
Introduction. Apollo 12 mare basalts have been divided into four chemically and texturally distinct groups: (1) olivine basalts, (2) pigeonite basalts, (3) ilmenite basalts, and (4) feldspathic basalts (1, 2, 3). On the basis of whole-rock major and minor element chemistry Rhodes et al. (3) proposed that the olivine and pigeonite basalts are comagmatic and related to each other by fractionation of olivine, and minor Cr-spinel and pigeonite from a magma of the composition of 12015. We have obtained detailed mineralogic and petrologic data on four representative basalts of the olivine-pigeonite groups, 12007, 12015, 12043, and 12072, to determine their fractionation histories.

Petrography and mineral chemistry. These four samples are described below in order of increasing groundmass grain size.

12015. Rock 12015 is an olivine vitrophyre consisting of phenocrysts of olivine and microphenocrysts of olivine, pyroxene, and spinel in a nearly opaque mat of dendritic pyroxene, filamental ilmenite, and glass. Olivine phenocrysts occur as equant to elongate skeletal grains <1 mm in size, which typically contain slot-shaped to irregular inclusions of matrix material and small (<0.1 mm) inclusions of Cr-spinel. These phenocrysts range in composition from Fo76 to Fo66. The two polished thin sections which we have examined differ significantly. In 12015,16, olivine (Fo69-59) occurs as abundant microphenocrysts up to 1.5 mm long and 20 mm wide with chain-like skeletal forms. Pyroxene also occurs as elongated, zoned microphenocrysts. In 12015,15 olivine is rare as microphenocrysts and instead pyroxene is more abundant as lath-shaped or tabular, zoned microphenocrysts. This difference in texture indicates that 12015,16 underwent slightly more rapid quenching than 12015,15 although both are from the same sample.

Pyroxene microphenocrysts have colorless cores of pigeonite surrounded by rims of pale pinkish augite. In section 12015,16, in which textures are indicative of more rapid quenching, the pyroxene crystallization trend is continuous from pigeonite (Wo65En44Fs31) to augite (Wo36En37Fs27), whereas in 12015,15 discrete rims of augite (Wo25En31Fs31-Wo29En37Fs34) surround cores of pigeonite (Wo17En39Fs30) with a well-defined compositional break. Pyroxene in 12015 is very aluminous (>9 wt.%). Spinel, occurring as inclusions in olivine and as separate microphenocrysts, has Fe/Mg+Fe between 0.60 and 0.89. The Ti/Cr increases with continued crystallization such that spinel microphenocrysts are surrounded by thin (2-5 µm) rims of ulvöspinel.

12072. Rock 12072 is an olivine basalt consisting of equant subhedral to anhedral phenocrysts of olivine (≤0.6 mm) and tabular to elongated phenocrysts of pyroxene (≤1 mm) in a variolitic groundmass consisting of pyroxene, plagioclase, ilmenite with minor amounts of spinel, troilite, cristobalite, Fe-metal, apatite, fayalite, and glass.

Olivine phenocrysts are typically rounded or ragged in outline and range in composition from Fo75-62. Pyroxene is texturally and compositionally complex. Phenocrysts occur as pinkish augite rims (Wo37En39Fs24) grown about colorless pigeonite cores (Wo10En56Fs34). Groundmass pyroxene (Wo22En17Fs31) consists of acicular, composite laths intergrown with acicular plagioclase grains.
12043. Rock 12043 is a pigeonite basalt consisting of large (~3.5 mm) tabular to lath-shaped phenocrysts of pyroxene and sparse, irregularly-shaped grains of olivine (<1 mm) in a subophitic to variolitic groundmass of pyroxene, plagioclase, ilmenite, and spinel, and minor cristobalite and Fe-metal. This groundmass is coarser-grained than 12072. Phenocrysts are ragged in outline because of continuous growth of pyroxene into the groundmass. As in 12072, pyroxene phenocrysts consist of colorless pigeonite cores (Wo,En,Fs) surrounded by buff-colored to pinkish augite (Wo,En,Fs). Augite has a continuous trend in composition to pyroxferroite (Wo,Fs) and some suggestion of a trend toward hedenbergite.

Olivine grains are deeply embayed, suggestive of resorption, and contain inclusions of spinel. Olivine ranges in composition between Fo70 and Fo80. Fe/Mg of spinel varies from 0.72 to 0.96 and of ilmenite from 0.98 to 1.00.

12007. This rock is a porphyritic microgabbro consisting of large (~3.2 mm), zoned phenocrysts of pyroxene in a coarse-grained (~1 mm), ophitic to variolitic groundmass consisting of plagioclase, pyroxene, and ilmenite with minor cristobalite, spinel, troilite, and Fe-metal. No olivine is present.

Pyroxene phenocrysts have irregular, colorless pigeonite cores surrounded by rims of pinkish- to buff-colored augite that merge continuously with groundmass pyroxene. Pyroxene zoning is complex, showing a high-Ca augite trend (Wo,En,Fs), a low-Ca augite trend (Wo,En,Fs), and a pigeonite trend (Wo,En,Fs), all of which come together at about (Wo,En,Fs). Augite is zoned both to pyroxferroite (Wo,Fs) and toward hedenbergite (Wo,Fs). Fe/Fe+Mg of ilmenite is >99.

Discussion. A general increase in complexity of pyroxene zoning trends occurs throughout this series of basalts. In all rocks pigeonite was the first pyroxene to crystallize. In 12015 pyroxene trends reflect what must be minor differences in cooling rate. In section 12015,16, the pyroxene crystallization trend is continuous from pigeonite to augite, whereas in 12015,15 discrete rims of augite surround pigeonite with a well-defined compositional break. This difference probably indicates that 12015,16 was quenched from a slightly higher temperature than 12015,15. Because crystallization of pyroxene occurred before plagioclase was stable, pyroxene compositions are very aluminous (>9 wt.%). As result of the rapid quenching, pyroxene microphenocryst trends do not extend significantly toward higher-Fe composition.

In 12043 and 12007 both pigeonite and augite show strong trends toward higher Fe. Augite trends extend to pyroxferroite. In 12007 a high-Ca trend is also present, and augite is differentiated both to pyroxferroite and toward hedenbergite.

On the basis of textures the rocks may be ordered according to decreasing cooling rate from 12015 (olivine vitrophere) through 12072 (subophitic to variolitic texture) and 12043 (porphyritic microgabbro) to 12007 (microgabbro) (3). This sequence also agrees generally with the mineralogy and phase chemistry. The most magnesian olivine compositions in 12015 and 12043 are respectively Fo76 and Fo70. Based on the corresponding whole-rock compositions (3) these olivine compositions are approximately in equilibrium (4) with these melts ([Fe/Mg]_olivine/[Fe/Mg]_rock=0.31-0.33). No whole-rock chemistry exists for 12072. Olivine decreases sharply in modal abundance from 12072 to 12043 and is absent from 12007. In addition the Fe/Mg+Fe ratio of ilmenite and spinel
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generally increases from 12015 to 12007.

Rhodes et al. (3) conclude that the olivine and pigeonite basalts are comagmatic and that the pigeonite basalts can be derived from a parental magma equivalent in composition to 12015 by subtraction of olivine (Fo72), minor Cr-spinel, and (in the later stages of fractionation) pigeonite. Our data on the petrographic relations and mineral chemistry are broadly compatible with this conclusion. Rhodes et al. (3) point out the importance of 12011, the most quickly cooled and least evolved of the pigeonite basalts, to relating these two basalt groups. Analysis of 12011, as well as several other samples, is being undertaken.