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AGE AND PETROGENESIS OF APOLLO 14 BASALTS. W. Compston, M. J. Vernon, H. Berry, R. Rudowski, C. M. Gray, N. Ware, Dept. of Geophysics and Geochemistry, Australian National University, and B. W. Chappell, M. Kaye, Dept. of Geology, Australian National University, Canberra, A.C.T.

A precise mineral age of 4.00 ± .04 b.y. was found for the non-mare type basalt, 14310, using mesostasis intergrown with pyroxene in the higher density fractions to obtain samples of high Rb/Sr. Handpicked plagioclase and pyroxene gave low Rb/Sr samples. Our result is some 3.0% greater than the mineral age obtained for the same rock by the Cal. Tech. group, which we interpret as an interlaboratory bias in determining Rb/Sr.

A well-defined mineral age, not distinguishable from that of 14310, was obtained for the basalt 14072, using ilmenite and plagioclase concentrates to obtain a wide range in Rb/Sr. The major element chemistry of this rock (Table 1) clearly distinguishes it as a mare basalt.

Two fragments of basalt and one of troctolite were separated from breccia 14321, and their ages determined using mineral concentrates separated from ~100 mg samples. Both basalts appear slightly older than 14310 at 4.15 ± 0.1 b.y.; allowing for interlaboratory bias, their age is probably the same as the mineral age of 12013. The age of the troctolite is not distinguishable from 14310 and may be less than the associated basalts. The measured value depends critically upon the analysis of olivine as a high Rb/Sr phase (or olivine with K-feldspar inclusions), and the olivine result is sensitive to Rb contamination during processing which would depress the age. However, plagioclase, total-rock and K-feldspar data independently control the troctolite age as not exceeding that of the basalts.

Electron microprobe analyses of the basalt clasts, specifically the higher Cr_2O_3 of their pyroxenes and their less calcic plagioclases, indicate that they are not related to 14310. On the other hand, the troctolite (Table 1) which has a granular equilibrated mineral assemblage of olivine (Fo_{86}) plagioclase (An_{95}) and accessory K-feldspar, could be an accumulate from a magma resembling 14310. However any such relationship must

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predate the mineral ages, as the initial $^{87}Sr/^{86}Sr$ of 14310 at 4.0 b.y., 0.7004, greatly exceeds that of the troctolite, 0.6996. This conclusion holds whether 14310 formed by impact melting of regolith near the lunar surface at 4.0 b.y. or whether it was derived from the mantle at that time. Crystal fractionation of the troctolite at or earlier than 4.0 b.y. is indicated by its excessively old total-rock model age.

A 100 mg sample of the Apollo 15 basalt, 15555, has been dated at 3.53 $\pm$ 0.18 b.y., at the older limit of ages measured by us for Apollo 12 basalts. Petrographic and chemical data (Table 1) show that 15555 is a mare basalt similar to some Apollo 12 basalts.

The Apollo 14 basalts as representative total-rock samples combine with the Apollo 12 and low K Apollo 11 basalts to define an approximate pre-crystallization "isochron" of 4.5 b.y., which is also fitted by the various fines. This demonstrates that Rb-Sr model ages of igneous or glass fragments are maximum estimates for crystallization ages, and that in general terms, the moon is composed of 4.5 b.y. old material. However, no specific material which crystallized earlier than 4.15 b.y. has been identified. The preservation of the 4.5 b.y. alignment during the formation of the basaltic magmas has been interpreted in three ways: (i) by production of the magmas from a lunar mantle which is heterogeneous in Rb/Sr on a regional scale; (ii) by non-equilibrium partial melting of a mantle in which most of the Rb and radiogenic Sr are situated in accessory minerals, whereas most of the common Sr is in a low Ca pyroxene; (iii) by assuming that most of the basalts collected so far were first formed on the lunar surface at 4.5 b.y. but were later totally remelted without change in their bulk chemistry. The first interpretation requires that Rb/Sr in the melt must equal that of the source to within a few percent for small degrees of partial melting. This conflicts with expectations for a lunar mantle composed of olivine, pyroxenes and accessory phosphates. The second requires that the crystal size of the major minerals in the mantle should be very large (of the order 1 m) and the diffusion constant for Sr very low, in order that radiogenic Sr produced in accessory phases will equilibrate only very slowly with common Sr dispersed in pyroxene. Under these conditions, a non-equilibrium melt composed mainly of accessory phases and the exterior parts of major phases would incorporate the daughter ^{87}Sr of the source without separation from its parent Rb, and hence preserve the source's model age. The third interpretation can be excluded at least for the mare basalts if the age of the Fra Mauro Formation can be placed at ≤ 4.0 b.y. This will be so provided the dated basalt clasts were assembled within breccia 14321 during the Imbrium impact. If the 4.0 b.y. interpretation for the Imbrium event can be confirmed, it follows that the Apollo 11 and Apollo 12 basalts which are stratigraphically younger than the Fra Mauro Formation must have formed after this time, not close to 4.5 b.y.

Eight samples of Apollo 14 fines show some variation in Rb-Sr model age but are remarkably similar in major element chemistry. Their average composition is shown in Table 1.

Table 1: Chemical analyses of Apollo 14 samples

	Crystalline rocks			Troctolite clast	< 1mm
	14053	14072	14310	from 14321	fines
SiO_2	46.18	45.15	47.57	43.50	47.72
TiO_2	2.94	2.57	1.24	0.19	1.74
Al_2O_3	12.84	11.07	20.70	23.29	17.43
FeO	17.09	17.82	8.22	4.56	10.33
MnO	0.26	0.27	0.12	0.06	0.14
MgO	8.59	12.16	7.59	15.82	9.41
CaO	11.18	9.84	12.54	12.27	11.00
Na_2O	0.44	0.32	0.73	0.28	0.73
K_2O	0.11	0.08	0.49	0.06	0.57
P_2O_5	0.13	0.08	0.41	0.03	0.52
Cr_2O_3	0.37	0.51	0.15		0.19
S	0.10	0.12	0.06		0.09
	100.23	99.99	99.82	100.06	99.87
O≡S	0.05	0.06	0.03		0.04
	100.18	99.93	99.79		99.83

< 1 mm fines is average of analyses of samples 14141, 14148, 14149, 14156, 14161, 14162, 14163 and 14259.

Troctolite analysed by microprobe analysis of fused sample.