CLOSED SYSTEM PARTIAL MELTING OF A K-RICH HIGHLANDS ROCK.

Marla Luisa Crawford, Department of Geology, Bryn Mawr College, Bryn Mawr, Pa. 19010.

Sample 73217 is a feldspathic breccia which can be divided into irregular volumes of two types based on the nature of the groundmass. The first type consists of a granular groundmass of plagioclase, hypersthene, augite and ilmenite with 1-2 mm fragments of anorthite, a much smaller number of coarsely exsolved pyroxene grains (both hypersthene with augite lamellae and diopsidic augite (augite I) with hypersthene lamellae) (Fig. I), very minor olivine (Fo47) and a few fragments of spinel troctolite. The second type has a groundmass of rhyolitic glass surrounding fragments similar to those above and, in addition, sodic bytownite (An72), coarse ilmenite grains, a second augite (augite II) with abundant glass inclusions, pigeonite with fine (<1 μm) augite lamellae and one grain each of whitlockite and zircon. The last two grains each measure about .16 mm; the zircon is clearly a broken fragment of a considerably larger zoned grain. Augite I grains appear to be absent from this part of the rock. The close association of the glass with low melting temperature phases, particularly sodic bytownite fragments, strongly suggests both melting and recrystallization of the breccia took place without any significant displacement of the volume of rock surrounding the sample.

The minerals in the rock can be grouped into three categories: unmelted relics, marginal zones between the relics and the glass, and new phases crystallized from the liquid produced by partial melting. Both textural and chemical criteria can be used to distinguish those phases which probably comprised the rock prior to brecciation and melting.

In the unmelted portion of the rock the relics are angular and a few of the plagioclase grains are fractured or show lamellar twinning possibly due to shock. The coarsely exsolved augite I and orthopyroxene grains have compositions similar to those of other lunar pyroxenes of supposed deep seated origin (1); at least one of the orthopyroxene grains is an inverted pigeonite. The anorthite, and more especially the augite I, contain numerous inclusions which appear to result from exsolution and incipient melting. In the plagioclase these inclusions consist of minute opaque rods (probably Fe) and glass, apparently with the same composition as the anorthite. Glass inclusions of this type, each with a shrinkage bubble, are common in plagioclase xenoliths in melt rocks such as 61156 and also in anorthite fragments in some soil breccias. The augite I has numerous minute grains of ilmenite or dark Ti, Fe rich glass, exsolved along discrete planes from the pyroxene host. Within the portions of the rock with the glassy groundmass the relic fragments of sodic bytownite and ilmenite show rounded or embayed margins while the anorthite is still angular. The bytownite grains do not show inclusions of the type found in the anorthite.

The marginal zones around the relic grains consist either of chemical changes within the relic caused by partial melting, or of new phases crystallized at the contact between the grains and the magma. The first category includes the outer margins of the bytownite grains which are sieved by glass inclusions. These outer portions of the plagioclase are
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more calcic than the unaffected interiors, a feature which can be explained by a process of selective melting of the albite component. The K/K+Na ratio of these grains does not change during this process, although the total K content decreases in the more calcic plagioclase. Narrow rims at the contact of the chromian pleonaste with the groundmass are depleted in Mg and Al and enriched in Cr and, to a lesser extent, Fe and Ti. Although it is not clear whether this is due to a resorption reaction with the melt or to later crystallization of a chromium enriched spinel, the latter seems more likely as the more chromian spinel is the lower temperature phase.

Portions of augite I grains melted completely and recrystallized to augite II containing less Ca, Cr and Al, and more Fe and Ti (Fig. 1, 2). This melting of patches of the augite occurred both within and at the margins of the grains. The plutonic orthopyroxene, on the other hand, is unaffected chemically but is mantled by a corona of augite II, or pigeonite followed by augite II. The whitlockite grain has a corona of tiny apatite needles which radiate into the glass.

Within the glassy groundmass rectangular hollow crystals of Ba-bearing potassium feldspar, apatite needles, thin hexagonal ilmenite plates and a few plagioclase grains are the last phases to crystallize. The plagioclase crystals which formed directly from the melt have a distinctively higher K/K-Na ratio (.18) than the relic grains (.10). This would be expected in plagioclase crystallizing from a highly potassic melt.

Pigeonite and augite II are volumetrically the most abundant phases crystallized from the melt. The augite II grains all contain melt inclusions as well as some ilmenite, troilite and Fe-Ni grains. In the coarsest augite II an SiO2 mineral occurs in the areas of melt inclusions. The very limited crystallization of this SiO2 phase may be due to additional heat supplied locally by the crystallizing augite. The minor element chemistry of the pigeonite and augite II clearly distinguishes them from the plutonic pyroxenes (Fig. 2). Pigeonite crystallized first and was later rimmed by augite II in apparent crystallographic continuity, with a fairly abrupt change in composition from pigeonite to augite. Some of the augite II grains show reverse zoning (En38Fs30Wo32 core to En44Fs17Wo39 rim) and the very fine grained pyroxenes in the glass have the same composition as the augite II rims.

There is no unequivocal evidence as to the heat source which initiated the melting of sample 73217. The nature of the relic grains points strongly to a plutonic origin for many, if not all, of those relics. However the brecciated texture of the rock and the occurrence of a few broken and shocked grains suggests the sample may well represent material partially melted by shock. If so this is one of the few examples in which shock melting was not complete and accompanied by mobilization of the magma (2). The presence of a glassy matrix should not be taken to indicate rapid cooling of the melt. To the contrary, the presence of exsolution lamellae in the pigeonite and the very well crystallized euhedral apatite, ilmenite, Fe-Ni and hollow potassium feldspar crystals suggest the melt was not quenched. The groundmass remained glass, because of its siliceous composition (76-78% SiO2).

Fractionation by shock melting has been suggested (3) as a possible mechanism for
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the formation of a variety of rocks found at the Apollo 16 and 17 sites. This rock shows that such fractional melting will produce a liquid selectively enriched in the components of low melting point minerals: K, Ti, Ba, P, Fe and Na. The melt is saturated with respect to pyroxene and very undersaturated in plagioclase. In fact the melt could produce rocks similar to the sodic ferrogabbro described by Weiblen and Roedder (4) and, following the crystallization of the pyroxene, to granitic rocks such as the light portion of 12013.

There is some evidence which implies that the rock became reduced during crystallization of the melt matrix: the native iron rods in the anorthite (5), high Ti and Cr contents relative to Al in pigeonite and augite II which suggest the presence of both Ti$^3+$ and Cr$^{2+}$ (6), reverse zoning in some augite II grains, and the formation of Fe-Ni crystals as inclusions in augite II grains and in the glass.

REFERENCES


Fig. 1 Summary of pyroxene compositions. Coexisting lamellar pairs connected by the dashed line. Single barbed arrow indicates pigeonite to augite II zoning trend, the double barbed arrow shows the compositional range for an augite II grain with reverse zoning.

Fig. 2 Pyroxene compositions expressed in terms of relative atomic percent of Al, Ti and Cr. Assuming no octahedral Al, pyroxenes between line a and line b imply the presence of Ti$^{3+}$ and those below line a imply Cr$^{2+}$ (6).