NOBLE GASES AND COSMIC RAY EXPOSURE AGES OF THE NEWLY DISCOVERED ALMAHATA SITTA C1+UREILITE BRECCIA SAMPLE.

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Introduction: Almahata Sitta is the most prominent and most extreme exception to the norm that meteorites are composed of material belonging to only one meteorite class. Of the recovered material from this polymict ureilite breccia, ~70-80% of the clasts have been classified as ureilites, with the remaining ~20-30% being a very diverse assemblage of different chondrite classes [1-3]. Almahata Sitta exploded at high altitude in the atmosphere and created a large strewn field in the Sudanese desert in 2008 [4]. Until recently, all investigated samples were well consolidated stones of monomict lithologies [e.g., 1,2]. It was suggested that a loosely consolidated matrix, surrounding the more resistant clasts found in the desert, was lost entirely during atmospheric entry [5]. Until last year, candidates for this putative matrix were missing. Fioretti et al. [2] and Goodrich et al. [6] reported last year on newly characterized samples from the Khartoum collection. Among these samples are the paired samples AhS-91 and AhS-91A: the first possible candidates for the inferred Almahata Sitta matrix [3,6]. These samples are composed mainly of C1 material, mixed with ureilitic olivine pyroxene, and plagioclase fragments, OC chondrules, and metal with ordinary and enstatite chondrite compositions [3,6]. AhS-91A and AhS-91 are the first Almahata Sitta samples to contain both ureilitic and chondritic material.

The formation of Almahata Sitta has long been a topic of discussion. The two main hypotheses that have been put forward differ as to whether Almahata Sitta is a regolith breccia or not [1,5]. By analyzing noble gases in the samples we can contribute to answer this question in two ways: 1) If Almahata Sitta is a regolith breccia then we expect some Solar wind (SW) noble gases to be present in the matrix portion of the sample. Solar wind is implanted into the top <1 mm of mineral grains when exposed on the surface of an asteroid. Note that we do not necessarily expect SW in the more consolidated stones as outlined in [5,7]. 2) Some variation in cosmic ray exposure (CRE) ages is possible if the samples originated in a regolith breccia. This is because the effects of galactic cosmic rays (GCR) decrease with depth in the asteroid and is negligible at a depth of a few meters. In a regolith breccia, the material gets gardened through impacts and some material spends longer time at shallow depth where there is more exposure to GCR than experienced by other material.

In a recent study [7], it was found that there is a larger spread in CRE ages of Almahata Sitta samples than previously thought [8,9]. However, the results were not sufficient to conclude with certainty that Almahata Sitta is a regolith breccia. SW has not been found in any of the Almahata Sitta fragments of various types analyzed so far [7-12].

In this study we analyzed sample AhS-91A to 1) investigate if this possible matrix sample contains SW, and 2) estimate the CRE age of this sample and compare it with the other Almahata Sitta samples.

Methods: Three aliquots of AhS-91A with masses between 7 and 15 mg were analyzed for concentrations and isotopic compositions of He, Ne, Ar, Kr, and Xe in the noble gas laboratory at ETH Zurich, following the methodology described in [7].

Results and Discussion: The CRE ages of the three AhS-91A samples are variable and significantly lower than those of most Almahata Sitta samples reported previously [7-9]. This could indicate exposure to GCR in a regolith. On the other hand, there is no evidence for SW noble gases in the sample, which is at odds with a regolith environment.

Low Cosmic Ray Exposure Ages. Production rates for CRE ages were estimated from the model by [13] using average elemental compositions of CI chondrites, ureilites, and various types of ordinary and enstatite chondrites from [8,14]. Production rates were taken as an average over the expected shielding depths in the Almahata Sitta meteoroid from [8]. Such averages of ^{21}Ne production rates were in good agreement with less shielding sensitive ^{21}Ne/^{26}Al production rate ratios in [7]. The frequently used ^{22}Ne/^{21}Ne shielding indicator does not work well for large bodies such as Almahata Sitta [13]. The exact proportions of ureilitic and ordinary chondrite material mixed in with the C1 material in the samples are unknown, but optical investigations of the samples prior to noble gas analysis showed that C1 material is dominating. The lowest production rates, and therefore the highest CRE ages, are obtained from a pure CI chondrite composition. This gives ^{21}Ne CRE ages of ~6, ~9, and ~12 Ma, respectively, for the three aliquots of AhS-91A. As far as elemental composition is concerned, these CRE ages are upper limits, because mixed in ureilitic, enstatite, and ordinary chondritic material would lower the CRE ages.

The ^{21}Ne/^{22}Ne ratio of the cosmogenic component is ~0.8 (Fig. 1). Despite the problems associated with the ^{22}Ne/^{21}Ne shielding indicator for large meteorites like Almahata Sitta [8,13], this relatively low ratio might indicate that the sample experienced very low shielding. If the sample experienced very low shielding in the meteoroid, then calculating the production rates as an average over the full possible shielding depth, as done above, would not work well [7,13]. Extremely shallow shielding in the cm range would increase the CRE ages by a few million years. This would bring the CRE age of one of the aliquots to ~17 Ma, within the range of CRE ages of 16-22 Ma reported previously [7-9]. However, the other two aliquots would still have significantly lower CRE ages of ~8 and ~12 Ma.

All Almahata Sitta samples analyzed so far except one have CRE ages between 16 and 22 Ma [7-9]. One E chondritic sample has previously been reported with a CRE age of only 11 Ma [7]. The preliminary data in this study shows that AhS-91A might have an even lower CRE age. It was suggested in [7] that the sample with the 11 Ma CRE age could represent the true 4π age of the Almahata Sitta meteoroid, or, an upper limit thereof, and that all other samples could have been pre-irradiated, somewhat surprisingly for about the same period of time, in a regolith. Other explanations provided for the low CRE age was gas loss and chemical heterogeneity. Adding AhS-91A as a second sample with significantly lower and variable CRE age to the data set appears to strengthen the interpretation that the samples experienced variable exposure to GCR on the parent body. However, at this early stage of the study we cannot exclude alternative explanations for the low and variable CRE age of AhS-91A.

Lack of Solar Wind Noble Gases. There is no evidence for SW noble gases in the bulk fragments of AhS-91A. The Ne isotopes do not show any resolvable contribution from SW noble gases but can be explained with a significant contribution from trapped noble gases originating from presolar grains and phase Q (Fig. 1). Compared to previously analyzed Almahata Sitta samples, the Ne isotopic composition in AhS-91A is more affected by trapped Ne, as expected based on the different meteorite classes with CIs being among the most trapped gas rich. The ^{3}He/^{4}He ratios show large contributions from cosmogenic He, making it difficult to disentangle the trapped He composition. The elemental ratios do not show any evidence of SW either.

No published data of any Almahata Sitta sample shows evidence for SW [7-12]. All previously analyzed samples were however well consolidated stones in which SW might not be expected, even in a regolith. However, AhS-91A is a fine-grained, friable, C1 breccia, intimately mixed with other lithologies found among the Almahata Sitta stones [3,6]. The petrology of AS-91A indicates that it is an extensively gardened regolith [3]. How such regolith material can form without incorporation of SW is a mystery. If Almahata Sitta is a regolith breccia, then the fraction of the regolith that AhS-91A sampled must have been shielded from SW. Perhaps AhS-91A came from a deep fraction in the regolith that nonetheless was brecciated by processes occurring typically at a shallower depth. This interpretation agrees with the low CRE ages of the sample; the CRE ages indicate that AhS-91A spent less time in a shallow part of a regolith than most Almahata Sitta samples analyzed to date.

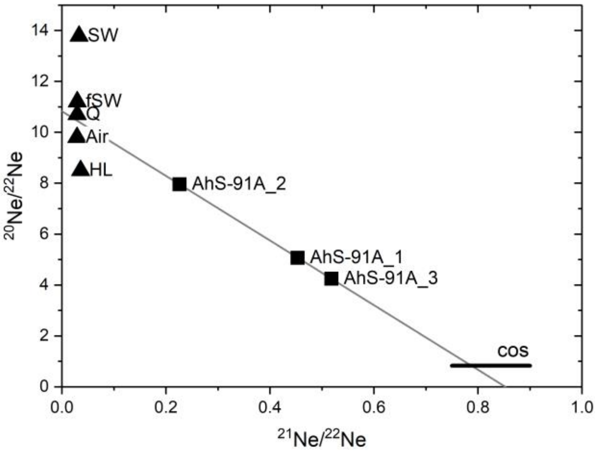

Fig. 1 Neon three isotope plot. The grey line is a linear regression through the three data points.

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