

ALLENDE TE: EVIDENCE FOR MULTIPLE ISOTOPIC FRACTIONATION EVENTS BEFORE AND AFTER OXIDATION AND ALTERATION; A. El Goresy¹, E. Zinner², C. Caillet^{1,3}, A. Virag^{2,4}, S. Weinbruch^{1,2}; ¹Max-Planck-Institut für Kernphysik, D-6900 Heidelberg 1, Germany; ²McDonnell Center for the Space Sciences and the Physics Dept., Washington University, St. Louis, MO 63130, USA; ³Dept. of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington, DC 20560, USA; ⁴Institut für Analytische Chemie, TU Wien, 1060 Wien, Austria.

Allende TE is a petrographically complex olivine-bearing inclusion with mass dependent fractionation of O and Mg [1,2,3]. It shares these properties with CG 14, a petrographically similar inclusion from Allende. TE consists of two distinct lithologies: A. The interior is an assemblage of Ca-bearing idiomorphic forsterite (1.22-1.70 CaO) and fassaite (4.2 TiO₂, 16.1 Al₂O₃). Minor spinel occurs overgrown on the forsterite. The texture is typical of crystallization from a silicate melt with a deduced crystallization sequence forsterite → spinel → fassaite. B. Numerous oval to amoeboid objects consisting of spinel, fassaite, and melilite (Ak₈₂) are located at the circumference of the olivine-rich lithology, their rim layers in contact with the Allende matrix. The boundaries between the two lithologies is sharp, and the overall texture suggests that the spinel-bearing objects are xenoliths that were injected at low velocity into the olivine-rich material when the latter was still partially molten. The olivine-rich interior displays alteration and oxidation textures with fayalite-rich rims and veins (Fa₂₀) around and along cracks in the olivine. Spinel in the xenoliths near the contact to the olivine-rich portion show moderate FeO-contents (~8.5%). Many contain small blebs of pure metallic Fe, suggesting that they were reduced to MgAl₂O₄ and pure Fe during a late heating event after their oxidation.

Each lithology has its distinct rimming sequence (from inside out): 1. *Olivine-rich portion*: Diopside (0.06 TiO₂, 0.63 Al₂O₃), Fe-diopside (3.5 FeO), pure andradite, spinel, hibonite (1.10 TiO₂, 1.25 MgO). Corundum is intimately intergrown with spinel and hibonite in composite grains in which a thin veneer of spinel separates corundum in the core from hibonite in the outer portions of individual grains. 2. *Spinel-bearing xenoliths*: Spinel, fassaite, anorthite, Fe-spinel (13.2 FeO), and hibonite (2.68 TiO₂, 2.16 MgO). The texture in the anorthite-bearing layer indicates replacement of fassaite by anorthite. This must have been accompanied by substantial loss of Ti, probably during reaction with gas during the formation of the rim. The texture at the contact between the lithologies suggests that the xenoliths were injected into the olivine-rich core of the inclusion after formation of its rim sequence: the rim is subducted below the xenoliths, down to 100 μm from the original surface, without substantial disturbance of its delicate layering.

In an attempt to reconstruct the petrology and isotopic evolution of the different components of TE we have performed ion microprobe O- and Mg-isotopic measurements in order to address the following questions: 1. Did the forsterite-rich portion and the xenoliths form from the same or from different O isotopic reservoirs? 2. Do the xenoliths show similar O-isotopic signatures? 3. Do Al-rich minerals from different rim layers have different (²⁶Al/²⁷Al)₀ ratios? 4. Were alteration and oxidation the last events that modified the O-isotopic composition of various parts of the inclusion?

For ion probe analysis petrologically well characterized portions from rim sequences and the cores of two xenoliths as well as unaltered and oxidized parts from the olivine-rich portion were drilled out of the section (PTS); their mineral constituents were disaggregated and mounted on gold foil. The oxygen isotopic compositions of unaltered olivine and coexisting fassaite (mean: δ¹⁷O = -19.0‰, δ¹⁸O = -7.0‰) cluster around the TE mixing line of Clayton *et al.* [1]. Oxidized olivines (mean: δ¹⁷O = -4.4‰, δ¹⁸O = -0.2‰) plot closer to the intersection between the TE mixing line and the terrestrial fractionation line, indicating equilibration with an isotopically normal O reservoir during the formation of the Fe-bearing olivine. Most individual spinel and fassaite grains in the core of xenolith #1 plot along an ¹⁶O-rich mass fractionation line between the Allende ¹⁶O-rich mixing line and the TE mixing line, but some also plot along the TE mixing line (Fig. 1). Their O-isotopic compositions apparently reflect two processes: 1. Fractionation of an initially ¹⁶O-rich in component, probably the result of distillation; the large spread of the data points indicates that equilibration among coexisting grains was not achieved. 2.

Equilibration with normal O. Spinel and hibonite in the outer rim layers of this xenolith cluster along the Allende mixing line with only few points close to the TE mixing line. In contrast, spinels in the rim of xenolith #2 show a larger degree of O-isotopic fractionation than those from the core and rim of xenolith #1 (Fig. 2); some hibonites from the same rim sample are less fractionated than the spinels. The Mg-isotopic fractionation of these hibonites ($F_{Mg} \approx +10.5\text{‰/amu}$) is also less than that of the spinels ($F_{Mg} \approx +18.5\text{‰/amu}$). The hibonites therefore cannot have formed by distillation of the isotopically heavier spinel-bearing material. Spinel and fassaite in the interior of xenolith 2 show $\delta^{17}\text{O}$ and $\delta^{18}\text{O}$ values comparable to those in the core of xenolith #1, suggesting a similar fractionation history. On the other hand, melilite and diopside grains in xenolith 2 spread out along the terrestrial fractionation line from its intersection with the TE mixing line towards heavier O (Fig. 3), apparently the result of a further fractionation event after diopside and melilite had equilibrated with normal O. This strongly suggests that some xenoliths were subjected to multiple distillation processes before and after O-isotopic equilibration.

The textural relationships and isotopic compositions are evidence for a complex evolutionary history of this inclusion. Both lithologies seem to have experienced different heating events, perhaps in different reservoirs. Both started with an initially ^{16}O -rich composition. The composition of the olivine-rich portion can be explained by one major distillation episode of an olivine-rich liquid [4]. In contrast, the xenoliths were distilled at least twice, once before and once after oxidation and alteration. The $(^{26}\text{Al}/^{27}\text{Al})_0$ ratios of hibonites in the rims of the two lithologies are very similar ($\sim 4.7 \times 10^{-5}$) which indicates that not much time elapsed between the formation of the rim of the olivine-rich core and the injection of the xenoliths into the partially molten droplet. O-isotopic fractionation of the melilite in xenolith #2 after its equilibration with normal O strongly suggests that alteration and oxidation took place in the solar nebula and not on the Allende parent body.

References: [1] Clayton *et al.* (1984) *GCA* **48**, 535; [2] El Goresy *et al.* (1989) *Meteoritics* **24**, 263; [3] Zinner *et al.* (1989) *Meteoritics* **24**, 345; [4] Davis *et al.* (1990) *Nature* **347**, 655-658.

