THE Pb-Pb AGE OF ANGRITE SAH99555 REVISITED Connelly[1,2], J.N., Amelin[3], Y., Bizzarro[2], M., Thrane[2], K., and Baker[4], J.A. [1] The Jackson School of Geosciences, The University of Texas at Austin, Austin, Texas, U.S.A. 78712, connelly@mail.utexas.edu, [2] Geological Museum, University of Copenhagen, Øster Voldgade 5-7, 1350 Copenhagen, Denmark, [3] Research School of Earth Sciences and Planetary Science Institute, The Australian National University, Canberra, ACT 0200, Australia, [4] School of Geography, Environment and Earth Sciences, Victoria University of Wellington, P.O. Box 600, Wellington, New Zealand.

Introduction: Representing a suite of well-preserved basaltic meteorites with reported ages from 4566.18±0.14 Ma to 4557.65±0.13 Ma, angrites have been recurring targets for cross-calibrating extinct and absolute chronometers [1-3]. These efforts have been frustrated by inconsistencies in the available chronological data set, including a 4566.18±0.14 Ma Pb-Pb age for Sahara 99555 (herein SAH99555; [1]) that is significantly older than a Pb-Pb age for D'Orbigny [2], despite the two meteorites yielding indistinguishable extinct chronometer ages [1, 4-8] . In two independent studies, we have re-evaluated the Pb-Pb age of SAH99555 using both a step-wise dissolution method (Copenhagen) and an intense acid leaching procedure prior to dissolution of the residue (Ottawa).

Methods: *Copenhagen:* Two rust-free fragments of SAH99555 from a cut slab were abraded and cleaned by repeated (10x) ultrasonicating in water, alcohol and acetone cycles. Processed as a single fraction, the 2 fragments were then subjected to a stepwise dissolution process using progressively stronger acids. The pyroxene fraction was picked in distilled ethanol from a lightly-crushed and sieved fraction of a third fragment. The pyroxene was pre-cleaned according to the method of [1] and dissolved in a 28M HF – 14M HNO_3 mixture. All fractions to be analyzed were spiked with a mixed ^{202}Pb-^{205}Pb-^{235}U spike before a chemical separation using HBr - HNO_3 solutions and anion resin in a 0.055 ml column. Pb from the whole rock fragments was analysed on a Finnigan-MAT 261 TIMS mass spectrometer at The University of Texas at Austin. Pb from the pyroxene fraction was analyzed on a Finnigan-MAT 262 TIMS mass spectrometer at the University of Oslo. Methods and results are more completely described in [9].

Ottawa: Whole rock analyses represent fragments or unprocessed material after crushing of two specimens of SAH99555. All fractions were washed 4-5 times in 0.5M HNO_3 with ultrasonic agitation during each leaching step – these washes were combined and analyzed as Wash-1 [10]. A second washing comprised one cycle of hot 6M HCl and two cycles of hot 7M HNO_3, with heating approximately one hour on a 120°C hot plate – these were combined as Wash-2 [10]. The residues were dissolved with concentrated HF and HNO3. A mixed ^{202}Pb-^{205}Pb-^{233}U-^{235}U tracer was added to the washes and dissolved residues before

Pb was separated on 0.05 ml anion columns using HBr and water. Uranium was separated on the same columns using HCl, HNO_3 and water. Pb was analyzed on a Triton TIMS, and U on a Nu Plasma MC-ICPMS at the Geological Survey of Canada. Methods and results are more completely described in [3] and [10], respectively.

Results: The two methods return highly-radiogenic analyses with $^{204}Pb/^{206}Pb$ ratios < 0.00098 for all whole rock residues and dissolution steps that define linear arrays in the two data sets. A pyroxene residue processed in Copenhagen has a higher $^{204}Pb/^{206}Pb$ ratio of 0.00221 and is collinear with the analyses of the stepwise dissolution analyses. The two arrays project through approximations of modern terrestrial Pb and correspond to overlapping $^{207}Pb/^{206}Pb$ ages of 4564.58±0.14 Ma and 4564.86 ± 0.38 Ma (Fig. 1). The first three dissolution steps in the Copenhagen data and seven of nine pyroxene residues processed in Ottawa plot above their respective whole rock arrays, indicating that an isolatable highly-radiogenic component of Pb resides in SAH99555. This "anomalous Pb component" may be either an inherited initial Pb component (model 1) or a high $^{207}Pb/^{206}Pb$ component that was redistributed during a post-crystallization impact or thermal event (model 2). Model 1 predicts the presence of three components of Pb, namely, highly-radiogenic initial Pb (Pb_i), post-crystallization radiogenic Pb (Pb_r) and terrestrial contamination Pb (Pb_c). Model 2 predicts the presence four components of Pb, namely, close to primordial Pb_i, Pb_c and pre- and post-redistribution event Pb_r referred to here as Pb_rI and Pb_rII, respectively.

Discussion: Validity of the $^{207}Pb/^{206}Pb$ ages as accurate estimates of the crystallization age of SAH99555 requires that only two components of Pb be characterized in either array and that one of them comprises a representative sampling of the radiogenic Pb accumulated in SAH99555 since its crystallization. Since both arrays project through modern terrestrial Pb, the second component is inferred to be terrestrial Pb contamination. Fulfilling the assumption of such a two component system with chronological significance requires that Pb_i (regardless of its heritage) was effectively removed during washing (Ottawa) or the early dissolution steps (Copenhagen) and that Pb_r was not heterogeneously sampled. Both models can satisfy this scenario, provided either: (1) the "anomalous Pb"

corresponds to Pb_i that is present in a readily soluble phase (model 1), or (2) the migration of Pb_rI was restricted to mineral grain scale, and Pb_rI and Pb_rII are not separated by the whole rock wash or partial dissolution steps (model 2) and that all primordial Pbi was removed by washing. In the latter case, the four-component system of model 2 is effectively reduced to three components. The linearity of the data in both data sets is consistent with efficient removal of radiogenic Pb_i, regardless of whether it is highly radiogenic or not (thereby reducing the system to two components). If Pb_rI was re-distributed, and is separated from Pb_rII during leaching, then the system is not reduced to two components, and preferential sampling of Pb_rI or Pb_rII together with mixing with Pb_c will return dates that are either too old or too young, respectively, for the crystallization age of SAH99555.

Although both models may explain the observed Pb-isotopic patterns, they both have difficulties. Model 1 requires a very high $^{238}U/^{204}Pb$ ratio (μ-value) in either the source region of SAH99555 (and presumably the parent body as a whole), or in a magma chamber that existed for sufficient time to evolve highly-radiogenic Pb that was incorporated as Pb_i. The degree of devolatization required for such a high μ-value in any precursor material to SAH99555 seems inconsistent with the volatile element contents in angrites [10, 11]. Model 2 requires representative sampling of Pb_r despite evidence in both data sets that an anomalous Pb component can be isolated during early leaching.

The older age of [1] is consistent with the existence of a radiogenic Pb_i component that was not soluble in the 2M HCl pre-dissolution acid cleaning steps. Linearity of that data set along a line projecting to modern terrestrial Pb infers that Pb_i and Pb_r were present in all fragments processed in constant relative amounts whereas the relative amount of Pb_c varied between analyses.

We interpret the linear arrays to be mixtures of representative Pb_r and Pb_c and that any Pbi that existed in these samples was effectively removed during the pre-dissolution washes (Ottawa) or early dissolution steps (Copenhagen). As such, we infer that the corresponding $^{207}Pb/^{206}Pb$ ages of 4564.58±0.14 Ma and 4564.86 ± 0.38 Ma are accurate estimates of the crystallization age of SAH99555, but we stress that these results are model dependent. Despite the angrites representing tempting targets to intercalibrate short-lived and long-lived chronometers, at least SAH99555 has complexities that require further investigation before it can serve as a robust anchor for early Solar System timescale work.
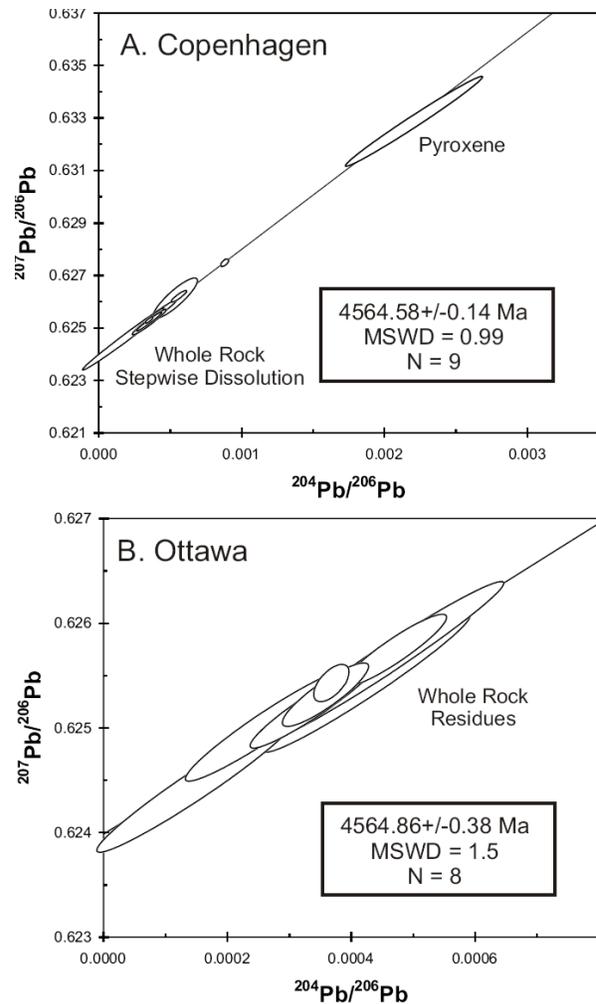

Figure 1: Pb-Pb plots of linear arrays for SAH99555 data generated (a) by stepwise dissolution of a single fragment and (b) by dissolution of residues after aggressive acid washes of 8 different fragments.

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