

## Origin of the mineralogical control on O isotopes in igneous CAIs

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In spite of numerous studies, the origin of the oxygen isotopic anomaly in the solar system is still not well established 45 years after its discovery by Clayton et al. [1]. It is now clear that this anomaly results from the isotopic difference between the Sun as measured by the Genesis mission [2] and most rocky planetary materials. Because meteoritic Ca-Al-rich Inclusions (CAI) have isotopic compositions spanning the whole range between the solar and planetary composition, understanding how their composition evolved is fundamental to constrain the origin of the anomaly. Specifically, individual igneous CAIs have isotopic heterogeneities also spanning most of the compositional range. This heterogeneity is controlled by their mineralogy: spinel is systematically <sup>16</sup>O-rich, melilite and anorthite are dominantly <sup>16</sup>O-poor and clinopyroxene is dominantly <sup>16</sup>O-rich [3]. The cause of this mineralogical control is however not understood and it is not clear if it results from early isotope exchange in the protoplanetary disk during magmatic crystallization, late isotope exchange by solid-state diffusion in the disk or on a parent body during fluid circulations. It is not even clear how many exchange events took place and how many reservoirs were encountered by CAIs.

Two recent studies have shown that contrary to usual assumptions clinopyroxene (cpx) in type B CAIs was initially <sup>16</sup>O-depleted and became progressively <sup>16</sup>O-rich during magmatic crystallization indicated by TiO<sub>2</sub> content [4,5]. Here I compiled O isotopes and TiO<sub>2</sub> data for various type of igneous CAIs and show that cpx became <sup>16</sup>O-rich during crystallization of all igneous CAIs including Type A, Type B and FUN (Fractionated with isotopic anomalies of Unknown Nuclear origin) inclusions. The isotopic systematics of highly mass fractionated FUN inclusions requires contribution of an internal component. Mass balance calculations indicate that the isotopic evolution of cpx during crystallization is well accounted for by dissolution of early-crystallized <sup>16</sup>O-rich spinel, a process expected from experimental petrology but overlooked during 35 years [6]. Spinel dissolution also explains the isotopic composition of anorthite and its polymorphs in these CAIs. This implies that igneous CAIs were isolated from the gas during a significant portion of their cooling history. Only one isotope exchange event with a <sup>16</sup>O-poor gas is required before the system closed to O. This exchange is associated with melilite crystallization/partial melting at high temperature (~ 1500°C). The <sup>16</sup>O-poor reservoir must have been present extremely early in the disk history, possibly even before the injection of <sup>26</sup>Al as indicated by <sup>26</sup>Al-poor FUN CAIs, which favors models in which the O anomaly is inherited from the interstellar medium or occurred by extremely rapid processes.

**References:** [1] Clayton R. N. et al. (1973) *Science*, 182, 485-488; [2] McKeegan K. D. et al. (2011) *Science*, 332, 1528-1532; [3] McKeegan K. D. and Leshin L. A. (2001) *Rev. Mineral Geochem*, 43, 279-318; [4] Aléon J. (2016) *EPSL*, 440, 62-70; [5] Kawasaki N. et al. (2018) *GCA*, 221, 318-341; [6] Aléon J.

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