

Role of volatiles during late-stage crystallization of intercumulus pockets: Comparison of the NWA 773 clan of lunar meteorites with terrestrial gabbro from Murotomisaki, Japan

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Introduction: Late-stage intercumulus pockets in the olivine cumulate (OC) lithology of the Northwest Africa 773 clan of lunar meteorites are enriched in incompatible elements [1]. Pyroxene crystals adjacent to the pockets are zoned, with Ti# ($Ti/[Ti+Cr]$) increasing and Fe# ($Fe/[Fe+Mg]$) remaining constant as the pockets are approached, providing an example of igneous differentiation on the Moon [1]. The pockets are also of interest because they typically contain the Ca-phosphates merrillite and apatite; apatite crystals in the pockets contain F, Cl and OH in various ratios, reflecting the composition and abundance of volatile elements during late-stage crystallization of the OC [2-4]. The presence of H₂O in the apatite indicates that water was present in pockets of residual liquid trapped in the OC; however, the abundance of water and effect of water on late-stage crystallization have not been resolved.

In this study, we (1) compare late-stage pockets of NWA 773 clan OC with pockets in terrestrial gabbro from a sill in Murotomisaki, Japan [5], and (2) determine F:Cl:OH ratios in lunar apatite using low-voltage EPMA (electron probe micro-analysis; see below). The main goals are to evaluate and compare the roles of volatiles, particularly water, during late-stage crystallization in lunar and terrestrial gabbros.

Methods: We compared minerals and textures of late-stage pockets from the Murotomisaki sill with pockets from NWA 2977 and NWA 773. In this study, our main observations are based on one sample (Muro-14) collected from the coarse gabbro unit in the central part of the sill [5]. We compared Muro-14 with a polished thin section (pts) of NWA 2977, which is part of the NWA 773 clan and consists entirely of OC [6,7]. Images of minerals and textures were collected using petrographic microscopes, SEM (BSE images, Hitachi S-3400N) and EPMA (BSE and x-ray elemental maps, JEOL JXA-8900). Major element compositions in feldspar were collected by EDS using the SEM and by WDS using the EPMA. Changes in feldspar composition were compared to distance from pockets.

Determining the ratios of F, Cl and OH in apatite is difficult because F and Cl K-alpha X-rays typically vary during exposure to an electron beam [8] and OH cannot be detected by EPMA. So, we have been developing an EPMA technique (in collaboration with D. Harlov; see [9]) that uses low voltage (7 kV) to limit variations in F and Cl count rates. A small spot size ($\sim 1 \mu m$) is desired because of the small grain size of much apatite in NWA 773.

Results: In both Muro-14 and NWA 2977, plagioclase is zoned, with more Ab-rich compositions closer to the pockets. In NWA 2977, feldspar varies from Ab₀₅ to Ab₁₅, whereas the Muro-14 feldspar is much more albitic (Ab₄₀ to Ab₉₅). Discontinuities in zoning and porosity in feldspar closest to the Muro-14 pockets suggest that H₂O-rich fluid from the pockets interacted with feldspar, resulting in albitization. Some discontinuities also occur in NWA 2977, but it is not known if feldspars adjacent to pockets in NWA 2977 interacted with a volatile-rich fluid.

Most analyses of apatite in NWA 773 are F-rich, but variations in F/Cl at low OH and F/OH at low Cl occur in different petrologic settings. Data from [2] combined with our results show that NWA 773 OC pockets vary in F/OH at low Cl, suggesting some enrichment in H₂O during late-stage formation of the pockets.

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