SECONDARY, AQUEOUS(?) METASOMATIC OLIVINE VEINS IN APOLLO 14 MARE BASALT 14072

Paul H. Warren[1] , Rosario Esposito[1] and Craig Manning[1], [1]Department of Earth, Planetary & Space Sciences, University of California, Los Angeles, CA 90095, USA, pwarren@ucla.edu.

The Apollo 14 mission acquired a precious two large samples of mare basalt, 14053 (251 g) and 14072 (45 g). The two show many similarities, including an unusual extent of subsolidus reduction, and so they have been regarded as a "pair" [1]. However, they were found at a separation of 250 meters, and about 46 degrees apart in terms of radials from nearby Cone Crater (diam. 350 m) [2], so there is little justification, apart from petrologic similarity (which is far from absolute: [3, 4]), for assuming they were not originally separated by several tens of meters, at least.

In any event, when we chose to study these *two* "most reduced" lunar basalts for comparison with secondary alterations in eucrite meteorites [5-9], *we asked for a thin section from a portion of 14072 well apart from the zone that had, via potted butt 14072,1, provided all of the thin sections previously studied* [10]. Unlike our 14072,1-derivative sample (14072,10), the newer 14072,69 has within its pyroxene (px) widespread narrow veins of olivine, in striking analogy to the eucritic secondary veining. The olivine veins were most likely deposited by some type of hot aqueous fluid (caveat: by aqueous we only mean water-bearing, not water-preponderant as with most terrestrial fluids).

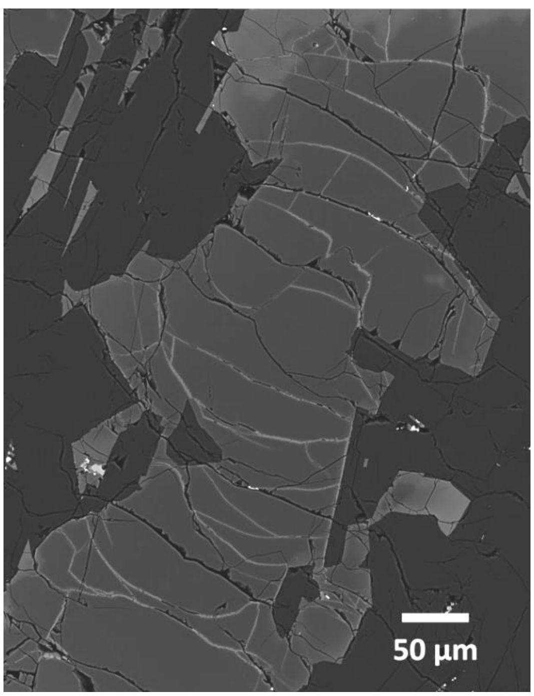

Fig. 1. Backscattered electron (BSE) image of 14072,69. Important phases in order of increasing brightness: plag (a uniform dark gray), px (various shades of gray), olivine. Minor phases include FeNi kamacite (near white).

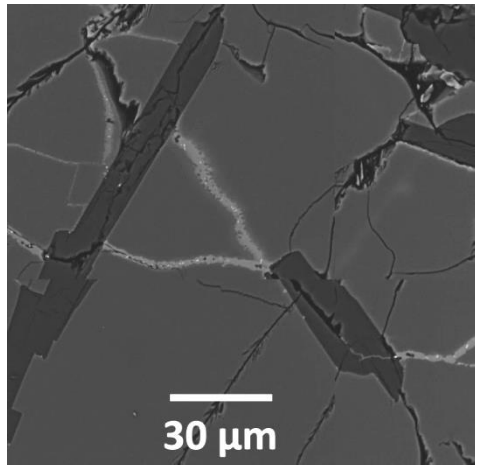

Fig. 2. BSE image of 14072,69. In general, veins disappear wherever parent cracks transit plag; here, a narrow exception.

Olivine veins are widespread within cores of large (primary igneous) 14072,69 pyroxenes (Fig. 1). They are seldom much more than 3 µm in width; 1 µm is typical. In length they can be up to 0.5 mm. Within any one large px, there are typically 10+ olivine veins, with mildly curvy shapes but a statistical tendency to be near-perpendicular to the long axis of the host px.

It might be conjectured that the olivine veins formed as impact shock-melts. However, a melt-injection origin would lead to indiscrimate, near-random siting for the veins. Instead, *the deposition of vein matter was a* ***chemical-reactive*** *process, highly* ***selective*** *vis-à-vis the surrounding material*; cf. eucrites [7, 8]. Veins tend to thin out as they near more evolved (Fe- and Ca-rich) margins of the host grains. The major mineral plagioclase is virtually devoid of veins. Where an olivine-filled crack transects a corner or peninsula of plag, the crack almost always becomes abruptly empty; the right side of Fig. 2 shows a very rare, and slight, exception. Clearly the fluid was unreactive with plagioclase.

Another similarity with eucrites is that the veins include a minor Cr-spinel component, and in this case (as in eucrite NWA 5073 [6, 9]) the Cr-spinel tends to occur as a discontinuous median near the center of the vein (Figs. 3-4). Caveat: We *assume* these minute BSE-bright grains are Cr-spinel by analogy with eucrites [5-9]. Electron microprobe analysis does not resolve them from surrounding olivine, but they are rich in Ti, Al and especially Cr. In a few places the medial parts of the veins are instead largely voids (Fig. 3).

Unlike eucrites, 14072 has a component of coarse, early igneous olivine. Where a secondary olivine vein

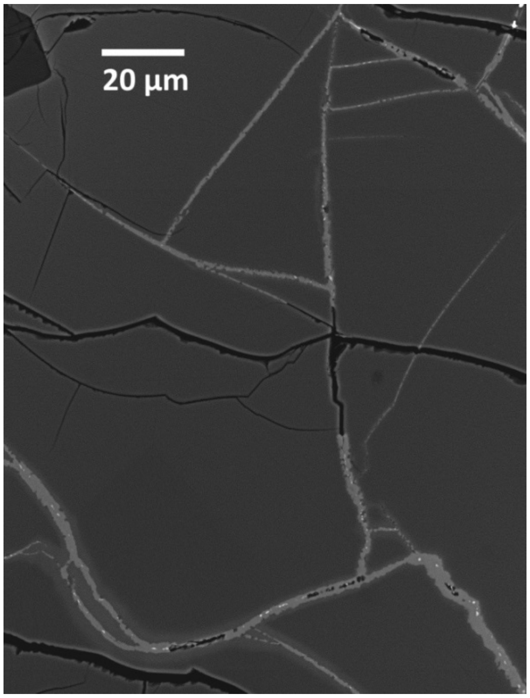

Fig. 3. Another 14072,69 BSE. Note porosity within veins at top and bottom. Also barely discernible at bottom is reaction boundary of lower-*mg* (FeO-rich) px at sides of the veins.

transected one of the early igneous olivines, a peculiar texture resulted (Fig. 4): The trace of the vein remains clearly discernible, not as compositionally distinct olivine, but as an extra-thin and discontinuous vein of Cr-spinel accompanied by minute voids (bubbles).

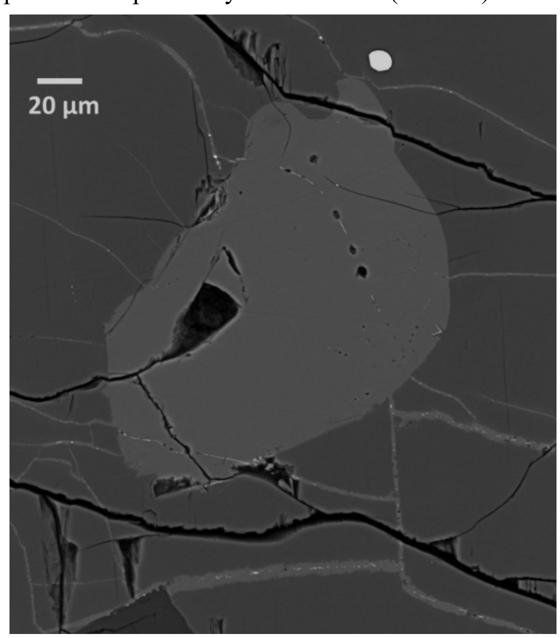

Fig. 4. Another BSE: Primary igneous olivine (surrounded by px) transected by metasomatic veins, manifest in "ghost" form as trains of elongate Cr-spinels + sets of tiny bubbles.

Compositionally, the 14072 secondary olivines are far more magnesian than their eucrite counterparts. Among olivines analyzed in 20 veins Fo_{45} is the lowest *mg* (the maximum, Fo_{58}, is likely a byproduct of close proximity, 12 µm, to a primary-igneous Fo_{62} olivine). In some places the surrounding px has a reaction zone extending up to (very rarely) ~ 6 µm from the olivine (Fig. 3). The px in these reaction zones has lower *mg* by as much as 5 mol% versus the original core/host px (typical *mg* ~ 71 mol%). Some olivine veins are studded with tiny grains of kamacite. Although the vein-like metals associated with eucritic metasomatism [7, 8] are remarkably Ni-free pure iron, the 14072,69 metals consistently have sufficient Ni to be detected even by SEM-EDS spectroscopy (i.e., not << 1 wt%).

Our 14072 observations have significant implications for the related eucrite veins [5-9]. As with the eucrites, the heating event associated with the fluid was not protracted. Exsolution is hard to detect at SEM scale. Equilibrium among *mg* ~ 50 olivine, px and iron metal would suggest [11, 12, assuming ~ 800°C] an fO_2 of IW−1.5, far above what Taylor et al. [1] conjectured for 14053. Assuming the H_2O/H_2 ratio was set by dissociation in a compositionally simple, low-pressure fluid, at 800°C this ratio would have been ~ 0.20 [12].

Water was probably involved, because transport of the olivine cations (and admittedly, the distances may have been short) implies at least moderate solubility, which in turn suggests that a dipolar molecule, water, was a significant component of the fluid. Our studies of this phenomenon in 14072, and the related issue of the unusally extensive reduction [cf. 1, 7-8, 13-14], are still at an early, fast-evolving stage.

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