition of Pb separated from the final (L_8) leachates from each of the 3 samples (FG-WR2, CG-WR2 and PX2) subjected to the 8-step leaching protocol, as well as from the L_7 leachates and the respective residues (R) from each of the 7 samples that were subjected to acid-washing (FG-WR1,2, CG-WR1,2, PX1,2, and PL) to evaluate the removal of common Pb during progressive leaching of these samples. The total Pb procedural blank during this study was 0.9 pg, and the Pb sample/blank ratios ranged from 18 to 53 for the 7 L_7 leachates, 963 to 1292 for the 3 L_8 leachates, 733 to 2131 for the 7 residues. The measured Pb isotopic compositions of each of these samples were corrected accordingly.

Pb isotope measurements (using Tl doping) were made on a Thermo-Finnigan Neptune MC-ICPMS at ASU using methods identical to those described in [8]. Analyses of two Pb isotope standards (2 ppb Pb – 1 ppb Tl) over the course of a single analytical session yielded the following reproducibilities (2SD): $^{206}Pb/^{204}Pb$ = 16.938 (± 0.228%) and $^{207}Pb/^{206}Pb$ = 0.91475 (± 0.020%) for NBS 981 (n=8); $^{206}Pb/^{204}Pb$ = 2,809 (± 2.97%) and $^{207}Pb/^{206}Pb$ = 0.07116 (± 0.023%) for NBS 983 (n=2). The unleached FG-WR3 sample was fully dissolved and its trace element composition was analyzed on a quadrupole ICPMS at ASU.

Results: The corrected $^{206}Pb/^{204}Pb$ of the final leachates range from 22.7 to 48.7 for the L_7 leachates, 110 to 533 for the L_8 leachates, and 19.8 (PL-R) to 711 (CG-WR2-R) for the corresponding residues (R) indicating efficient removal of common Pb during the leaching protocol used here. The compositions of the residues for NWA 6291 are nevertheless much less radiogenic than for the other quenched and plutonic angrites, a characteristic that was also observed for NWA 2999 [9]. The $^{232}Th/^{238}U$ ratio of FG-WR3 is 3.47 (±10%, 2SD), similar to that reported for NWA 2999 pyroxene and for the plutonic angrites (~2.5-3.9), but significantly lower than for D'Orbigny and SAH 99555 (~7-8) [9]. The $^{207}Pb^*/^{206}Pb^*$ model ages for angrite samples, assuming the Canyon Diablo troilite (CDT) composition as the initial Pb isotopic composition, are incorrect as the angrite parent body was extremely volatile-depleted and had a super-chondritic U/Pb ratio [3]. Therefore, we report an internal isochron age for NWA 6291 which does not require the assumption of an initial composition. The CG-WR2-R sample showed a slight excess in ^{204}Pb (possibly from more intense dissolution of spinel) and the PL-R was very unradiogenic, and were not included in the regression. The 5 remaining residues and 3 L8 leachates yield an internal Pb-Pb isochron age of 4561.29 ± 0.78 Ma (MSWD = 2.5) using $^{238}U/^{235}U$ = 137.84 [6,7] (Fig. 1).

Discussion: This angrite age is signifantly lower than the D'Orbigny age by ~2 Ma [3,5], and older than the ages of the plutonic angrites by ~5 Ma [3]. However, it is consistent with the preliminary isochron age of 4561.35 ± 0.42 Ma reported for NWA 2999 by [9] (recalculated using $^{238}U/^{235}U$ = 137.84). The similarity of the Pb-Pb ages and Th/U ratios of these two meteorites is suggestive of their pairing. The higher abundances of metal and the presence of fine- and coarse-grained domains in these samples may be a consequence of a chondritic impactor on the angrite parent body, potentially affecting the isotopic systematics. The Hf-W system shows similarities for AdoR and NWA 2999, and indicates a higher Hf/W in their source reservoir; however, the W isotopic composition of NWA 2999 does not support a chondritic origin of the metal [2,10]. Moreover, a ~4561 Ma Pb-Pb age for NWA 2999 is consistent, within errors, with its revised ^{182}Hf-^{182}W isotopic systematics [10], suggesting that the Pb-Pb and Hf-W ages are indeed meaningful. The low Th/U ratio of these meteorites (~3.5) limits the possible U isotopic variations from ^{247}Cm decay [5,11] (limiting the required age correction to only ~-0.3 Ma) and would not affect the concordance between Pb-Pb and Hf-W ages within the current uncertainties and cannot explain the older ages of these two meteorites relative to the other plutonic angrites (e.g., AdoR and LEW86010).

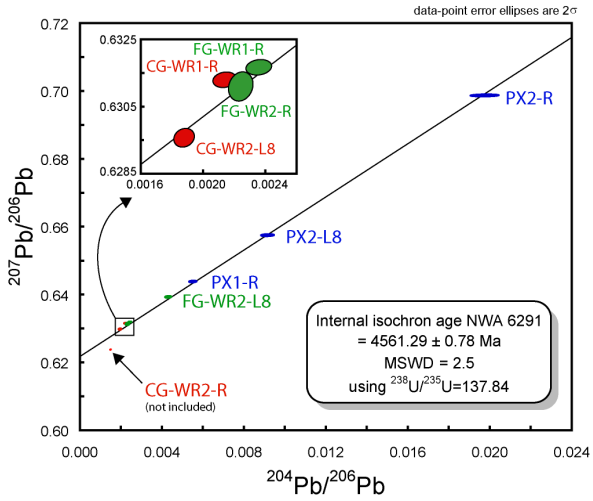

Fig. 1: Internal Pb-Pb isochron NWA 6291 calculated using $^{238}U/^{235}U$ = 137.84 [6,7]. Isochron regression includes 5 residues (FG-WR1,2-R, CG-WR1, PX1-R, PX2-R), and 3 final leachates (FG-WR2-L_8, CG-WR2-L_8 and PX2-L_8).

Acknowledgments: The sample of NWA 6291 was obtained from the meteorite collection in the Center for Meteorite Studies at ASU. We thank Rebekah Hines and Phil Janney for their assistance in the clean lab and mass spectrometry lab in the Isotope Cosmochemistry and Geochronology Laboratory at ASU.

References: [1] Connolly H. C. et al. (2006) *MAPS, 41,* 1383–1418. [2] Markowski A. et al. (2007) *EPSL, 262,* 214-229. [3] Amelin Y. (2008) *GCA, 72,* 221-232. [4] Glavin D. et al. (2004) *Meteorit. Planet. Sci., 39,* 693-700. [5] Brennecka G. A. et al. (2010) *LPS XVI,* Abstract #2117. [6] Richter S. et al. (2010) *Int. J. Mass Spectrom., 295,* 94-97. [7] Condon D. J. et al. (2010) *GCA, 74,* 7127-7143. [8] Bouvier A. and Wadhwa M. (2010) *Nature Geosci., 3,* 637-641. [9] Amelin Y. and Irving A. J. (2007) *Workshop Chron. Met. & Early Solar System,* Abstract #4061. [10] Kleine T. et al. (2009) *LPS XL,* Abstract #2403. [11] Brennecka G. A. et al. (2010) *Science*, *327,* 449-451.