ALTERATION PHASES IN THE E101.1 COMPOUND CAI: EVIDENCE OF NEBULAR PROCESSES?

D. Levy[1,2], J. Aléon[1], A. Aléon-Toppani[2], R. Brunetto[2]. [1] IMPMC, Sorbonne Université, MNHN, UPMC, IRD, CNRS, UMR 7590, 61 rue Buffon, 75005 Paris, France; [2] IAS, Université Paris Saclay, CNRS, UMR 8617, 91405 Orsay. Mail: dan.levy@mnhn.fr

Introduction: Ca-Al-rich inclusions (CAIs) found in chondrites, are the oldest rocks of the solar system. They formed at high temperature at the inner edge of the solar system in reducing conditions [1]. However, many CAIs contain secondary phases formed at relatively low temperature and high oxygen fugacity. After proposing that these phases formed in the nebula [e.g. 2], it has been admitted that the majority of these phases formed by fluid circulations on the parent-body [3,4]. However, the distribution of FeO-rich minerals of some CAIs, such as E101.1 [5,6], still suggests a possible nebular origin, which would imply oxidizing conditions not expected by thermodynamics in a gas of solar composition. E101.1 is a compound CAI from the reduced CV3 chondrite Efremovka. The host is a compact type A CAI cristallized from a melt and mainly composed of melilite (~$Åk_{25}$), associated with spinel, perovskite, fassaite and FeNi metal [5]. Xenoliths are sinuous fragments dominated by diopside having isotopic signatures consistent with condensation [6] and containing anorthite. The FeO-rich minerals are systematically enclosed inside these fragments. In order to determine if the FeO-rich minerals could have formed before accretion on the parent asteroid, we performed a detailed mineralogical study.

Methods: Secondary phases were characterized by electron microprobe (EPMA) whenever possible. Fine grained minerals and complex assemblages were studied by transmission electron microscopy (TEM) using nine focused ion beam sections. Mid-infrared (MIR) spectroscopy was used to locate amorphous melt pockets previously noticed in the sample [5,6].

Results: Secondary phases are predominantly kirschsteinite (61-79 mol%) and Mg-rich melilite enriched in ferro-åkermanite (13-28 mol%, hereafter Fe-åkermanite) associated with wollastonite. Anorthite is locally enriched in Na and replaced by nepheline. Local variations in this unusual mineral assemblage are observed. Notably, Fe-åkermanite is only present when the secondary assemblage is in contact with the host. By contrast, it is absent and kirschsteinite is the dominant mineral when enclosed completely in primary xenolith diopside. At the submicron scale, the contact between kirschsteinite and diopside is not sharp. The kirschsteinite-diopside interface often consists of Fe-enriched diopside, kirschsteinite enriched in Mg, monticellite and minute Fe metal, all smaller than 50 nm in size, which replace coarser-grained and sometimes euhedral kirschsteinite. Anorthite and Fe-åkermanite are sometimes locally amorphous. Numerous veins of amorphous Si-rich materials are observed. MIR spectroscopy confirms the presence of 1 to 100 µm amorphous melt pockets spatially associated with the xenoliths, chemically consistent with a mixture between the host and the xenoliths including secondary minerals.

Discussion: The interfaces between minerals indicating notably reduction of kirschsteinite into monticellite and metal, the amorphous phases and the amorphous melt pockets show that E101.1 underwent several high temperature events. An impact on the Efremovka parent body and the incorporation of the xenoliths into the host type A CAI are the two major high temperature events [6]. Fe-åkermanite and anorthite were most likely amorphized by a late impact. Distribution of Fe and Na in the amorphous melt pockets indicates that they formed after the formation of FeO and Na_2O-rich minerals but predate amorphization of Fe-åkermanite and anorthite. It is not clear whether they consist of residual glass resulting from the incorporation of the xenoliths into the host or of impact melts. Fe-åkermanite probably formed during the incorporation, as supported by its systematic location at the contact with the host CAI. All interface reactions indicate that coarse grained kirschsteinite and wollastonite are early phases, initially associated with condensate diopside. This strongly suggests that they were present before incorporation of the xenoliths and formed in the solar nebula. If correct, this implies that refractory xenoliths witnessed fO_2 conditions inconsistent with the canonical astrophysical context of formation of CAIs.

References: [1] Grossman et al. (2008) *Reviews in Mineralogy* 68:83-140. [2] Keller and Buseck (1991) *Science* 252:946-949. [3] Krot et al. (1998b) *Meteoritics & Planetary Science* 33:1065-1085. [4] Krot et al. (2000) *Geochemistry International* 38:S351-S368. [5] El Goresy et al. (2002) *GCA* 66:1459-1491. [6] Aléon et al. (2018) *GCA* 232:48-81.