PETROLOGY AND PETROGENESIS OF APOLLO 17 BASALTS AND APOLLO 17 ORANGE GLASS, D.H. Green, A.E. Ringwood, N.G.Ware, W.O.Hibberson
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The mineralogies of two very fine grained Apollo 17 basalts Nos. 70215 and 74275 have been examined in detail. Basalt 70215 is a high-titanium (13.1% TiO_2), basalt [<1% normative olivine, 100 Mg/Mg+Fe = 43.6][1] but basalt 74275, while of similar TiO_2 content (12.8% TiO_2) is more magnesian and olivine-rich [8% normative olivine, 100 Mg/Mg+Fe = 50.5]. Basalt 70215 contains phenocrysts of olivine with a range in composition from $(100\ Mg/Mg+Fe)_{max}$=74.0 towards more iron-rich rims and also contains rare phenocrysts of a spinel phase (48% M_2TiO_4,35%, M Cr_2O_4, 17% M Al_2O_4) and of armalcolite [$(100\ Mg/Mg+Fe)_{max}$=48, 2.0% Al_2O_3, 2.1% Cr_2O_3]. The bulk of the rock consists of quenched, strongly zoned olivine, calcium-rich pyroxene zoned to Fe-rich sub-calcic pyroxenes, ilmenite ($100\ Mg/Mg+Fe_{max}$ = 18) and anorthite. Experimental studies of a synthetic glass of the composition of basalt 70215 showed that olivine and spinel occurred in the liquidus at 1160 ± 10°C and were joined by armalcolite at 1140 ± 10°C. The composition of olivine [100 Mg/Mg+Fe = 74] and armalcolite [100 Mg/Mg+Fe = 50, 2.1% Al_2O_3, 2.0% Cr_2O_3] in a run at 1140°C are identical to those of the most magnesian phenocrysts of the natural rock and the composition of the coexisting spinel [60% M_2TiO_4, 27% M Cr_2O_4, 13% M Al_2O_4] is close to the Mg-rich natural spinels. Pyroxene or plagioclase do not coexist with olivine, spinel or armalcolite of these compositions in the equilibrium melting experiments but both phases, coexisting with olivine and armalcolite, are present at 1100°C. The combination of experimental and mineralogical data demonstrates that basalt 70215 composition existed as a liquid containing rare olivine and very rare spinel and armalcolite crystals at ≥1140°C and was rapidly quenched from that temperature.

At 5 kb,1220 ± 10°C,olivine and spinel occur in the liquidus but at 1200°C spinel is absent and olivine, ilmenite and sub-calcic clinopyroxene (5% CaO, 2.2% Al_2O_3, 2.1% TiO_2) occur together with liquid. At 8 kb, 1260°C, sub-calcic clinopyroxene (5.4% CaO, 2.6% Al_2O_3, 2.2% TiO_2) is the liquidus phase and clinopyroxene remains the liquidus phase at 10 kb, (6.7% CaO, 3.4% Al_2O_3, 2.2% TiO_2) and 15 kb, 1340°C (10.1% CaO, 4.7% Al_2O_3 2.4% TiO_2).

Basalt 74275 is also a fine-grained basalt with rare olivine phenocrysts,some containing spinel inclusions, in a quench assemblage of zoned pyroxene, armalcolite, ilmenite, olivine and plagioclase. The composition of olivine phenocryst cores varies up to 100 Mg/Mg+Fe = 79.5 (TiO_2 = 0.3%, Cr_2O_3 0.3%,

PETROGENESIS - APOLLO 17 BASALTS

Green, D.H., et.al.

CaO = 0.3%), these olivines being the most magnesian yet observed in mare basalt samples, including olivine vitrophyres such as 12009, 12022. The most magnesian spinel crystals are included in olivine at composition (100 Mg/Mg+Fe = 75) and the evidence from the rock suggests that olivine may have crystallized alone over the compositional range 100 Mg/Mg+Fe = 79.5→75 before being joined by spinel (100 Mg/Mg+Fe = 28.5; 40% M_2TiO_4, 41% M Cr_2O_4 19% M Al_2O_4). Armalcolite ((100 Mg/Mg+Fe)$_{max}$=44, 2.3% Al_2O_3 1.9% Cr_2O_3) is variable in composition and does not occur included within cores of olivine phenocrysts - it is probably best assigned to the quench rather than phenocryst phase of crystallization. Although no experimental studies have yet been carried out on the composition of basalt 74275, the phase relationships observed for 70215 and Apollo 17 Orange Glass compositions and the value for $K_D=(Fe/Mg)_{Ol}/(Fe/Mg)_{Liq.}$ = 0.27 established for high titanium basalts from these studies allow the prediction that olivine with 100 Mg/Mg+Fe = 79 - 79.5 will be the liquid phase (at >1200°C) for basalt 74275 at atmospheric pressure. The data on samples 70215 and 74275 demonstrate that, if these samples are derived from lava flows and are not impact melts, highly olivine-normative and relatively magnesian liquids containing up to at least 12.5 - 13% TiO_2 existed as lava flows (T>1150°C) at the lunar surface. These lavas were not saturated in plagioclase, pyroxene, ilmenite or armalcolite at or near the lunar surface and are not residual liquids from near-surface fractional crystallization. The lavas were saturated in olivine (100 Mg/Mg+Fe = 74-79) alone or olivine + Ti-Cr-spinel on extrusion.

The Apollo 17 Orange Glass composition[2] has olivine (100 Mg/Mg+Fe = 81) on the liquidus at 1330 ± 10°C, at atmospheric pressure and olivine crystallizes alone (or with rare spinel at T<1200°C) to 1150 ± 10°C where olivine (100 Mg/Mg+Fe = 72) is joined by armalcolite (100 Mg/Mg+Fe = 47; 1.6% Al_2O_3;2.6% Cr_2O_3) At this temperature Orange Glass is 30 ± 3% crystallized and the liquid matches some Apollo 17 and Apollo 11 basalts in major element composition. Olivine remains the liquidus phase with increasing pressure but at 20 kb olivine is followed by orthopyroxene and at 25 kb orthopyroxene is the liquidus phase. The orthopyroxene at 25 kb 1480°C, has 100 Mg/Mg+Fe = 81.1, 1.1% TiO_2 2.1% Al_2O_3, and 2.4% CaO and is either accompanied by sub-calcic clinopyroxene on the liquidus or joined by clinopyroxene slightly below the liquidus. The occurrence of orthopyroxene on the liquidus of Apollo 17 Orange Glass composition at 20-25 kb firmly establishes a link with Apollo 12 and 15 mare basalts and with Apollo 15 Green Glass composition particularly in confirming the significance of 100 Mg/Mg+Fe values of 80 for the source regions of mare basalts of both high Ti and low Ti

PETROGENESIS - APOLLO 17 BASALTS

Green, D.H. et. al.

character and the roles of orthopyroxene, sub-calcic clinopyroxene and olivine as the major phases of the source region. From the Apollo 17 Orange Glass studies, it is probable that basalt 74275 will have olivine + orthopyroxene as liquidus phases at 12 - 15 kb.

Experimental phase relationships and mineral chemical data show that 70215, 74275 and Orange Glass are not simply related by near surface crystal fractionation (olivine ± spinel ± armalcolite) but represent different magma batches, derived probably from an olivine pyroxenite source but with different depths of magma segregation and/or degrees of partial melting.

1. Lunar Receiving Laboratory Apollo 17 Lunar Sample Information Catalogue (1973).

2. Reid, A.M. et.al, Eos 54, 606-607, (1973).