CALETA EL COBRE 022: AN UNUSUAL NAKHLITE WITH ABUNDANT AQUEOUS ALTERATION

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Introduction: Nakhlites are Martian clinopyroxene-rich cumulates [1] showing variable amounts of aqueous alteration [2]. They are keys to better understand the martian crust. Caleta el Cobre 022 (CeC 022) is one of only 11 nakhlites (after pairing) discovered to date.

Results: CeC 022 is a clinopyroxenite that crystallized at 1224±69 Ma (Sm-Nd age) and with a cosmic ray exposure age of about 11 Ma (for ^{3}He, ^{21}Ne and ^{38}Ar), similar to other nakhlites. Augite is the major mineral (~58 vol%). It displays rounded cores with iregular sector zoning (ca. $En_{34}Fs_{27}Wo_{39}$) (*Fig. 1*) and Fe-richer overgrowth ($En_{31}Fs_{29}Wo_{40}$). Fe-richer sharp rims ($En_{27}Fs_{35}Wo_{38}$, 10-15 µm wide) are observed only when augite is in contact with the mesostasis. Low-Ca pyroxene ($En_{35}Fs_{61}Wo_{4}$) is found replacing augite overgrowth near olivine phenocrysts (*Fig. 1*). Olivine crystals ($Fa_{69.7}\pm_{1.5}$) represent ~3 vol%, and are not zoned (*Fig. 1*). CeC 022 contains large plagioclase laths (up to 1 mm) for ~19 vol%, with homogenous $An_{29.7}\pm_{4.3}Ab_{67.2}\pm_{4.0}Or_{3.1}\pm_{0.5}$ composition, that differs from K-rich feldspar in the mesostasis (up to $An_{4.5}$ $Ab_{60.4}Or_{35.1}$). Intergranular Fe-Ti oxides are abundant (~3 vol%), up to 1 mm size, and present fine-scale ilmenite exsolutions in magnetite. The mesostasis (~16 vol%) contains alkali feldspar, low-Ca pyroxene ($En_{31}Fs_{65}Wo_{4}$), dendritic apatite, quenched dendritic iron oxides and silica. Olivine presents abundant aqueous alteration as iddingsite, with at least two phases differing in their Fe and Si contents. Both phases are hydrated. Their crystallinity is also different with the Fe richer phase being more crystallized. This material is found mainly in the olivine phenocrysts (*Fig. 1*), with oxides and sulfides often present in the center of the veins. Iddingsite is also found in patches in mesostasis pockets replacing relict olivine crystals. In addition, some mesostasis pockets show iddingsite at a microscale, evidencing pervasive aqueous alteration.

Discussion: All petrographic, chemical, noble gas and isotopic analyses confirm that CeC 022 is a nakhlite. It shows similarities with the subgroup formed by Nakhla, Lafayette, Goverador Valadares, and NWA 998 [3], slow-cooled nakhlites. It has similar bulk composition, pyroxene and olivine (unzoned Fe-rich olivine) composition, crystal size distribution analysis, and large plagioclase phenocrysts. Also, CeC 022 displays new unique features with the Fe-richest augite cores measured to date (higher than NWA 5790 [4]). This points to a relatively slow cooling history similar to the Nakhla subgroup [3]. Nonetheless, the plagioclase and the REE compositions are closer to faster-cooling nakhlites NWA 817, NWA 5790 or NWA 10153 [3]. The sharp fine Fe-rich augite rim in contact with mesostasis, the quenched oxides, and the high glassy proportion in the abundant mesostasis pockets also point to a fast crystallization. The abundant aqueous alteration and large amount of mesostasis possibly place CeC 022 close to the surface. These overall characteristics set CeC 022 apart from other nakhlites and suggest it might originate from a different lava flow or sill from the same volcanic system.

Conclusion: In comparison with other nakhlites, CeC 022 is unusual in terms of petrography, mineral composition, and extent of aqueous alteration. This brings a new complexity in the nakhlite formation with possibly several lava flows, and/or magma mixing prior to eruption and/or complex post-eruption aqueous alteration.

References: [1] Treiman, A.H. (2005). *Chemie der Erdre-Geochemistry*, 65(3), 203-270, [2] Hicks, L.J., et al. (2014) *Geochim. Cosmochim. Acta* 136:194-210, [3] Udry and Day (2018) *Geochil. Comm. Acta* 208, 292-315, [4] Jambon A. et al. (2016) *Geochim. Cosmochim. Acta* 190:191-212.

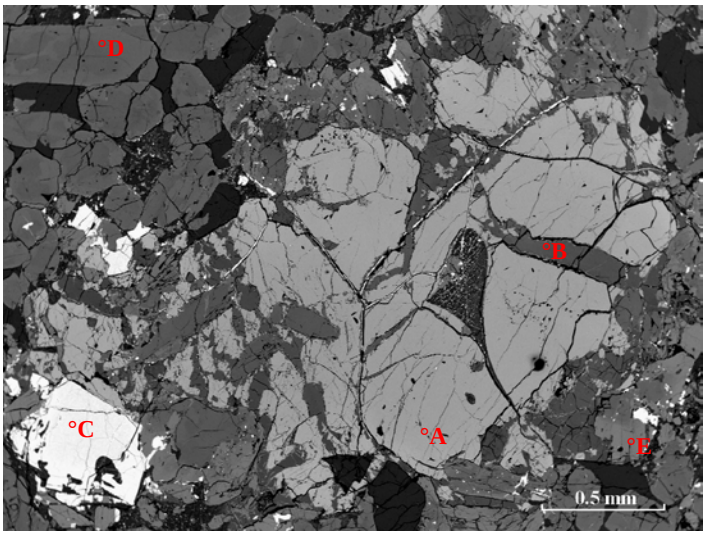

Fig. 1 : Olivine crystals in CeC 022. A : Olivine, B : Iddingsite veins in olivine, C: (Titano)magnetite, D : Pyroxene with irregular cores, E : Low-Ca pyroxene overgrowth.