Solar noble gases in the Angrite parent body – Evidence from volcanic volatiles trapped in D’Orbigny glass

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Introduction: Angrites are meteorites that formed particularly early and rapidly during solar system evolution, only ~5-10 Ma after the CAIs, and remained mostly unaltered ever since [1]. Angrites are presumably products of igneous processes [2,3], although nebular condensation was also suggested [4]. D’Orbigny (“D’O”, 16.6 kg) is special in being the first angrite containing abundant glass [5]. As for the bulk angrites, most workers assume an igneous origin for the glass, whereas [4,5] suggest a nebular origin. Most importantly, D’O glass might contain fossil 247Cm, which could explain unusually old Pb-Pb ages [6]. Bulk samples of D’O and Sahara 99555 also show too old 244Pu-Xe ages [7].

Surprisingly, the glass contains significant amounts of trapped Ne, whereas Ne in the bulk is dominated by spallogenic Ne (Fig. 2). Extrapolation towards trapped Ne implies that trapped Ne in the glass is solar with \( \frac{^{20}\text{Ne}}{^{22}\text{Ne}} = 11.9 \pm 0.4 \), which is between SW and SEP composition, the typical solar range [8]. The solar composition of the trapped Ne in D’O glass agrees well with the clearly solar element pattern found in D’O glass (Fig. 3): The trapped noble gases in D’O glass are enriched in He and Ne relative to Xe and the typically trapped meteoritic compositions, as found e.g. in the bulk samples of D’O, angrite Sahara 99555 [9,10] and CV 3 chondrite Grosnaja [11].

Here, we compare the trapped, radiogenic and spallogenic noble gases in both D’O glass and bulk. Possibly, D’O glass was formed 10 Ma after the bulk silicates. D’O glass contains interior solar noble gases that may originate from early volcanic activity on the angrite parent body (APB) and were trapped upon fast cooling of the glass.

Results: We measured the noble gases in D’O glass (2 analyses) and bulk (3). The latter yields an average cosmic-ray exposure (CRE) age of 11.7±0.7 Ma. D’O glass, however, shows a CRE age of only 1.6±0.6 Ma (Fig. 1), implying a pre-exposure of the bulk relative to the glass. The ages obtained from spallogenic 3He and 21Ne agree well with those from the heavier noble gases, indicating that neither D’O glass nor bulk did suffer significant diffusive loss.

Discussion: Pre-exposure of the D’O crystalline material. The pre-exposure of D’O bulk relative to the glass (Fig. 1) occurred most likely on the APB, as discussed below. We can exclude mistakes in the laboratory e.g. during weighing or calibration, because glass and bulk samples were analyzed each independently in two laboratories. Otherwise, the glass aliquots could have contained identical fractions of ~85 % gas-poor glass, e.g. introduced into D’O during entry into the terrestrial atmosphere. Addition of gas-free glass is conceivable in view of the much lower U/Th-3He (glass <0.8 Ga, bulk 4.2±0.6 Ga) and 244Pu-Xe retention ages for the glass [7]. However, the K-Ar age of the glass (3.9±1.3 Ga) is higher than that of the bulk.

Fig. 3. The element patterns of the trapped noble gases in D’O glass (stars) and bulk (squares) normalized to Xe and solar composition [8]. D’O glass clearly contains solar noble gases, while D’O bulk is dominated by the typical trapped meteoritic component, as found in Sahara 99555 [9,10] and Grosnaja [11].

Solar noble gases in D’O glass. Various mechanisms can result in the presence of solar noble gases in D’Orbigny. However, their exclusive presence in the glass is difficult to reconcile, while the crystalline phase appears solar gas-free. We suggest that the solar gases in D’O glass originate from the interior of the APB. They were transported with volcanic CO$_2$ in rising magma and trapped in the rapidly forming glass during quenching near the surface of the APB. Indeed, mm-sized vesicles found by x-ray CT examination of D’O and Sahara 99555 prove that volcanic activity occurred on the APB [12]. The APB is assumed to have a radius of <100 km [13]. Explosive volcanism could have occurred on such small bodies within the first 10 Ma [14]. While the vesicles in the bulk probably completely degassed, the µm-sized bubbles, which were observed in the glass [5] could have kept their gases. Other potential mechanisms to incorporate solar gases into the glass are unlikely: Exposure to solar wind of the glass in a regolith appears impossible without evidence for solar gases in adjacent crystalline material. Furthermore, D’O is not brecciated [3]. Trapping of an APB atmosphere in shock-produced glass similar to that observed in Martian meteorites can be excluded, because D’O does not show shock features [3] and the APB is too small to keep an atmosphere [13]. Nebular condensation of the glass [4,5] could have trapped ambient gas, provided that the nebula did not dissipate before condensation. However, the presence of significant amounts of solar He and Ne makes adsorption unlikely. However, exposure to strong solar wind of primitive, pre-accretional material in the early solar system might be capable to result in solar-gas-rich planetesimals [17]. Such a scenario is consistent with the observation of solar-like noble gases in the enstatite chondrites, once thought to be “subsolar” [18].

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References: