Type A breccia is considered to be weakly lithified regolith that locally contains scattered clasts of mare basalt thrown up on the Apennine front, mostly from South Cluster. Type B breccia is the most common type collected on the Apennine front and is also common at the LM site and in samples from the mare surface at station 9. Because these breccias are the dominant rock type collected from the front and do not contain mare-like basalt clasts, they are presumed to represent premare material of the front. Type C breccias, of which there are only three documented samples, are also considered to represent Apennine front material, differing from type B mainly in the proportion of coarse-grained feldspathic clasts and in the intrusive relation of matrix and clasts in type C. Accordingly, rocks underlying the Apennine front are thought to be breccias whose clasts are mainly coarse-grained feldspathic rocks and nonmare-type basalts in varying proportions.

The distribution of rock types (Fig. 6) reveals an unexpected abundance of nonmare-type rocks on the mare surface, especially around the LM site and station 9. The best samples of mare basalts were obtained from two craters (Elbow and Dune) that penetrated through the regolith on the mare and from the rille edge, where the regolith is very thin or absent. Much of the mare surface, where sampled, is covered by a ray that contributed an unknown quantity of foreign material to the surface. Furthermore, the area is bounded on two sides by high mountains composed at least partly of breccias; the downslope movement of material and lateral transport both tend to contaminate the mare surface. The North Complex, on a third side of the area, may also contribute breccias to the mare surface (*2*). These features, combined with the general lack of large craters on the mare surface, tend to enhance the contamination of the surface by foreign debris.

A distinctive feature of the breccias collected from the Apennine front is the lack of the multiple brecciation that is so well displayed in the Apollo 14 samples. This strongly suggests that the Apollo 15 crew sampled a level of the lunar crust that is lower and thus less reworked than that sampled during the Apollo 14 mission.

APOLLO LUNAR GEOLOGY INVESTIGATION TEAM*

References and Notes

1. M. H. Carr and F. El-Baz, in *Miscellaneous Geological Investigations Map I-723* (U.S. Geological Survey, Washington, D.C., 1971), p. 1.
2. K. A. Howard, *ibid.*, p. 2.
3. R. Greeley, *Science* **172**, 722 (1971).
4. K. A. Howard, unpublished data.
5. G. G. Schaber and J. W. Head, "Surface operational map of the Apennine-Hadley landing site, Apollo 15" (open-file report, U.S. Geological Survey, Washington, D.C., 1971).
6. D. E. Wilhelms and J. F. McCauley, *Miscellaneous Geological Investigations Map I-703* (U.S. Geological Survey, Washington, D.C., 1971).
7. Work done under NASA contract T-65253-G. Published by permission of the director, U.S. Geological Survey.
* This paper is based on the report submitted by the Apollo Lunar Geology Investigation Team to the National Aeronautics and Space Administration for inclusion in the Preliminary Science Report for Apollo 15. Contributors to the report are G. A. Swann, N. G. Bailey, R. M. Batson, V. L. Freeman, M. H. Hait, H. E. Holt, K. B. Larson, V. S. Reed, G. G. Schaber, R. L. Sutton, and E. W. Wolfe (U.S. Geological Survey, Flagstaff, Arizona); K. A. Howard and H. G. Wilshire (U.S. Geological Survey, Menlo Park, California); J. W. Head (Bellcomm, Inc., Washington, D.C.); J. B. Irwin and D. R. Scott (NASA Manned Spacecraft Center, Houston, Texas); W. R. Muehlberger (University of Texas, Austin); and L. T. Silver and J. J. Rennilson (California Institute of Technology, Pasadena). Information on rock types was supplied by the Lunar Sample Preliminary Examination Team [see *Science* **175**, 363 (1972)]. The authors assume full responsiblity for the categories of rock types as presented here and for all interpretations concerning the samples.

9 November 1971

Chemistry, Geochronology, and Petrogenesis of Lunar Sample 15555

Abstract. *Lunar sample 15555 is a mare type basalt generally similar in chemical composition to the Apollo 12 basalts. Sample 15555 is older than any Apollo 12 basalt but younger than the Apollo 14 basalts analyzed thus far.*

Data are given for rock 15555, the largest sample yet returned from the moon, collected at the edge of Hadley Rille during the third period of extravehicular activity on the Apollo 15 mission. Sample 15555 is thought to be a fragment of very locally derived bedrock (*1*). It is an equigranular basalt containing olivine, plagioclase, and pyroxene in the size range from 0.3 to 1 mm (*1*). We received a 0.56-g chip of sample 15555 for major element analysis. Since 0.3 g was sufficient for that purpose, we decided to use the remainder for microprobe analyses of minerals and for an isotopic age-determination by the Rb-Sr method (*2*).

The results of a chemical analysis of the major elements of sample 15555 are given in Table 1. Data were obtained by x-ray spectrometry (except for Na), as for earlier lunar samples (*2*). Sample 15555 was thus seen to be a mare type basalt, generally similar in composition to Apollo 12 basalts. Its content of ($MgO + FeO$) and all other single components and its content of normative olivine resemble those of sample 12020. However, the MgO/FeO ratio of sample 15555 is lower than that of the Apollo 12 basalts, with 100 $Mg/(Mg + Fe)$ equal to 44.3 for sample 15555 as compared with 53.5 for sample 12020. All Apollo 12 samples containing normative olivine have appreciably higher Mg/Fe ratios than sample 15555; those with low Mg/Fe ratios (for example, samples 12038 and 12052) have lower contents of total ($MgO + FeO$) and normative quartz and higher contents of alkalies. These results independently suggest crystal fractionation (*3*). Such is not the case for sample 15555.

After the sample was washed and screened, we separated 0.12 g in the 75- to 150-μm size range into the mineral concentrates shown in Table 2 by hand-picking various density fractions. Every mineral sample is a different concentrate; so, except for the total rock, there was no expectation of close agreement in the Rb and Sr concentrations between the A and B samples. The "ilmenites" both contain of the order of 50 percent ilmenite, both as free grains and as composites with pyroxene. The chemical processing and mass spectometry tech-

Table 1. Chemical analysis of rock 15555.

Component	Percentage (by weight)
SiO_2	43.82
TiO_2	2.63
Al_2O_3	7.45
FeO	24.58
MnO	0.32
MgO	10.96
CaO	9.22
Na_2O	0.24
K_2O	0.04
P_2O_5	0.07
S	0.06
Cr_2O_3	0.59
Total	99.98
$O \equiv S$	0.03
Total	99.95

Table 2. Isotope dilution analyses for Rb, Sr, and $^{87}Sr/^{86}Sr$ of rock 15555 and its mineral concentrates; ppm, parts per million; σ, standard deviation.

Component	Weight (mg)	Rb (ppm)	Percent blank correction $\pm \sigma$	Sr (ppm)	Percent blank correction	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$ $\pm \sigma$
Total A	10.0	0.68	3.5 ± 1.6	89.7	<0.1	0.0220	0.70042 ± 5
Total B	11.0	.72	3.1 ± 1.4	91.7	< .1	.0226	.70062 ± 10
Plagioclase A	6.3	.22	15.0 ± 6.9	295.5	< .1	.0022	.69960 ± 5
Plagioclase B	4.0	.20	23.4 ± 10.8	390.9	< .1	.0015	.69933 ± 4
Ilmenite A	5.7	1.22	3.5 ± 1.6	38.1	.32	.0927	.70402 ± 10
Ilmenite B	5.9	0.93	4.4 ± 2.0	31.2	.38	.0867	.70372 ± 5
Pyroxene A	11.0	.26	8.0 ± 3.7	17.8	.35	.0426	.70158 ± 5
Pyroxene B	12.0	.34	5.8 ± 2.7	20.2	.28	.0483	.70180 ± 5

Table 3. Mineral analyses of rock 15555, showing the extremes of compositional ranges found in the grain mounts for each mineral species.

Component	Ilmenite	Spinel	Olivine	Olivine	Pigeonite	Subcalcic ferroaugite	Plagioclase	Plagioclase	Glass
SiO_2	0.27		36.39	29.99	52.93	46.68	47.39	49.91	83.31
TiO_2	51.91	30.92		0.13	0.24	1.12	0.07	0.10	0.48
Al_2O_3		1.83			0.65	0.99	33.12	31.12	10.72
FeO	45.5	58.38	33.04	64.27	19.61	32.30	0.28	0.71	0.64
MnO	0.46	0.43	0.36	0.79	0.38	0.47			
MgO	0.45	0.90	29.63	3.88	20.82	4.86	0.15	0.11	
CaO			0.25	0.39	4.75	13.07	18.13	16.44	2.15
Na_2O							0.99	1.42	0.37
K_2O							0.04	0.27	1.66
Cr_2O_3	0.47	6.90	0.21	0.08	0.51	0.13			
V_2O_3		0.12							
Total	99.06	99.48	99.88	99.53	99.89	99.62	100.17	100.08	99.33

niques used were similar to those already described (*3*).

The analytical data (Table 2) define an isochron of $3.63 \pm 0.14 \times 10^9$ years (95 percent confidence) if plagioclase A is excluded, or $3.54 \pm 0.13 \times 10^9$ years if it is not (Fig. 1). The regression analysis marginally indicates a "perfect" fit for all points, and so the latter estimate is preferred. The precision of the isochron is mainly limited by variability in the Rb processing blank, which becomes increasingly important with the smaller samples. However, the present precision is adequate to permit one to clearly distinguish the age of rock 15555

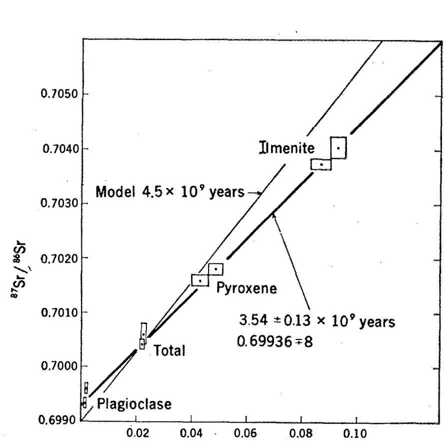

Fig. 1. Isochron diagram for total rock and mineral separates from sample 15555. The rectangles represent the 95 percent confidence limits for each analysis.

as older than that of any basalts from the Apollo 12 site, but younger than all the basalts reported so far from Apollo 14. Our data do not conclusively distinguish rock 15555 in age from the Apollo 11 basalts, but it appears slightly younger.

Mineral analyses for rock 15555 are given in Table 3. The most magnesian olivine compositions are Fo_{61} (61 mole percent forsterite); yet the experimental data on Apollo 12 basalts are adequate to show that the liquidus olivine for this rock composition would be $Fo_{72 \pm 2}$, and an olivine of Fo_{61} composition would become stable only in this composition at temperatures of 1140° ± 10°C, at which stage the liquid would be quartz-normative and crystallizing olivine plus pyroxene, with plagioclase appearing at about that temperature (*4*). It is possible that rock 15555 was a fractionated lava into which ~ 20 percent olivine ($\geqq Fo_{61}$) ± pigeonite accumulated at a temperature of ~ 1140°C. The proposed origin is similar to that suggested for samples 12022 and 12040, but for these examples the added olivine was ~ Fo_{67} and ~ Fo_{74}, respectively.

We have carried out calculations designed to test whether the subtraction of olivine ($\geqq Fo_{61}$) and pigeonite from rock 15555 would yield liquid compositions analogous to those of Apollo 12 basalts such as samples 12021 or 12065, that is, quartz-normative, iron-rich liquids crystallizing olivine close to Fo_{61} composition. These calculations show that no simple relationship exists between the analyzed Apollo 12 basalts and rock 15555. However, it remains possible that rock 15555 contains added olivine and pyroxene, locally concentrated during the cooling of a parent magma. This parent magma would be slightly different from the parent magmas of the sampled Apollo 11 and Apollo 12 rocks, but clearly of the mare type, in contrast to "highland basalts," such as sample 14310.

B. W. CHAPPELL

Department of Geology, Australian National University, Canberra, Australia

W. COMPSTON

D. H. GREEN, N. G. WARE

Department of Geophysics and Geochemistry, Australian National University

References

1. National Aeronautics and Space Administration Lunar Receiving Laboratory report on Sample 15555 (1971).
2. W. Compston, B. W. Chappell, P. A. Arriens, M. J. Vernon, "Proceedings of the Apollo 11 Lunar Science Conference," *Geochim. Cosmochim. Acta* **2** (Suppl. 1), 1007 (1970).
3. W. Compston, H. Berry, M. J. Vernon, B. W. Chappell, M. J. Kaye, "Proceedings of the Second Lunar Science Conference," *Geochim. Cosmochim. Acta* **2** (Suppl. 2), 1471 (1971).
4. D. H. Green, A. E. Ringwood, N. G. Ware, W. O. Hibberson, A. Major, E. Kiss, *ibid.* **1**, 601 (1971).

19 November 1971