METAMORPHOSED CALCIUM-ALUMINUM-RICH INCLUSIONS IN THE TANEZROUFT 057 CK4 CARBONACEOUS CHONDRITE. N. Chaumard[1], B. Devouard[1], B. Zanda[2], and J.-L. Devidal[1], [1]Laboratoire Magmas et Volcans, UMR 6524 Blaise Pascal University – CNRS, 5 rue Kessler, 63038 Clermont-Ferrand, France (n.chaumard@opgc.univ-bpclermont.fr), [2]LMCM, MNHN UMR 7202 CNRS, 61 rue Buffon, 75005 Paris, France.

Introduction: Tanezrouft 057 (TNZ 057) is a metamorphosed carbonaceous chondrite classified as a CK4 [1]. CKs, which have close similarities with CVs in terms of oxygen isotopes, mineralogy, and bulk compositions [e.g. 2, 3], were initially described as containing few calcium-aluminum-rich inclusions (CAIs) [4]. However, some CKs such as TNZ 057 have significant CAI contents [5]. We studied the mineralogy and chemistry of CAIs in TNZ 057 to characterize their modification due to parent body processes.

Methods: A total surface of 893 cm^2, consisting of cut slabs and polished thin sections, was analyzed to estimate CAI modal abundances. CAIs were recognized by visual identification on the polished slabs. In addition, SEM-BSE imaging and EDS compositional maps were obtained using a JEOL JSM-5910LV electron microscope, while quantitative analyses and WDS compositional maps were obtained on a CAMECA SX100 electron microprobe. REE concentrations were determined by laser ablation ICP-MS, using an Agilent 7500cs ICP-MS coupled with a Resonetics M-50 laser.

Results: The modal content of CAIs in TNZ 057 is 9.1 ± 1.4 area%. Two types of CAIs can be recognized: (1) fine-grained CAIs with a whitish aspect and irregular shapes are dispersed in the whole meteorite. Their sizes range between ~100 µm and ~1.5 cm; (2) a few, large, coarse-grained CAIs, up to ~3 cm represent 4.7 ± 0.9 area%. They have a compact and often rounded core, surrounded by a fine-grained mantle.

Mineralogy and petrology. Fine-grained CAIs are mainly composed of Ca-rich pyroxene and plagioclase. Some Ca-rich pyroxenes occur as zoned laths with Mg-rich cores and Fe-rich rims. Compositions range from $En_{42.8}Fs_{8.4}Wo_{48.8}$ to $En_{74.3}Fs_{22.2}Wo_{3.5}$. We analyzed Ca-rich pyroxene grains with up to 7.4 wt% Al_2O_3, 3.3 wt% TiO_2, and 3.0 wt% FeO. Laths of primary plagioclase occur in the core of fine-grained CAIs while plagioclases in the external parts are texturally similar to those in the matrix, containing numerous tiny opaque crystals. Plagioclase has compositions varying from $An_{30.6}$ to almost pure anorthite ($An_{97.4}$) but there is no clear relation between crystal shape and chemical composition. Fine-grained CAIs also contain minor phases such as olivine ($Fa_{30.6}$), low Ca-pyroxene, Cr-rich magnetite, and Ti-oxides.

One coarse-grained CAI (CG1) was studied in detail (Fig. 1). The core of CG1 is composed of a primary fassaite-spinel-rhönite assemblage. Fassaite is present as large nodules and contains 18.9 ± 1.2 wt% Al_2O_3 and 16.5 ± 2.5 wt% TiO_2 (Fig. 1). Spinel mainly occurs as euhedral crystals (10–200 µm in size) with FeO contents varying from 4.7 to 19.5 wt% from the center to the rim of the CAI (Fig. 1, 2). This primary assemblage is surrounded by a secondary grossular and pure anorthite fine-grained mixture (Fig. 1, 2). Grossular composition ranges from $Gr_{80.9}Py_{1.7}$ to $Gr_{96.9}Py_{1.6}$ and can have significant FeO contents up to 7.2 wt%. The mineral assemblage described above is crosscut by forsterite (Fo_{90}) and Ca-rich pyroxene-anorthite-bearing veins (Fig. 2). The core of the CG1 CAI is surrounded by a thick fine-grained mantle (Fig. 1), composed of Ca-rich pyroxene (enriched in Fe in the external part) and zoned plagioclase, with minor Ca-phosphate, ilmenite, and titanomagnetite.

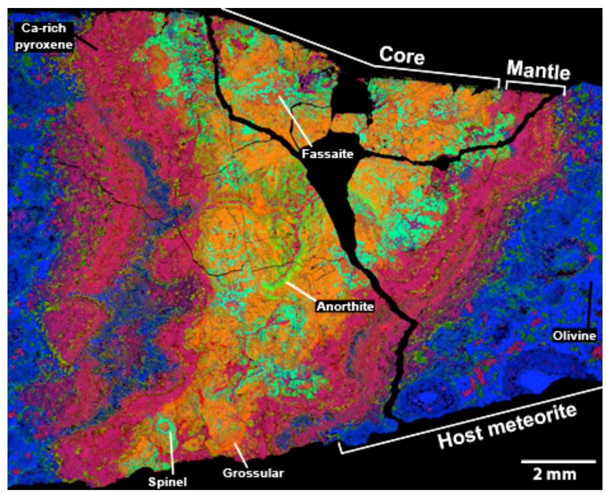

Figure 1: RGB compositional map (R=Ca, G=Al, B=Mg) of a coarse-grained CAI (CG1) in TNZ 057.

Rare Earth Elements. We measured the REE contents of Ca-rich pyroxenes in fine-grained CAIs. Within a given CAI, Ca-rich pyroxenes display similar patterns (Fig. 3), but there are large disparities from one CAI to another. In some cases, the REE patterns of Ca-rich pyroxene are similar to those of group II and III CAIs [6] and to those reported in fassaite (Fig. 3).

Discussion: Parent body thermal metamorphism affected all the CAIs in TNZ 057 to various degrees and caused complete chemical equilibration of some fine-grained CAIs as irregular assemblages of plagioclase + Ca-rich pyroxene +/- olivine +/- Ca-poor pyroxene. Parent body metamorphism of CAIs results in the equilibration of olivine and chemical zoning in Ca-rich pyroxene and spinel. Primary fassaite is destabilized into Ca-rich pyroxene and Ti-oxides. Ca-rich pyroxene in metamorphosed CAIs in TNZ 057 retained a pristine REE signature despite thermal metamorphism that caused reequilibration of major elements. We suggest that the bulk REE pattern of TNZ 057 reflects the average REE contents of CAIs.

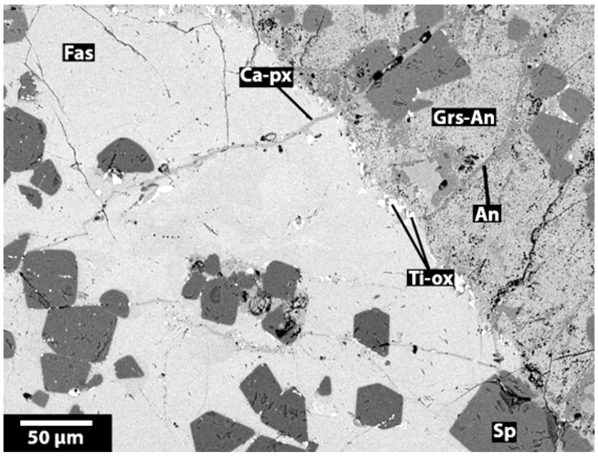

Figure 2: BSE image of the core of a coarse-grained CAI (CG1) in TNZ 057, showing fassaite (Fas), spinel (Sp), anorthite (An), Ca-rich pyroxene (Ca-px), grossular (Grs), and Ti-oxides (Ti-ox).

The compact texture and the rounded shape of the core of CG1 suggest that it was formed by crystallization of a molten droplet, later followed by the accretion of a fine-grained mantle. Zonation of Ca-rich pyroxene in this mantle strongly suggests that it rimmed the CAI prior to parent body accretion. In addition, this mantle is enriched in REEs compared to CI chondrites, implying a region of formation similar to that of CAIs. Fine-grained mantles around CAIs have consequently been included in the estimation of CAI abundances. Due to the large surface observed, the modal abundance of CAIs can be considered as representative of the whole meteorite. Even though some recrystallized CAIs were probably missed, the modal abundance of CAIs in TNZ 057 is close to 10 vol%, a value typical of CV chondrites [7]. Thus, CAI abundance should not be used as a criterion of classification to distinguish CV from CK chondrites.

Grossular is interpreted as a secondary phase after melilite. The absence of monticellite in the CG1 CAI may imply that grossular formed by open-system alteration of melilite, as suggested by [8]. Since grossular was enriched in FeO during parent body metamorphism, the alteration process that produced grossular predates the CK thermal event, possibly in the solar nebula. The occurrence of grossular suggests an upper temperature for the metamorphic event of TNZ 057 around 800°C, the upper limit for grossular stability [9]. Forsterite and Ca-rich pyroxene-anorthite-bearing veins are interpreted as evidence for an alteration process following grossular formation, probably on the CK parent body.

Conclusion: Abundant CAIs in TNZ 057 display evidence for alteration and thermal metamorphism processes in addition to pristine signatures similar to those described in CAIs from CV chondrites. This similarity in nature and abundance of CAIs in CK and CV chondrites confirms the close relationship between these two groups shown by other mineralogical criteria and oxygen isotopes [e.g. 2, 3].

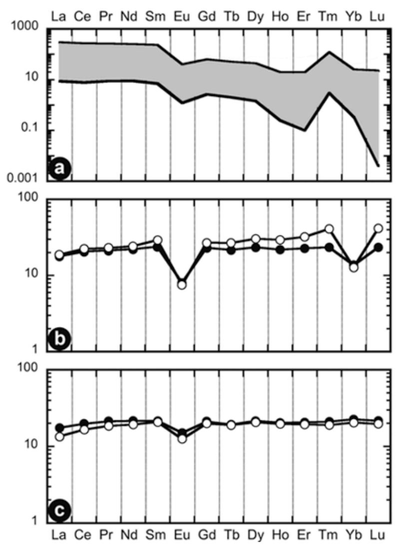

Figure 3: REE patterns of Ca-rich pyroxene in distinct fine-grained CAIs from TNZ 057. (a) Field of REE compositions of Ca-rich pyroxenes from various group II CAIs. (b) Grains with a typical group III CAI pattern. (c) Grains with a fassaite-type pattern.

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