
We have examined the thin sections of 24 peanut-sized basaltic fragments which were separated from Apollo 11 soil samples 10002 and 10085. Our study of these thin sections was done in conjunction with an INAA study by (1). This report summarizes our petrographic investigation of the 14 samples which are high-K.

General Petrography. The 14 samples under consideration (except one vitrophyre) all have a distinctive intersertal texture which allows unambiguous separation from the Apollo 11 low-K basalts. This classification by texture corresponds exactly with the chemical groupings (1) - all these samples are high-K basalts. Plagioclase crystallizes late in the paragenetic sequence, precipitating after the lava is about 60% crystalline. This produces the intersertal texture characteristic of the Apollo 11 high-K rocks: Plagioclase and the residual minerals (cristobalite, apatite, ulvöspinel, Zr-phases) are interstitial to the (earlier crystallizing) pyroxene. Olivine is embayed and mantled by pyroxene, and ilmenite tends to be equant regardless of the grain size. The presence of armalcolite in some of these samples and the absence of early Cr-spinel in all of them further serves to distinguish these specimens from the low-K suite. Although they share the same general petrographic features, the 14 high-K peanuts differ in detail. Texturally, the average grain size ranges from about 10 microns to about 1000 microns. With two exceptions, however, the textural variations are the same as those reported by (2) for the large high-K rocks. There is no evidence that these small fragments are any different from the well-known large specimens. The petrography and trace element data are considered sufficient to classify these samples, so we have not undertaken detailed microprobe studies on them. To summarize our observations, we may rank the entire high-K suite in order of increasing grain size: 10002, 122<10049<10085,796;10085,915<10085,919<10002,120<10032<10085,820<10057<10017<10002,119<10071<10085,920<10072<10024<10085,789.

Vitrophyres. Two of the fourteen basaltic fragments do not fall into this textural sequence, but are vitrophyres. 10031 contains about 60% crystals which consist of equant armalcolite mantled by rutile-bearing ilmenite, platy ilmenite (50x5um), partially resorbed olivine (up to 600um long), equant sector-zoned pyroxene (50um) with feathery edges, and minute troilite spheres. These crystals are enclosed in a dark brown glass which contains numerous incipient crystallites of ilmenite and pyroxene. The armalcolite has Fe/(Fe+Mg)=0.53, contains 2.3% Cr2O3, 1.3% Al2O3 and has 6.4 mole % Ti2+Ti4+O5. Ilmenite ranges in composition from Gf14-12 (Fig. 1) and contains up to 3.2% Cr2O3. Pyroxene is only weakly zoned from Wo28En40Fs17 to Wo33En29Fs21, but Al2O3 and TiO2 increase from 4.0% to 6.5% and 5.5%, respectively, from core to rim. The glass has a normative composition of about Pyx28Feld49 Qtz21Oth4. Texturally and petrologically, 10031 is very similar to 10060,71, clast 6, a vitrophyre described by (2). The principal difference between the two is that the phenocrysts in 10031 are about twice as large as those in clast 6.

10085,832 has 8.4% crystals including euhedral armalcolite (0.1 vol %) grains up to 200um in length mantled by a thin rim of ilmenite, euhedral lath-shaped olivine (up to 290um in length) commonly with hollow glassy cores, euhedral lath-shaped olivene with an average size of 4x50um, minute troilite spheres in both the glass and some olivine, and small (10-20um) H-shaped pyroxene crystals, typically with curved limbs. The armalcolite is unzoned with Fe/(Fe+Mg)=0.49, Cr2O3=2.2%, Al2O3=1.6% and Ti3O5=9.1 mole %. The olivine (3.1 vol %) ranges from Fa27 to Fa32 (Fig. 1), and there is no sign of reac-
Apollo 11 Vitrophyres

D.W. Beaty

Ilmenite (3.8 vol %) compositions range from Gi10 to Gi14 (Fig. 1), and the Cr2O3 content varies from 0.5% to 8.1%. Pyroxene (1.4 vol %) has a slight range in composition, zoning from Wo7–3.5En3.5Fs2.5Oth1.5 to Wo25–10En10Fs10Oth10. Cr2O3 content is high (1.0%) while Al2O3 (2.2%) and TiO2 (2.7%) are relatively low. The glass has normative composition of Fl42Pyx50Ilm5 Qtz6, and is slightly zoned around the phenocrysts. For example, the amount of normative quartz in one traverse increased from 5.8% to 7.3% up to the edge of an olivine crystal.

Discussion. A total of four vitrophyres have now been studied from the Apollo 11 site. Three of them were quenched at about 60% crystalline, and one at about 10% crystalline. It has recently been demonstrated (1,2) that these four rocks have the same bulk composition as the Apollo 11 high-K suite. Therefore, it is worthwhile to make a detailed comparison of these two groups of samples, which will henceforth be called high-K crystalline and high-K vitrophyre, in order to determine what physical processes led to their different appearances.

Petrographically there are two important differences besides the overall textures: mineral morphologies and grain sizes. In the vitrophyres, ilmenite occurs as thin plates with irregular edges and pointed terminations. In the crystalline rocks ilmenite tends to be subhedral and equant, regardless of the grain size. Olivine in the vitrophyres is typically euhedral, despite the fact that it is grossly out of equilibrium with the glass, whereas in the crystalline rocks olivine is invariably small, embayed and mantled by pyroxene. Secondly, the olivine and armalcolite crystals are enormous in the vitrophyres as compared to the crystalline rocks. 10031 has an olivine grain 600µ across which is about 10 times as large as the olivine in any of the crystalline samples.

Petrologically, the mineral compositions in the two suites of samples also differ. The pyroxene in the crystalline rocks shows growth on both branches of the two pyroxene field (Fig. 1), along with limited growth of ferrohedenbergite. In the vitrophyres the pyroxene zones from Wo20 to Wo45 along a line of constant Fe content, then decreases to Wo35 with constant Mg content (Fig. 1). The vitrophyric pyroxene also shows well-developed zoning towards Al on an Al,Ti,Cr plot (Fig. 1), whereas in the crystalline samples the low-Ca pyroxenes fall in a field below the 0.5 Ti–0.5 Cr join (Fig. 1), the high-Ca pyroxenes lie above that join, and zoning (away from Cr) is typically indefinite. The most magnesian olivine in the vitrophyres is Fa26–28 (Fig. 1), whereas in the crystalline rocks it is usually Fa30. Ilmenite ranges up to Gi14 in the vitrophyres (Fig. 1), but up to Gi20 in the crystalline rocks. Therefore, not only are some of the mineral morphologies different, but most of the mineral compositions are distinctly different. Only armalcolite has a common chemistry.

What does this evidence tell us about the relationship between the vitrophyres and the crystalline rocks? Clearly the vitrophyres did not originate through a meteorite impact with a partially crystalline high-K lava flow, as suggested by (2). In that case the mineral compositions, morphologies and sizes of the early-formed minerals would have been indistinguishable. The differences in mineral composition suggest that the vitrophyres crystallized at higher temperatures than the crystalline rocks. The pyroxenes in the vitrophyres have compositions which would be in the two pyroxene field in the crystalline samples, along with zoning profiles suggestive of hypersolvus growth (Fig. 1). The vitrophyric olivine is more magnesian (Fig. 1) in spite of the fact that the vitrophyres and crystalline samples have the same bulk Fe/(Fe+Mg). The high Cr-contents of the vitrophyric ilmenite also indicate higher temperature than the crystalline rocks, which have low-Cr. In summary,
Apollo 11 Vitrophyres

D.W. Beaty

the vitrophyric and crystalline high-K samples have the same bulk composition, yet the parent magmas crystallized minerals of different composition.

One possible interpretation of the above data is that the vitrophyres crystallized at a higher temperature, which in turn requires that they have crystallized under higher pressure. Alternatively, the differences may have been produced by any of a variety of kinetic effects concerning crystal nucleation and growth. Whatever the cause, these two systems are significantly different. Because of their chemical similarities, these two rock types must have been produced in the same source region, but they may or may not have been cosanguinous. It has been suggested (2) that the crystalline samples were produced by successive eruptions of a differentiating magma chamber. The vitrophyres could not have been produced from the crystal-rich cumulate portions of this chamber, because such a phenocryst charged magma would no longer have the common bulk composition. It seems more plausible that the vitrophyres represent a second aliquot of magma produced by the high-K source region, which partially crystallized at depth, and was then rapidly erupted to the surface.

References

Figure 1. A-11 VITROPHYES   A-11 HIGH-K