ORIGIN OF THE LUNAR HIGHLANDS; C.E. Ford, G.M. Biggar, M.J. O'Hara, D.J. Humphries & P.N. Spencer, Grant Institute of Geology, Edinburgh University

The Apollo 16 rocks range from crystallised igneous liquids and cumulates to brecciated, remelted and recrystallised types. In melting experiments at atmospheric pressure (Table 1) the range of chemical composition represented by the Apollo 16 rocks is consistent with a pseudo-ternary system comparable to the An-Fo-SiO_2 system (Fig 1). All the rock compositions lie close to the plane $XO.R_2O_3$-YO-ZO_2.

All of the rocks have a temperature interval from about 1300°C to 1200°C during which spinel is first precipitated either alone or with plagioclase <u>or</u> olivine and subsequently resorbed when olivine and plagioclase occur together. Whereas plagioclase + spinel and olivine + spinel cumulates could be expected but have not been found, the reported olivine+plagioclase+spinel cumulates should not occur. None of the lunar rocks retain a chemical memory of appreciable spinel fractionation. Many of them do not even retain a memory of crystallisation through the stability field of spinel. Those rocks which do contain spinel, notably 62295 and the spinel-troctolites, are perhaps best explained as remelted troctolite cumulates in which the spinel, which is formed on initial remelting, subsequently fails to re-equilibrate.

The major element chemistry fits very closely a fractionation model dominated by the accumulation of plagioclase:-

60025 (37.6%) + 60335 (62.4%) = 68415 ($\Sigma r^2 = 1.457$)

60025 (58.6%) + Avge Hi-Al basalt (Prinz)(41.4%)= 68415 ($\Sigma r^2 = 0.187$)

or plagioclase + olivine:-

Avge spinel troctolite (20.45%) + 62235 (79.55%) = Avge Hi-Al basalt (Σr^2=0.8)

Avge spinel troctolite(46.8%) + glasses in 14310 at 1211°(53.2%) = Avge Hi-Al basalt (Σr^2=2.5)

These equations do not require any specific rock to be genetically related to any other rock, merely that the rock <u>types</u> as represented by the returned lunar highland samples can be interrelated by crystal-liquid processes.

The key questions now to be answered are (1) What point in the chemical sequence represents the parent magma? (2) How did fractional crystallisation of this magma manage to avoid the involvement of spinel? (3) Where did the parent magma come from?

The recognition of apparent phenocrysts in rocks such as 68415, 68416 and the texture suggestive of crystallisation from a near all liquid state indicate that any parent magma must be at least as anorthositic as these rocks. The close similarity of the soil compositions also suggest the volumetric significance of this composition. Such a parent liquid is capable of fractionation to give about 60% anorthosite cumulus and 40% derivative high alumina basalts. A parent liquid located at the mafic end of the observed rock sequence would require the existence of large volumes of 'unseen' derivative liquid and necessitates unproven plagioclase flotation which would in turn prevent troctolite accumulation.

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HIGHLAND ORIGIN

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The lack of memory of a spinel 'event' can be explained if under some other conditions of crystallisation spinel did not occur in the crystallisation sequence. Spinel occurs under all experimental conditions examined so far. One sequence of events could bypass the stability field of spinel and lead to some fractional crystallisation. At moderate water vapour pressures the Apollo 16 rocks are rendered all liquid at temperatures below 1200°C. Depressurisation at constant temperature below the stability range of spinel leads to fairly rapid growth of plagioclase which could fractionate provided that olivine nucleation and growth was delayed. Separation of a vapour phase and temperature adjustments due to latent heat effects might provide the ideal stirring mechanism required to explain volatilisation losses of water, alkalis, oxygen and other volatiles, and re-melt previous accumulations of troctolite.

High water pressure suppresses the plagioclase liquidus temperature in favour of ferromagnesian minerals. A pressure somewhat over 5 kb is required to produce olivine crystallisation before plagioclase in 68415 which is close to a possible parent magma composition. Liquids like 68415 can be produced by partial melting of a lunar interior in the presence of water vapour. In the absence of water vapour the same lunar interior could provide mare type basalts.

Table 1

Atmospheric pressure experiments at $fo_2 \equiv$ Fe/FeO, Mo capsules

T°/Rock	60025	68415	60335	62295	60315
1370	p,l	p,l	p,l	s,l	
1330	p,l	p,l	p,l	s,l	l
1300	p,l,ore	p,s,l	p,s,l	s,l	s,l
1276	p,l,ore	p,s,l	p,s,l	o,p,s,l	o,s,l
1256		p,s,l	p,o,s,l		o,s,p,l
1227		p,o,s,l	p,o,s,l	o,p,l	o,s,p,l
1216		p,o,s,l	p,o,s,l	o,p,l	o,s,p,l
1200	solid	p,o,l	p,o,l	o,p,l	o,p,l

Higher pressure/depressurisation experiments on 60335 + 10% H_2O at $fo_2 \equiv$ FeO/Fe_3O_4, Pt capsules.

T	P_1 kb	t_1 hrs	P_2 kb	t_2 hrs	Result
1250	1	0.5			s,l
1250	1	0.5	0	0	s,p,l q-pyroxene
1250	1	0.5	0	1	s,p,l

Abbreviations p = plagioclase, s = spinel, o = olivine, l = liquid

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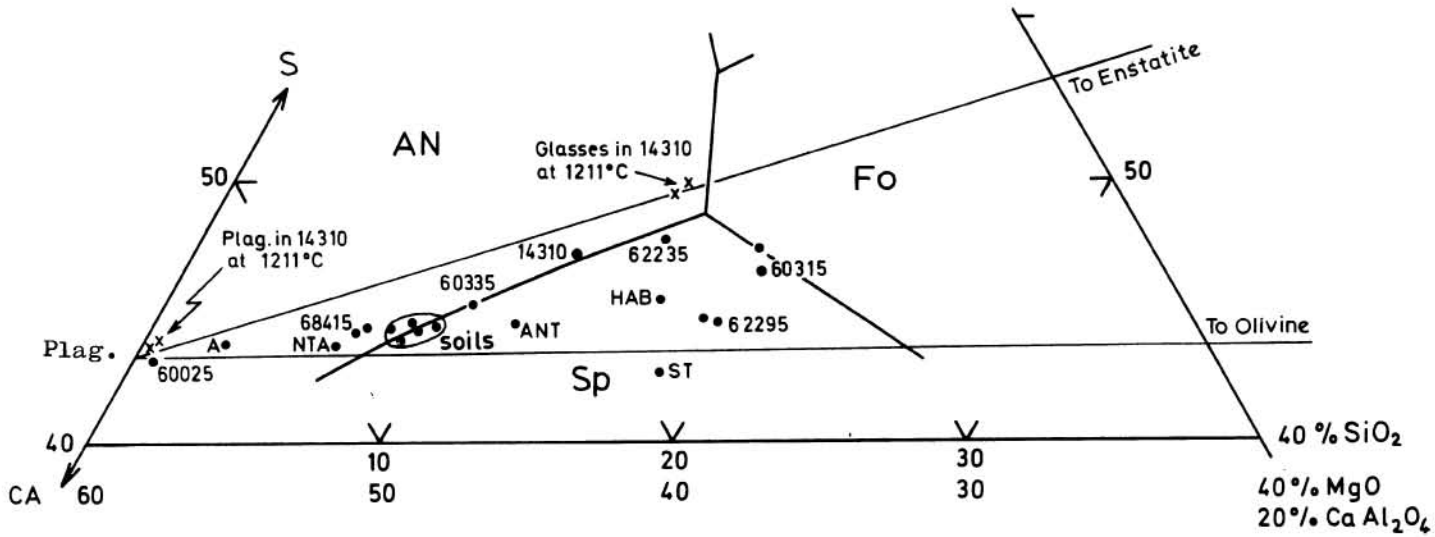

Fig. 1 Spinel projection into $CaAl_2O_4$ - MgO - SiO_2 ($XO.R_2O_3$ - YO - ZO_2)

Field boundaries are those of the pseudo-ternary system An-Fo-SiO_2 at atmospheric pressure. The location of several rock compositions at the boundary of the spinel field is fortuitous since in this projection crystallisation of spinel would not alter the apparent course of liquids also crystallising other phases. The suggested crystal-liquid trend is Average Anorthosite (cumulus) ⟵ Soils (parent liquid) ⟶ Average High Alumina Basalt (derivative liquid). The latter gives rise to a second sequence consisting of Average troctolite (cumulus) ⟵ Average High Alumina Basalt ⟶ 62235 (KREEP-like derivative liquids).

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