SYMPLECTITES IN DUNITE 72415 AND TROCTOLITE 76535 INDICATE MANTLE OVERTURN BENEATH LUNAR NEAR-SIDE. H. H. Schmitt[1]

[1]University of Wisconsin-Madison, P. O. Box 90730, Albuquerque NM 87199, hhschmitt@earthlink.net

Introduction: Symplectites of Cr-spinel, Ca-clinopyroxene, and Mg-orthopyroxene in two samples from the Apollo 17 collection provide strong mineralogical and textural evidence in that they originated in the lunar mantle. These two samples, 72415 and 76535, [1], [2] previously have been included as examples of Mg-suite rocks [3]. Dymek et al. [4] also suggested a deep mantle origin for 72415 and 76535.

Crushed dunite 72415 also contains iron isotopic ratios enriched in light iron isotopes suggesting mantle derivation [5].

Petrography: Dunite sample 72415 has symplectic intergrowths of Cr-spinel, Ca-clinopyroxene, and Mg-orthopyroxene. The sympletites exist "as small ovoid inclusions in olivine, along relic olivine-olivine grain boundaries, and as broken fragments within the granulated matrix." [6] The intergrowths consist of vermicular Cr-spinel in Ca-clinopyroxene and Mg- orthopyroxene. Plagioclase and Fe-metal may or may not be visible in the intergrowths. Ca-plagioclase (anorthite) and iron metal exist as inclusions in olivine grains and along olivine-to-olivine grain boundaries.

In troctolite 76535, Cr-spinel (also identified as Mg-Al-chromite [7]), Ca-pyroxene and Mg-orthopyroxene symplectites, comparable to those in 72415, lie along some olivine-olivine, olivine-plagioclase, and Mg-orthopyroxene-olivine grain boundaries. These symplectites also exist as inclusions in olivine. These 76535 symplectites may indicate that this rock had a similar history as dunite 72415; but its plagioclase content would place its original accumulation from the magma ocean later and higher in the mantle than the dunite. 76535 consists of 50-60% plagioclase (anorthite), about 35% Mg-olivine, and about 5% Mg-orthopyroxene. The 76535 orthopyroxene contains much less Ca than orthopyroxene in 72415, [2] suggesting formation of the latter at higher pressure [8]. Shearer, et al. [3] and Elardo et al. [7] provide excellent summaries of the nature of these symplectites and previous speculation about their origin.

Symplectite Petrogenesis: As originally suggested by Bell et al, [9] symplectic Cr-spinel and Ca-clinopyroxene may indicate the breakdown of a high-pressure-stabilized Ca-Mg-Cr-garnet with the release of excess SiO_2, that is:

Garnet Cr-spinel

$(Mg,Ca)_3(Al,Cr)_2Si_3O_{12} = Mg(Cr,Al)_2O_4 +$

Ca-cpx silica

$(Ca,Mg)(Al,Si)_2O_6 + SiO_2$

The SiO_2 could react with olivine to produce orthopyroxene, that is:

Olivine silica opx

$(Mg,Fe)_2SiO_4 + SiO_2 = (Mg,Fe)_2Si_2O_6$

In the excellent back-scattered electron (BSE) and WDS X-ray maps published by Elardo et al. [7], Cr-spinel is relatively evenly distributed throughout the symplectites, whereas areas of Ca-clinopyroxene tend to be concentrated near contacts with plagioclase and areas of Mg-orthopyroxene tend to be concentrated near olivine. This distribution appears consistent with the reactions noted above and with likely Mg-Ca zoning within the parent garnet. Elardo et al. noted that relic grain boundaries separate fine and coarse textures within some symplectites. These workers interpret these relic grain boundaries as showing metasomatic replacement plagioclase by the symplectites. Alternatively, the relic grain boundaries may indicate that Ca-rich portions of Cr-rich garnet replaced plagioclase to be in turn replaced by the Ca-clinopyroxene and Cr-spinel portions of symplectite.

As the magma ocean crystallization products accumulated, Cr-rich garnet may have appeared on the high-pressure liquidus of the interstitial cumulate liquid with resorption of previously crystallized plagioclase. Experimental work on simplified lunar magma ocean compositions indicates that garnet, along with olivine and orthopyroxene, probably existed on the liquidus at lower mantle pressures (~3 GPa) [10]. Alternatively, garnet might have replaced original cumulate plagioclase, Cr-spinel and olivine under prolonged high-pressure, as in the following reaction:

anorthite Cr-spinel Olivine

$CaAl_2Si_2O_8 + Mg(Cr,Al)_2O_4 + 4(Mg,Fe)SiO_3 =$

Cr-Garnet

$2(Mg,Ca)_3(Cr,Al)_2Si_3O_{12}$

Breakdown of a high-pressure mineral composition may be indicative of moderately rapid transport of the Apollo 17 dunite and troctolite from high- to low-pressure regions of the lunar mantle. The rate of retrograde pressure drop would have need to be fast enough to prevent broad-scale recrystallization but slow enough to allow limited diffusive redistribution of high-pressure mineral components, along with some migration of excess SiO_2 to react with olivine, to form the symplectic intergrowths.

The reported Rb-Sr age date of 4.55±0.1 Ga for crystallization of 72415 [11] may indicate an initial crystallization age as an early cumulate from the lunar magma ocean.

The above interpretation of Mg-suite symplectites having formed through decomposition of a high-pressure Cr-rich garnet would appear consistent with lunar mantle overturn [12] that brought olivine cumulate close to the lower crust. This overturn, at least on the near-side, may have been triggered by the shock and pressure-release dynamics associated with of the Procellarum, continental-scale basin-forming event.

Norwegian vs. Lunar Symplectites: Similar symplectitic textures replace sodium-rich clinopyroxene (omphacite), biotite and hornblende, formed at high pressure (eclogite facies) in the Basal Gneiss region of western Norway [13]. The symplectite replacing each of these Norwegian minerals consists of plagioclase and a low-sodium clinopyroxene. Also, fine-grained coronas of fine-grained spinel-hypersthene exist between garnet and olivine in peridotitic rocks.

Symplectite formation in the Norwegian rocks required the diffusion of silica into the minerals to convert their sodium component to sodic plagioclase (jadite in the case of Na-rich clinopyroxene and Na-rich clinopyroxene-related crystal structure components in biotite and horndblende). Subduction of the rocks in the Basal Gneiss region reached into the coesite field of SiO_2 stability [14] or about 100km depth. These rocks then rose to the triple point for Al_2Si0_5 (kyanite-silimanite-andalusite) at about 15km during which symplectites developed in minerals exposed to a sufficiently high activity of SiO_2. In this terrestrial case of symplectite formation due to pressure release, age data indicates the affected minerals rose from about 100 km depth (~3 GPa) to about 15 km depth (~0.4 GPa) in 10-15 million years [15].

In the lunar case, transport of the olivine and troctolite cumulates may have been from between 550 and 400 kilometers (2.7-2.3 GPa) (the former depth being the probable base of the lunar magma ocean [16], [17]) to about 50 km (~0.23 GPa) in a similar time frame. (This lunar lithostatic pressure calculation is based on an average lunar mantle density of 3300 kg/m^3 and gravity at 1.6 m/sec^2 to give a lithostatic pressure gradient of about 5.3 MPa/km. Above 50 km, the crustal density was assumed to be 3000 kg/m^3.) A post-overturn depth of about 50 km is consistent with the McCallum and Schwartz estimate of 40-50 km based on an apparent five phase equilibrium in 76535 between olivine, plagioclase and the three phases included in the symplectite [18]. McCallum and Schwartz [18] and Elardo et al. [7] determined the clinopyroxene-orthopyroxene annealing temperatures to be 800-900^o C for this assemblege.

A major unknown in both cases consists of the activity of water within the host rocks that would aid in intra- and inter-grain transport of SiO_2 and potentially other components. The presence of stable hydrous silicate minerals in the terrestrial case, and of no hydrous minerals but strong pyroclastic evidence of mantle water in the lunar case [19], indicates that water activity in both was low but not zero.

Conclusion: Symplectites of Cr-spinel, Ca-clinopyroxene, and Mg-orthopyroxene in Apollo 17 samples 72415 and 76535 support the hypothesis of late overturn of magma ocean cumulates, at least below the Procellarum basin. Pressure release related to such an overturn probably triggered the decomposition of a high-pressure Cr-rich garnet present in the original mantle cumulates. This overturn event, may be the event represented by the common ~4.35 Ga age indicated by Borg et al. [20] [21] to be consistent across many FAN and Mg-suite samples.

References:

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