A RECORD OF EARLY PRECOMPACTION EXPOSURE OF HIBONITES TO ENERGETIC PARTICLES: EVIDENCE FROM SPALLOGENIC HELIUM-3 AND NEON-21.

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Introduction: PLAty hibonite Crystals (PLACs) and isotopically related hibonite-rich CAIs (i.e., non-platy hibonite crystals and hibonite aggregates; hereafter collectively referred to as PLAC-like CAIs) have the largest nucleosynthetic anomalies of all materials believed to have formed inside the Solar System (e.g., variations >100‰ in ^{50}Ti and ^{48}Ca [1–3]). This and their ^{26}Al-poor character have been attributed to an early formation, prior to a widespread distribution of ^{26}Al and large-scale homogenization of nucleosynthetic components in the solar nebula [2,3]. As PLAC-like CAIs may be among the first materials to have formed inside the Solar System, they are key samples to search for evidence of irradiation by cosmic rays, which may include a record for an early active Sun [e.g., 4,5]. Evidence for this would be found in the presence of noble gas isotopes created by spallation inside PLAC-like CAIs (in addition to those produced by exposure to cosmic rays in the meteoroid phase). Recently, we reported high cosmogenic ^{21}Ne and ^{3}He in two PLAC-like CAIs from the Murchison meteorite (PLACs 28 and 77, analyzed in bulk) [6]. These high gas amounts suggest that at least one of the two grains experienced a precompaction exposure to cosmic rays. However, since some components in the Murchison meteorite appear to have been exposed to cosmic rays in the parent body regolith [7,8], it was unclear if the excess ^{3}He and ^{21}Ne is the result of exposure in the regolith or in the nebula.

To investigate whether high amounts of cosmogenic ^{21}Ne and ^{3}He are characteristic of PLAC-like CAIs, we have studied 18 additional PLAC-like CAIs for He and Ne isotopes. To better understand whether the high gas amounts are due to regolith exposure, we have also analyzed other components from the same Murchison acid residue (i.e., spinel-hibonite inclusions, SHIBs, N=5, and single grains of spinel, N=3). Here, we present preliminary results.

Samples and Methods: The samples were picked from the same Murchison HCl-HF-treated density separate of the Murchison meteorite (ME 2752, Field Museum of Natural History) as PLACs 28 & 77, which we presented previously [6]. All samples were placed on carbon tape for SEM imaging and EDS analyses. The morphology of the PLAC-like CAIs resembles those presented in [3], and includes platy and irregular, non-platy single grains and hibonite aggregates. SHIBs are typically dense, round objects, and the shapes of spinel crystals range from platy to octahedral. The sample heights (i.e., smallest dimensions) span the following ranges: Single hibonite crystals 3–39 µm (av. 13 µm), hibonite aggregates 18–45µm (av. 28 µm), single spinel crystals 4–214 µm (av. 84 µm), SHIBs 18–65 µm (av. 38 µm). After removal from the tape, the grains were cleaned in acetone, isopropanol and water, dried and pressed into a clean gold foil. To remove adsorbed air molecules, the grains were baked for 3 days at 80°C and pumped down for over a week prior to noble gas analysis. Noble gases were extracted with a Nd-YAG 1064 nm laser and He and Ne isotopes were measured with an ultra-high-sensitivity noble gas mass spectrometer at ETH Zurich [9]. The analytical protocol was developed specifically for analyses of low gas amounts [10]. To convert He and Ne amounts to concentrations, the sample masses were estimated using the density of hibonite and spinel and volumes estimated from SEM images obtained at varying tilt and rotation angles. For simplicity, we use maximum volumes calculated as prisms (base × maximum height) enveloping the true shapes of the particles. Therefore, all concentrations and exposure ages are minimum values. We estimate that for some grains, ages and concentrations could be up to a factor of 3 higher than reported here.

Results: The ranges of measured ^{3}He and ^{21}Ne amounts and minimum concentrations are summarized in Table 1 for each sample type. Analyses with sufficiently precise Ne isotope ratios have ^{20}Ne/^{22}Ne ratios <2, suggesting that our heating and evacuation procedure efficiently removed adsorbed air Ne. Therefore, all measured ^{21}Ne is considered to be cosmogenic (i.e., ^{21}Ne$_{cos}$).

Table 1. Range of gas amounts, concentrations and production rates. STP refers to standard temperature and pressure; 1 cm^3 STP = 2.6868×10^{19} atoms.

		PLAC-like CAIs		SHIBs		Spinel crystals	
Amounts:		min	max	min	max	min	max
He-3	(10^{-15} cm^3 STP)	0.9	245.1	1.9	7.9	2.9	520.4
Ne-21	(10^{-15} cm^3 STP)	1.9	63.4	2.9	1.4	3.9	140.4
Concentrations:							
He-3	(10^{-8} cm^3 STP g^{-1})	1.2	110.4	1.3	2.4	1.6	4.3
Ne-21	(10^{-8} cm^3 STP g^{-1})	0.9	28.8	0.2	0.7	0.5	1.0
Production rates:							
He-3	(10^{-8} cm^3 g^{-1} Ma^{-1})	1.77	1.82	1.81	1.84	1.79	1.94
Ne-21	(10^{-8} cm^3 g^{-1} Ma^{-1})	0.30	0.31	0.37	0.38	0.41	0.46

The data show a systematic relationship between ^{3}He and ^{21}Ne concentrations and mineralogy (Table 1, Fig. 1). On average, spinel-bearing samples (single crystals and SHIBs) have lower minimum ^{3}He and ^{21}Ne concentrations than the spinel-free PLAC-like CAIs. In particular, the seven samples with the lowest concentrations contain (or are entirely composed of) spinel. Only one spinel grain overlaps with the lower end of the concentrations found in PLAC-like CAIs.

Discussion: Assuming that cosmogenic ^{3}He and ^{21}Ne was entirely acquired in the Murchison meteoroid, nominal exposure ages can be calculated for each sample. For this, we use the same shielding assumptions for the Murchison meteoroid as [7] and production rates calculated by [11] as well as elemental abundances of the samples obtained by EDS. For the eight spinel-bearing samples (single crystals and SHIBs), we calculate minimum exposure ages between ~1 and 2 Ma (Figs. 1, 2), which are comparable to many Murchison chondrules and the bulk meteoroid exposure age of ~1.6 Ma ([7], Fig. 3). This suggests that the spinel-bearing samples did not experience significant exposure to cosmic rays prior to compaction of the parent body. In contrast, the nominal exposure ages of the 18 spinel-free PLAC-like CAIs range from ~3 to 93 Ma (T_{21} based on cosmogenic ^{21}Ne) and ~1 to 60 Ma (T_3 based on cosmogenic ^{3}He), indicating that they experienced additional, variable exposure to cosmic rays. The discrepancy between T_{21} and T_3 (Fig. 1) is small for most grains and since $T_{21} \geq T_3$ this is consistent with preferential diffusive loss of the lighter element He.

Since Murchison is known to include materials from the parent body regolith, we need to consider whether the measured excess ^{3}He and ^{21}Ne in most PLAC-like CAIs are due to irradiation in the regolith. Therefore, we compare our dataset to [7], who found evidence for pre-exposure (i.e., $T_{21} > 4$ Ma) in 7 of 32 studied Murchison chondrules (~22%). The fraction of PLAC-like CAIs with $T_{21}>4$ Ma is significantly higher (~78%). In the regolith exposure scenario favored by [7], this observation could be explained if our Murchison fragment had a higher relative abundance of regolith material. However, if this were the case, we would expect to find similar ^{3}He and ^{21}Ne excesses in spinel grains and SHIBs, as they were recovered from the same acid residue. This is contrary to our observations. Instead, the mineralogy dependence of the presence of excess ^{3}He and ^{21}Ne may point to a different precompaction exposure origin. If the eight spinel-bearing samples are representative for the exposure history of this rock while it was part of the Murchison parent body, the new data would indicate that most PLAC-like CAIs acquired excess ^{21}Ne and ^{3}He in a different location, likely prior to incorporation into the Murchison parent body. As PLAC-like CAIs are thought to have formed in the solar nebula, but earlier than regular, ^{26}Al-rich CAIs, this exposure may have occurred early in Solar System history, perhaps while located close to the young Sun or during a period of high cosmic ray fluxes, e.g., from an early active Sun. Alternatively, these anomalous CAIs may predate the formation of the Solar System. The excess ^{3}He and ^{21}Ne could then be the result of prolonged exposure to galactic cosmic rays in the interstellar medium.

Overall, our preliminary results suggest that the presence of excess cosmogenic ^{21}Ne and ^{3}He can be added to the growing list of isotopic properties in which PLAC-like CAIs are distinct from ‘regular CAIs’ [3,12,13] and SHIBs.

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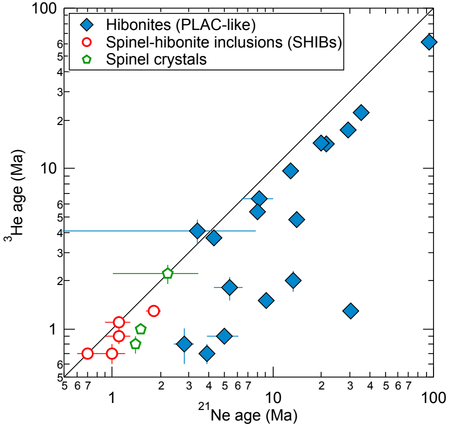

Figure 1. Minimum nominal meteoroid exposure ages: The ages of spinel-bearing samples are comparable to the exposure age of Murchison (~1.6 Ma) and typically younger than those in PLAC-like CAIs. For many samples, ^{21}Ne ages are > ^{3}He ages, likely due to diffusive He loss. Plotted uncertainties are from noble gas analysis only (uncertainties from mass estimates and production rates are not considered).

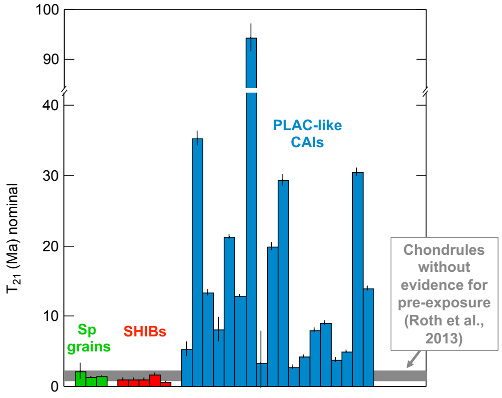

Figure 2. Comparison of nominal exposure ages of different sample types with those found in chondrules without evidence for regolith exposure [7].