Rb-Sr STUDIES OF LUNAR BRECCIAS AND SOILS, R. K. Mark, R. A. Cliff*, C. Lee-Hu, G. W. Wetherill, Dept. of Planetary & Space Science, UCLA, Los Angeles, Calif. 90024, *current address: Dept. of Earth Sciences, Univ. of Leeds, Leeds, England.

This study was undertaken in an effort to determine the ages of formation of the lunar breccias sampled and of the older-generation clasts contained therein.

Table 1 reports data for two breccias from the Apollo 14 site. Sample 14321 is a polymict breccia, containing microbreccia and basalt clasts. A subsample, 14321,184, has been studied in collaboration with a consortium headed by G. Goles. Three generations of clasts have been identified (1). Grieve and others (2) suggested a temperature for the final lithification of 14321 well below 700°C, and Williams (3) proposed a peak temperature during lithification of about 1000°-1050°C, in the Imbrium ejecta blanket.

This basalt clast, as well as others in 14321 are of a mare affinity, but are richer in Al and incompatible elements and poorer in Fe and Ti than typical mare basalts (compare (4), (1), and (5)). The mineral isochron obtained for the basalt clast 14321,184-55 yields an age of 4.07 ± 0.10 b.y. with an initial Sr isotopic ratio of 0.69961 ± 0.00014 (2σ errors). Papanastasiou and Wasserburg (6) reported an age of 3.95 ± 0.04 b.y. and Compston and others (7) reported 4.15 ± 0.10 b.y. on other basalt clasts from 14321. This age must predate the formation of 14321, and therefore, presumably the Imbrium event.

The analysed microbreccia clasts (of the latest generation prior to assemblage of 14321), fall distinctly above the basalt isochron, thereby precluding isotopic equilibration at the time 14321 was formed.

Sample 14066 is also a polymict breccia. A subsample 14066,21 has been studied in collaboration with a consortium headed by J. Reynolds and C. Alexander. Williams (3) proposed a peak temperature of about 1100°C for the final lithification. While the light crystalline fragments from 14066 are quite rich in Rb and K, 14066 is somewhat less enriched in REE than the microbreccia clasts from 14321 (8). Individual clast #17 (latest generation) was removed from 14066,21. Fragments of crystalline rock have been hand-picked from this clast. A light-colored fragment and two density separates are all quite radiogenic (0.7282-0.7377). Measurements were also made on hand-picked dark fragments and on a piece of clast #17 (2.01 WR).

These clasts from 14066, as well as the microbreccia clasts from 14321 and basalt 14310 fall on a regression line on the Sr evolution diagram, with slope 4.05 ± 0.10 b.y. and intercept 0.70046 ± 0.00028. This line is distinct from and parallel to the basalt (14321,184-55) mineral isochron. There is, however, no independent evidence to indicate that this set of samples were in isotopic equilibrium at this time. It is also distinct from T=4.3 b.y. and T=4.6 b.y. isochrons. Inclusion of these samples therefore indicates that not all Apollo 14 materials lie on a single 4.3 b.y. isochron, as has been inferred by O'Nions and Pankhurst (9). The more radiogenic clasts from both 14321 and 14066

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are KREEP-rich and have a KREEP REE abundance pattern. However, these clasts are enriched in K and Rb by up to a factor of 2 above that reported by Hubbard and Gast (10), without a corresponding increase in REE, Sr, or Ba concentrations.

Table 1 reports data for several Apollo 15 and 16 soils. The "whole rock" samples are generally less radiogenic than Apollo 12 and 14 soils and have model ages indistinguishable from 4.6 b.y. Sample 15271,45 is from Station 6 at the Appenine Front and 15471,25 is from Station 4 at Dune Crater. The samples fall close to a mixing line (with respect to Rb, Sr,K) with mare basalt 15555, in a manner consistent with an increasing proportion of mare basalt in the soil away from the Front.

The Apollo 16 soils studied are from Station 1. Sample 61241,26 ($<$ 1 mm) is from the upper gray soil. 61221,23 ($<$ 1 mm) and 61222,3 (1-2 mm) are from darker soil below the surface. Dark lithic (microbreccia) fragments (15%) and anorthosite fragments (15%) were hand-picked from 61222,3. The dark lithic fragments were crushed and plagioclase clasts were hand-picked. A thin section of one such fragment exhibits plagioclase clasts in a subophitic groundmass.

Both the anorthosite fragments and the plagioclase clasts have very low Rb/Sr ratios and their strontium isotopic ratio is near their initial ratio. Presuming an age of 3.7 to 4.6 b.y. for the anorthosite fragments, their initial strontium isotopic ratio was 0.6993. This value is above BABI and indicates formation or some reequilibration since 4.6 b.y. The same calculation for the plagioclase clasts from the dark lithic fragments yields an initial Sr isotopic ratio 0.6999. This is distinct from the anorthosite and indicates formation or equilibration in a more radiogenic system. If these plagioclase clasts equilibrated with the rest of the microbreccia fragments during formation, then an age of 3.7 b.y. is indicated.

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(5) James, O. B., and Wright, T. L., 1972: Geol. Soc. Amer. Bull., v. 83, p. 2357-2382.
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(8) Laul, J. C., et al., in "Lunar Science-III," Ed. C. Watkins (Houston: Lunar Science Institute), 1972, p. 480-482.
(9) O'Nions, R. K., and Pankhurst, R. J., 1972: Nature, v. 237, p. 446-447.
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SAMPLE	Rb (ppm)	K (ppm)	Sr^{86} (ppm)	Rb^{87}/Sr^{86}	$Sr^{87}/Sr^{86} \pm 1\sigma$
14321,184-55 basalt clast					
whole rock	2.31	1061	9.52	0.0676	.70351±.00005
plagioclase	2.01	2355	22.62	0.0247	.70109±.00008
pyroxene	0.290	142	1.50	0.0538	.70261±.00010
'cristobalite'	3.09	-	2.65	0.325	.71813±.00016
'magnetic'	2.26	1626	3.20	0.197	.71117±.00011
14321 microbreccia clasts					
,184-30	9.48	3471	16.70	0.1580	.70928±.00016
,184-35C (mean 3 splits)	28.9	10685	17.6	0.465	.72782±.00022
,184-40	22.8	5187	13.92	0.457	.72682±.00019
,235-2	16.7	6143	18.48	0.252	.71519±.00008
14066,21					
-2.01 whole rock	6.15	2751	17.55	0.0966	.70621±.00008
-2.04 dark fragments	4.74	2459	19.43	0.0679	.70403±.00015
-2.04 light fragments	40.1	12016	17.22	0.649	.73771±.00015
ρ<2.96	42.9	12446	25.10	0.476	.72823±.00008
ρ=2.96-3.3	37.2	10590	19.02	0.545	.73210±.00007
14310 basalt whole rock	13.0	4100	17.82	0.203	.71186±.00008
15555 basalt whole rock	0.670	313	8.58	0.0217	.70032±.00008
15471,25 (<1 mm)	3.35	2269	11.39	0.0818	.70416±.00004
15271,45 (<1 mm)	5.91	3917	13.57	0.1213	.70680±.00005
61241,26 (<1 mm)	2.51	960	17.12	0.0409	.70171±.00004
61221,23 (<1 mm)	2.17	832	17.25	0.0350	.70130±.00005
61222,3 (1-2 mm)					
dark lithic fragments	4.20	1492	16.36	0.0716	.70369±.00005
plagioclase clasts	0.136	349	17.22	0.0022	.70006±.00014
anorthosite fragments	0.199	92.9	18.37	0.0030	.69950±.00006

Table 1