REOPENING A CAN OF WORMY INTERGROWTHS: A NEW LOOK AT CHROMITE SYMPLECTITES IN Mg-SUITE TROCTOLITE 76535

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Introduction: At the Sixth Lunar Science Conference, there was an "animated debate" [1] concerning the origin and significance of symplectites in some olivine-bearing lunar rocks. Mg-suite troctolite 76535 is one such rock. Symplectite assemblages in 76535 consist of Mg-Al-chromite and two pyroxenes [1-5]. These symplectites occur primarily at olivine-plagioclase grain boundaries (e.g. Fig. 1a), but importantly, most grain boundaries are symplectite-free. Previously proposed symplectite formation mechanisms include crystallization of trapped interstitial melt and an olivine-plagioclase reaction which included diffusion of Cr from cumulus olivine and/or remobilization of pre-existing cumulus chromite grains [1-5]; however the topic never saw a substantial resolution.

A characteristic feature of olivine in Mg-suite rocks is that it is significantly depleted in Ni, Co and Cr relative to mare basalt olivine. The low Cr content of the cumulus olivine implies that Mg-suite magmas, and by inference their source material, were also low in Cr [6]. If correct, this would be a curious feature given that 76535 contains significant Cr sporadically, but highly, concentrated in symplectite assemblages. However, the symplectite formation mechanisms above imply that this Cr-depletion may be illusory.

With the goal of better constraining the origin of the symplectites in 76535 and petrogenesis of the Mg-suite, we present a detailed petrologic and textural investigation of symplectites, as well as their relationships to intercumulus and primary cumulus phases. We have also investigated chromite veins (Fig. 1b), olivine-hosted melt inclusions (MIs; Fig. 1c) and intercumulus assemblages (Fig. 1d) in 76535 to determine what information they record in regards to the origin of the symplectites and the magmatic processes that formed the Mg-suite layered intrusions.

Analysis: Sample 76535 has experienced minimal shock and retains original, albeit metamorphic, textures and well-preserved symplectites. Several thin sections were analyzed in this study: 76535,46 ,56 and ,159. Prior to microbeam analyses, samples were documented via optical and electron microscopy to fully understand textural relationships and identify potential targets for subsequent analysis. Olivine, orthopyroxene (OPX), clinopyroxene (CPX), chromite, apatite and merrillite were analyzed for major and minor elements using the electron microprobe at the University of New Mexico.

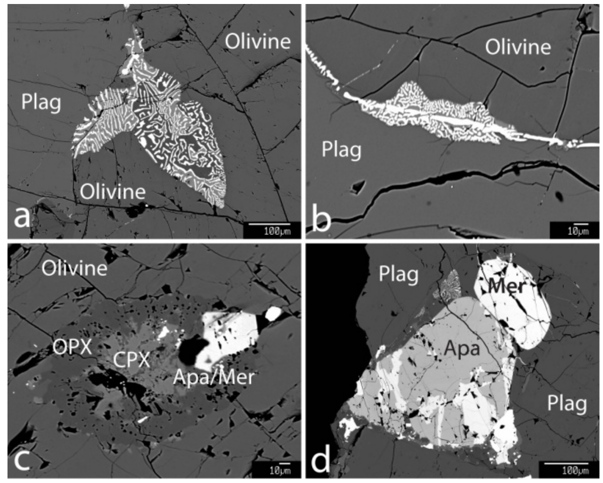

Figure 1: BSE images of a typical symplectite (a), an example of chromite veining with a small symplectite (b), an olivine-hosted melt inclusion (c), and an intercumulus assemblage (d) that contains a small symplectite.

Results: Symplectites occur mostly along olivine-plagioclase grain boundaries, but by far most boundaries are free of symplectites. Figure 1a shows a typical symplectite at such a boundary. Symplectites are sometimes associated with discontinuous chromite veining along grain boundaries. Figure 1b shows a chromite vein with a small symplectite. Chromite veins along olivine-plagioclase boundaries often occur within close proximity to chromite-free olivine-plagioclase boundaries. Chromite was not observed as discrete crystals or as inclusions in cumulus phases.

Multiphase intercumulus assemblages also contain small symplectites (Fig. 1d); however olivine-hosted MIs do not contain chromite. Both the MIs and intercumulus assemblages contain apatite-merrillite intergrowths. Apatite between the two textural occurrences is identical in terms of halogens. Other phases present in intercumulus assemblages include OPX, CPX, baddeleyite, zircon and Fe-Ni metal. Other phases in MIs include OPX, CPX, Fe-Ni metal, a K-Ba-Si-rich phase (probably K-spar), and pyrochlore.

Olivine-hosted melt inclusions (e.g. Fig. 1c) are low in Cr. Whereas OPX and CPX in symplectites contain an average of 7400 and 8100 ppm Cr_2O_3, respectively, OPX and CPX in the melt inclusions contain an average of 900 and 1200 ppm Cr_2O_3, respectively (Fig. 2). Sample 76535 also contains large interstitial OPX grains that are similar in composition, including Cr, to symplectite OPX (Fig. 2).

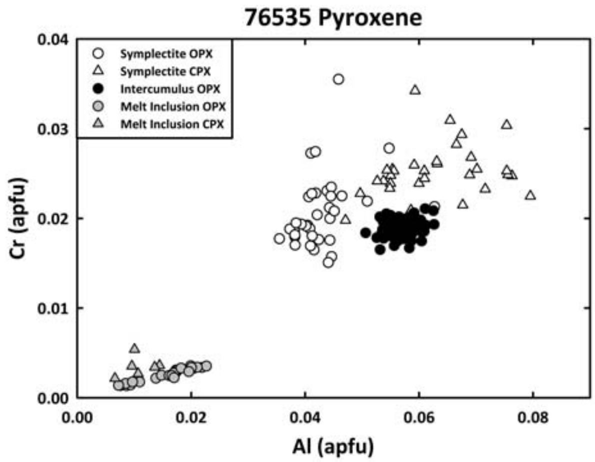

Figure 2: A plot of Cr vs. Al in atoms per formula unit for pyroxenes in troctolite 76535. Melt inclusion pyroxenes are significantly depleted in Cr relative to symplectite and intercumulus pyroxenes.

Discussion: In light of our new data, presented in [7], we have reassessed previously proposed symplectite formation models. The crystallization of intercumulus melt pockets was favored by [3, 5]. This mechanism would require significant adcumulus growth of plagioclase and olivine for a melt pocket to produce the large amount of chromite observed in symplectites. However, the symplectites exhibit textures more consistent with consumption of olivine and plagioclase in a mineral-mineral reaction [i.e. 8], with some symplectites preserving relict grain boundaries. Additionally, symplectites do not contain other minor phases (e.g. apatite, baddeleyite) that are indicative of intercumulus assemblages, which do seem to represent trapped melt pockets [e.g. 1-2, 4]. Based on these observations, we rule out crystallization of trapped melt.

Symplectite formation via a reaction between olivine and plagioclase that included diffusion of Cr from olivine or the remobilization of pre-existing chromite was preferred by [3-4] and [2], respectively. In the diffusion model, Cr in symplectite chromite is derived from originally more Cr-rich cumulus olivine. However, we observe olivine not in contact with and far away from symplectites that is also low in Cr. If olivine lost Cr, we would expect chromite in contact with or surrounding olivine throughout the rock. The low Cr content of the MIs also argues against Cr diffusion (Fig. 2). Furthermore, reduced systems such as lunar magmas can have Cr^{2+}/Cr^{3+} ratios greater than 1 [9-10], and olivine partitions the two valence states roughly equally [10]. Cr diffusion creates the need for a Cr^{2+} oxidation mechanism to create the large amounts of Cr^{3+}-rich chromite. This, combined with the observation that olivine in chromite-saturated melts at low f_{O2} contain 1000's of ppm Cr_2O_3 [9-10], rules out diffusion of Cr from olivine.

The remobilization of pre-existing chromite is argued against by the high-Cr content of olivine in equilibrium with chromite-saturated melts, low Cr-content of MIs, and lack preserved primary chromite. If the parental melt was saturated in chromite, the olivine should be much richer in Cr, and diffusional loss of that Cr is argued against above. We would also expect at least some cumulus chromite to be preserved as discrete grains or as inclusions, which is not the case.

Failure of these symplectite formation mechanisms implies that open system addition of Cr to 76535 is required. We have evaluated three potential models for Cr addition: solid state addition of chromite, Cl-rich fluid metasomatism [i.e. 4], and metasomatism by a melt. Solid state addition may come in the form of differential settling of dense chromite from higher regions of the 76535 pluton. However, there are no chromite–rich samples of the Mg-suite that may represent such a region, and the mechanism by which chromite settles through a partially molten intrusion and stalls in the troctolite layer is unclear. A Cl-rich fluid has the potential to mobilize the typically fluid immobile Cr^{3+} [e.g. 11]; however, such a fluid should also have re-equilibrated intercumulus apatite to more Cl-rich compositions than MI apatite. This is not the case and seems to rule out an exogenous Cl-rich fluid.

Chromite is, however, a near liquidus phase in many lunar basalts. Metasomatism of the 76535 pluton by a chromite-saturated melt provides a mechanism for adding Cr to the rock along cracks and grain boundaries (i.e. melt pathways). Chromite would be deposited locally, resulting in the symplectite forming olivine-plagioclase reaction. Most olivine is unaffected and the shielded MIs retain their low Cr content. Although speculative, melt metasomatism is the model we feel best fits the available data [see 7 for more detail]. If correct, it would imply that the Mg-suite parental magmas were extremely low in Cr compared to mare basalts, a condition that would require further explanation [i.e. 6]. Furthermore, if the intimate interaction of migrating melts with early lunar crustal rocks was a widespread phenomena, it would likely delay closure of or reset radiogenic isotopic clocks, and could help explain the Mg-suite-FAN age overlap [7].

References: [1] Bell et al. (1975) *LSC VI,* 231-248. [2] Gooley et al. (1974) *GCA* ***38****,* 1329-1339. [3] Dymek et al. (1975) *LSC VI,* 301-341. [4] McCallum and Schwartz (2001) *JGR* ***106****,* 27,969-27,983. [5] Albee et al. (1975) *LSC VI,* 1-3. [6] Elardo et al. (2011) *GCA* ***75****,* 3024-3045. [7] Elardo et al. *GCA* In Press [8] Kushiro and Yoder (1966) *J. Petrol.* ***7****,* 337-362. [9] Roeder and Reynolds (1991) *J. Petrol* ***32****,* 909-934. [10] Hanson and Jones (1998) *Am. Min.* ***83,*** 669-684. [11] Klein-BenDavid et al. (2011) *Lithos* ***125***, 122-130