PETROLOGY AND GEOCHEMISTRY OF AN UNUSUAL FERROAN ANORTHOSITIC-TROCTOLITE ASSEMBLAGE FROM APOLLO 16. R. A. Zeigler, B. L. Jolliff, R. L. Korotev, and L. A. Haskin, Department of Earth and Planetary Sciences, Washington University, One Brookings Drive, St. Louis, MO 63130 (zeigler@levy.wustl.edu).

Overview: Sample 60053.2-12 is a 31 mg rock fragment found among the 2–4 mm split of Apollo 16 soil 60053 as part of a study of mafic components of Cayley Plains regolith [1]. It is demonstrably monomict, has ferroan mineral compositions, and consists of plagioclase, olivine, exsolved low-Ca and high-Ca pyroxene, Cr-spinel, troilite, ilmenite, and Fe metal. Two characteristics make it unusual: (1) primary olivine is replaced by the assemblage olivine + orthopyroxene + troilite + Fe metal, and (2) the proportion of olivine is high for a ferroan-anorthositic-suite (FAS) assemblage [2]. Here, we report its trace-element and mineral compositions and discuss the olivine alteration assemblage and process. The alteration is consistent with reaction of primary olivine and a C-O-S vapor involving a reduction in oxygen fugacity upon cooling.

Methods: The chemical analysis reported here was determined by instrumental neutron activation analysis (INAA) of the whole rock fragment [2]. Mineral identifications and compositions were obtained by optical microscopy and electron microprobe analysis of a polished thin section prepared from half of the irradiated sample.

<table>
<thead>
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<th>FeO</th>
<th>CaO</th>
<th>Ni</th>
<th>Ba</th>
<th>Tb</th>
<th>Ir</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>Sc</th>
<th>Sr</th>
<th>Ce</th>
<th>Eu</th>
<th>Tb</th>
<th>Lu</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
<th>SiO₂</th>
<th>Cr₂O₃</th>
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<td>0.05</td>
<td>0.55</td>
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</table>

Table 1. INAA composition of 60053.2-12. CaO, FeO, and Na₂O are in wt %. It is in ng/g, and all others are in µg/g.

Petrography: The modal proportions of minerals are as follows: 77.4% plagioclase, 21.3% olivine (primary, see below), 1.3% pyroxene. On the basis of this mode, the assemblage is that of anorthositic troctolite. Plagioclase grains are subhedral to anhedral, ranging to about 0.8mm size. Compositionally, the plagioclase is nearly uniform (An₉₆,70₅₃). Plagioclase is fractured and brecciated; however, many grain boundaries appear intact, thus it retains some relic igneous texture. The most unique feature of this sample is the olivine alteration assemblage, which occurs in forms ranging from relic primary olivine grains to elongate, rounded masses 0.25–0.75mm in size (Fig. 2a).

The alteration assemblages consist of an olivine "host" (Fo₇₀₋₅₀) with Opx (Wo₁₋₉₀₁₉₁) and opaque minerals present as reaction products in the grain. Iron metal is the dominant opaque phase, with lesser troilite and trace Cr-spinel and ilmenite (Table 2A, B). Troilite and Fe metal occur ubiquitously within the alteration assemblages, whereas chrome spinel and ilmenite occur in only a few locations. Small pyroxene grains (typically ~0.2mm) occur separately from the alteration assemblages (Fig. 2a). These grains show micron scale (1-5 µm) exsolution in both pigeonite and augite hosts (Fig. 1). The pyroxene grains include traces of micron-size opaque mineral grains.

Pyroxene compositions indicate equilibrium between pigeonite and augite grains, but the low-Ca pyroxene grains in the alteration assemblages are not in equilibrium
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Figure 1. Pyroxene quadrilateral showing compositions superimposed on isotherms of [4] and Fo-Fa of olivine compositions. Symbols of the same color represent pyroxene analyses from a given exsolved grain. The sample labeled “bulk” is a broad beam analysis of roughly 50:50 augite-pigeonite exsolution. The very low-Ca pyroxene compositions represented by the gray circles are grains contained within the olivine alteration assemblage. Dashed lines between olivine and pyroxene suggest equilibrium relationships.

Discussion. The replacement mineral assemblage of Opx, Fe-metal, and troilite appears to represent a primary olivine composition. This is supported by the data in Table 2D, which shows the compositions of the olivine grains upon modal recombination using BSE image analysis. The recalculated olivine grain compositions have stoichiometry approaching that of olivine, although they are somewhat deficient in octahedral cations. Also, the compositions are very similar, except for Cr and Ti in one grain where ilmenite and Cr-spinel may have been inclusions in or co-crystallized with primary olivine. The Mg$^+$ of the recombined olivine compositions is more nearly in equilibrium with the exsolved pyroxene grains than is the measured olivine (Fig. 1), although, by analogy with mineral compositions in a ferroan troctolitic-anorthosite clast in MAC88105 [2], the equilibrium olivine should be even slightly more ferroan.

Colson [5] investigated equilibrium reactions that could produce alteration associated with the replacement of olivine by enstatite and troilite, as observed in some lunar rocks, e.g., clasts in 67016 [6,7]. This reaction and the common occurrence of troilite filling veins in lunar rocks and breccias suggest mobilization of Fe$^{2+}$ and possibly other cations by vapors associated with cooling magmas, volcanic activity, or impacts. Of the reactions considered by [5], one likely to have produced the assemblage in 60053,2-12 is the reaction of S with olivine to produce enstatite plus troilite plus Fe metal. The reaction might have been driven by C-O-S vapors. The reaction was apparently triggered by the presence of olivine plus vapor, and from the expected decrease in oxygen fugacity with decreasing temperature [5]. An important implication of the reconstructed composition of primary olivine is that the consistent excess silica and octahedral cation deficiency (Table 2D) implies Fe loss, i.e., mobility within the vapor phase as it moved through the rock.

This olivine reaction texture is rare in lunar rocks. As mentioned above, the reaction of olivine to form enstatite plus troilite is observed in clasts of breccia 67016 from North Ray crater. Troilite vein fillings, on the other hand, are fairly common.


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