PETROLOGY OF LUNAR HIGHLAND ROCKS OF APOLLO 16

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Petrological studies have been carried out on Apollo 16 rocks 60025 (cataclastic anorthosite), 60315 (recrystallized breccia), 62295 (spinel troctolite), and 68416 (feldspathic basalt). Major constituent minerals in these rocks, as determined by microprobe, are as follows: 60025, plagioclase (An 97-95)*, augite, hypersthene and chromite (Chr 61, Sp+Her 27, Ulvö 12); 60315, bronzite, olivine (Fo 75-71), plagioclase (An 96-78), magnesian ilmenite (7-8 wt.% MgO), metallic iron (4-9 wt.% Ni) and troilite; 62295, plagioclase (An 93-91), olivine (Fo 89-82), spinel (Chr 4-2, Sp 97-92, Her 20-5), and augite; 68416, plagioclase (An 97-56), orthopyroxene, clinopyroxene, olivine (Fo 68-63), ilmenite (1-3 wt.% MgO), and metallic iron (3-12 wt.% Ni). Interstitial glass in 68416 is greatly enriched in SiO_2 (79 wt.%), Al_2O_3 (11%) and K_2O (5.0%) and contains 4% normative corundum.

Pyroxenes of anorthosite 60025 have a wide compositional gap between augite and hypersthene (Fig. 1), indicating that they were equilibrated at relatively low temperatures. Their Fe/Mg ratios are relatively high and the highest among those in the specimens we have studied. Pyroxenes in recrystallized breccia 60315 have a narrow range of Fe/Mg values and a wide miscibility gap, and the Fe/Mg ratios of coexisting olivine and orthopyroxene are consistent with the equilibrium values (1), indicating that the mafic minerals in this rock are nearly equilibrated. A composite grain (0.5 mm in diameter) in rock 60315 consists of fine lamellae of olivine (Fo 75-74) and plagioclase (An 91-87). It has a bulk composition near that of aluminous pigeonite or subcalcic augite with 13 wt.% Al_2O_3 (X in Fig. 1) and was probably a pyroxene formed at high pressures and temperatures. Pyroxenes in feldspathic basalt 68416, including bronzite, pigeonite, subcalcic augite and augite have a wide range of Fe/Mg values and do not show a miscibility gap, suggesting rapid, non-equilibrium crystallization at relatively high temperatures.

Olivine in troctolite 62295 is the most magnesian found in this study (Fig. 1) and one of the most magnesian olivines reported in the lunar samples.

Large anhedral plagioclase grains in rock 60315 have calcic cores (An 96-95) with narrow, more sodic rims (An 92-91), whereas fine-grained plagioclase laths range to a more sodic composition (An 95-78), indicating that the degree of equilibration during recrystallization is much less for plagioclase than for the mafic minerals.

Anhydrous melting experiments on troctolite 62295, one of the most magnesian rocks among the lunar samples (Fig. 3), show that spinel (Chr 3-4, Sp 89-78, Her 7-17) is on the liquidus and is followed by olivine (Fo_{92-90}), plagioclase (An_{92}) and orthopyroxene ($\pm$ clinopyroxene) up to about 10 kb (Fig. 2). Although the rock could be a spinel (and olivine) cumulate, the original liquid, which was on the Sp-Ol or Sp-Ol-Pl boundary, would have been derived under anhydrous conditions from an olivine-rich source material with a high Mg/Fe ratio.

* Mol. % unless otherwise indicated

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Most of the lunar highland rocks plot in a narrow fan-shaped field An-62295-X in the An-Ol-SiO_2 system (Fig. 4). The Fe/Mg ratio of the liquid of 62295 composition increases with crystallization and approaches the average Fe/Mg value for the highland rocks (arrow A in Fig. 3). Thus troctolite 62295 has a more primitive composition and the magma from which it crystallized could be parental to many highland rocks. It is suggested that most of the plagioclase -rich highland rocks were formed by plagioclase cumulation in magmas similar in composition to 62295 or the Ol-Sp-Pl boundary (X), with or without subsequent impact remelting. The melting experiments on feldspathic basalt 68416 show a wide temperature range (~150°) for plagioclase + liquid, but the Sp-Pl-Ol boundary is reached at about 1250°C at 5 kb, nearly the same as that for 62295 composition. These results are consistent with the above discussion.

Both the total iron and the Fe/Mg ratio contents of the highland-type rocks are much smaller than those of the mare-type crystalline rocks (Fig 3). It is not likely that such differences are only due to the difference in degree of partial melting of the same source material. If a considerable amount of iron was lost from the mare-type magmas by volatilization, for example, magmas with low Fe/Mg ratio would be formed. Heating experiments on mare-type basalts in vacuum show that elements are lost in the sequence Na, K, Fe, (Mg, Si) by vaporization. Ca and Al appear to be the most "refractory" elements. Na and K losses were observed at 1150°C. In the absence of carbon, iron loss was not detected below 1400°C (Rhenium crucibles). Since Na and K are present with low concentrations of Fe in highland rocks, these rocks could not have been formed solely by vaporization loss. It is unlikely, therefore, that the mare-type basaltic rocks are parental to the highland-type rocks. As far as these two different rock types were derived from materials of the same or similar compositions, it is likely that the mare-type crystalline rocks are products of advanced fractional crystallization, whereas the highland-type rocks are products of a lesser degree of fractional crystallization. If the mare-type and highland-type rocks were derived from different source materials (2, 3), they could have been formed independently and their distinct compositional difference can be explained more easily.

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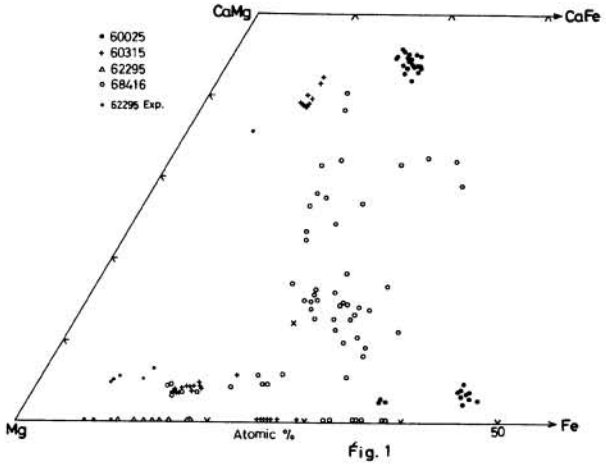

Fig. 1

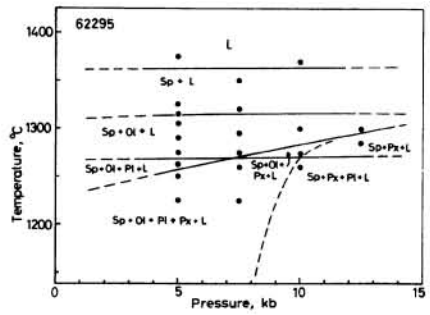

Fig. 2

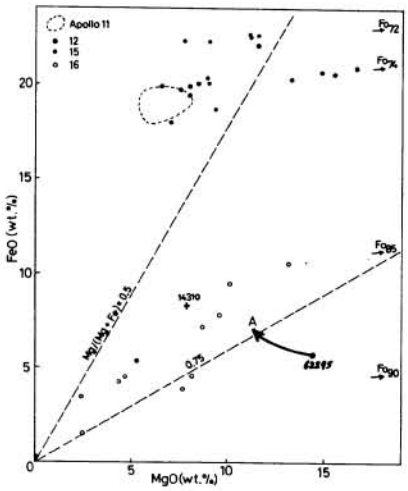

Fig. 3

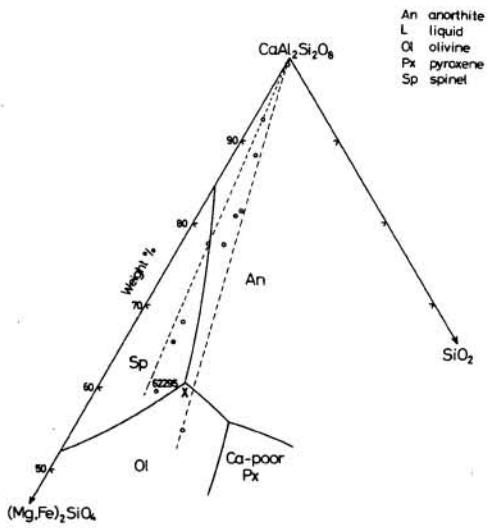

Fig. 4