SEARCHING FOR RARE HIGHLAND IGNEOUS ROCKS AT APOLLO 14: FRAGMENTS OF MAGNESIAN-SUITE ASSEMBLAGES. BRADLEY L. JOLLIFF, DEPARTMENT OF EARTH AND PLANETARY SCIENCES & MCDONNELL CENTER FOR THE SPACE SCIENCES, WASHINGTON UNIVERSITY, ST. LOUIS, MO 63130.

Most of the rocks returned from the Apollo 14 landing site were impact melt breccias. A statistical survey of lithic fragments in an Apollo 14 soil revealed only some 8% or less to be pieces of monomict lithologies [1]. Many of these have relatively alkaline mineral assemblages characterized by plagioclase An contents less than 80–85% and a few percent or more of modal K-feldspar. From the Apollo 14 sample collection, only about 20 subsamples, mainly clasts extracted from impact breccias, have been characterized as igneous, monomict, magnesian-suite rocks [2]. In this abstract, modal mineralogy and mineral compositions are given for four possibly pristine, monomict samples for which only the bulk compositions as determined by INAA, and in one case, phosphate compositions, have been previously reported [1,3]. The four assemblages are 14161,7037 norite, 14161,7076 gabbronorite, 14161,7080 norite, and 14161,7350 magnesian anorthosite. Three of the four have elevated REE concentrations due to accessory whitlockite, but other incompatible trace elements are not in proportionately high concentrations relative to Apollo 14 KREEP (impact-melt breccias [1,4]). Mineral compositions within each of the four samples are quite uniform, indicating that they are monomict; all except ,7076 were listed in the compilation of [2] as possibly pristine. Sample 14161,7037 has an unusual mineral assemblage in that it contains a trace of sphene (cf. [5]) mantling troilite, vanadian rutile, and regions of silica-K-feldspar granophyre and pyroxene-plagioclase vermicular intergrowths. The residual melt of this assemblage appears to have reached the field of silicate-liquid immiscibility after some 98% crystallization, yet the bulk assemblage has low incompatible-trace-element (ITE) concentrations. An unanswered question is whether igneous rocks from the Apollo 14 site come from mantle-derived intrusions into the crust or from the differentiation of early, thick, basin-impact melt sheets. Ages for most of the igneous samples, where determined, exceed 4.0 billion years, so they predate the major known basins. The samples described in this abstract have significantly different mineral assemblages and compositions from one another, and they have incompatible-element enrichments different from those of "Apollo 14 KREEP" [1,4]. Thus, it appears likely that they derive from mutually unrelated, endogenous intrusions into the pre-basin upper crust of the Moon.

Descriptions of textures. Sample 14161,7037 is a monomict breccia with a fragmental matrix. It has a cataclastic texture dominated by orthopyroxene and plagioclase clasts typically ranging up to ~300 μm, but one mass of nearly monomineralic orthopyroxene spans 2 mm and constitutes about a third of the thin section. Orthopyroxene contains thin, oriented (exsolved) chromite needles. Scattered in several different locations are 100–200 μm silica–K-feldspar granophyric intergrowths and clinopyroxene-plagioclase-silica vermicular intergrowths. Compositions of plagioclase and pyroxene suggest that these intergrowths belong to the noritic assemblage, but resulted from crystallization of late-stage residual liquid as that liquid reached a field of immiscibility. Troilite occurs in several small grains in the thin section; in one, it is mantled by sphene (Table 6), possibly a result of late-stage sulfidization and replacement of ilmenite (?). Other accessory minerals include chromite and vanadian rutile.

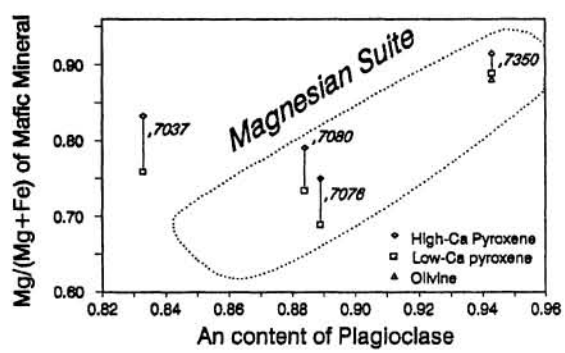
Sample 14161,7076 is also a cataclastic, monomict breccia, consisting mainly of hypersthene, augite, plagioclase, and accessory olivine, ilmenite, troilite, and zircon. Neither alkali feldspar nor whitlockite were found in thin section, but the bulk Ba concentration of 725 ppm and REE concentrations of ~100 × chondrites [1] indicate that they were present in the sample. Plagioclase and pyroxene form clasts and monomineralic "stringers" up to ~0.75 mm, but generally, they are finely crushed. Thin exsolution lamellae are observed in pyroxenes. This sample bears compositional similarities to magnesian alkali-gabbronorite [6] from sample 67975.

Sample 14161,7080 norite has been highly shocked such that all of its feldspars are maskelynite (isotropic). Low-Ca pyroxene constitutes about half of the mode (Table 1) and occurs in heavily fractured masses up to about 0.8 mm across. Only a few grains of augite occur in the thin section, and K-feldspar glass occurs as thin wisps in plagioclase glass and in one separate 50 μm mass. Whitlockite forms cataclastic masses reaching ~100 μm across; no apatite was found in the section. The sample contains a trace of troilite and Fe-Ni metal.

Sample 14161,7350 is a highly magnesian, olivine-bearing anorthositic assemblage. The thin section consists mostly of coarse, highly fractured plagioclase split by an ~300 μm zone of crushed olivine, low-Ca pyroxene, and diopside. Bulk REE concentrations of ~100–300 × chondrites are due to a composite apatite-whitlockite grain several hundred μm across [3].

Table 1. Modal mineralogy of magnesian-suite lithic fragments from sample 14161 (weight percent).

	,7037	,7076	,7080	,7350
mass (mg)	20.7	10.3	15.6	11.8
Plagioclase	36.9	57.5	42.0	87.9
Low-Ca Pyroxene	59.4	28.2	49.4	0.5
High-Ca Pyroxene	1.7	14.2	6.0	1.0
Total Pyroxene	61.1	42.4	55.4	1.5
Olivine		0.5		7.7
Apatite	tr			1.0
Whitlockite		tr	0.5	0.9
Ilmenite		tr		
K-feldspar	1.0	tr	2.0	1.0
silica	0.5			
zircon		tr		tr
spinel	tr			
sphene	tr			
troilite	tr	tr	tr	



IGNEOUS SAMPLES FROM APOLLO 14: JOLLIFF B. L.

Through surveys of lithic fragments in soil samples, which are polymict materials, we continue to find new samples of rare lunar rock types that allow us to effectively sample broad areas of the Moon and better understand its lithologic diversity. Developments in micro-analytical techniques such as the ion microprobe and mass-spectrometry of plugs removed from thin sections by micro drill make small, monomict samples such as those identified and characterized by our INAA survey a scientifically valuable part of the lunar sample collection.

Acknowledgments. Funding for this work was through NASA grant NAGW-3343.

Table 2. Feldspar compositions of magnesian-suite igneous lithic fragments from sample 14161.

	,7037 Plag coarse n=6	,7037 Plag fine n=2	,7037 Plag late* n=2	,7037 K-feld Avg n=2	,7076 Plag Avg n=7	,7080 Maskel Avg n=8	,7080 K-feldspar Gls 1 n=1	,7080 K-feldspar Gls 2 n=3**	,7350 Plag Avg n=8
	Chemical Composition (Weight Percent)								
SiO2	46.55	47.10	53.30	62.26	45.97	45.76	65.26	62.73	44.19
Al2O3	33.68	33.01	29.62	19.02	35.32	34.63	19.02	19.77	35.11
FeO	0.14	0.26	0.05	0.04	0.16	0.21	0.08	0.32	0.04
MgO	0.03	0.04	0.05	0.02	0.12	0.04	0.00	0.00	0.05
CaO	16.94	16.32	12.60	0.11	17.64	17.72	0.69	0.20	19.20
BaO	0.00	0.00	0.06	3.81	0.03	0.03	1.57	3.65	0.03
Na2O	1.78	2.01	3.87	0.19	1.17	1.15	1.00	0.99	0.61
K2O	0.13	0.16	0.36	14.09	0.07	0.18	13.32	12.35	0.04
Total	99.26	98.90	99.90	99.54	100.48	99.73	100.94	100.0	99.27
	Cation Formula based on 8 Oxygens								
Si	2.155	2.186	2.415	2.947	2.104	2.114	2.983	2.932	2.058
Al(IV)	1.838	1.806	1.581	1.061	1.905	1.885	1.025	1.089	1.927
Sum	3.993	3.992	3.996	4.008	4.009	3.998	4.007	4.021	3.985
Fe(2+)	0.005	0.010	0.002	0.002	0.006	0.008	0.003	0.013	0.002
Mg	0.002	0.003	0.003	0.002	0.008	0.003	0.000	0.000	0.003
Ca	0.841	0.811	0.611	0.006	0.865	0.877	0.034	0.010	0.958
Ba	0.000	0.000	0.001	0.071	0.001	0.001	0.028	0.067	0.001
Na	0.160	0.181	0.340	0.017	0.103	0.103	0.089	0.089	0.055
K	0.008	0.010	0.021	0.851	0.004	0.011	0.777	0.736	0.002
Sum	1.016	1.014	0.979	0.948	0.988	1.003	0.930	0.915	1.021
	Molecular Proportions of Anorthite (An), Albite, Orthoclase (Or), and Celsian (Cs)								
An	83.3	81.0	62.8	0.6	88.9	88.4	3.6	1.1	94.3
Ab	15.9	18.0	34.9	1.8	10.6	10.4	9.6	9.9	5.4
Or	0.8	0.9	2.2	90.1	0.41	1.1	83.8	81.6	0.2
Cn	0.0	0.0	0.10	7.5	0.06	0.06	3.0	7.4	0.1

* In vermicular intergrowth with pyroxene and adjacent silica-K-feldspar granophyre.
** Oxide sums exceded 100 by several percent, so each was normalized before averaging.

Table 3. Pyroxene compositions of magnesian-suite igneous lithic fragments from sample 14161.

	14161,7037 OPX n=5	14161,7037 Aug n=3	14161,7076 OPX n=5	14161,7076 Aug n=5	14161,7080 OPX n=17	14161,7080 Aug n=3	14161,7350 OPX n=1	14161,7350 Diop n=4
	Chemical Composition (Weight Percent)							
SiO2	53.93	53.60	52.67	51.75	53.18	51.76	56.51	52.67
TiO2	0.70	0.50	0.76	1.32	0.93	1.26	0.51	1.10
Al2O3	0.45	0.61	0.75	1.78	1.05	1.46	0.82	1.57
Cr2O3	0.62	0.42	0.28	0.68	0.46	0.57	0.40	0.56
FeO	15.43	5.68	19.26	9.30	16.58	7.63	7.32	2.92
MnO	0.21	0.10	0.27	0.26	0.23	0.15	0.16	0.07
MgO	27.17	15.95	23.94	15.55	25.75	16.16	33.23	17.56
CaO	1.17	22.22	1.84	19.68	1.88	20.95	1.37	23.07
Na2O	0.01	0.15	0.00	0.16	0.01	0.16	0.00	0.11
Total	99.69	99.24	99.78	100.48	100.07	100.10	100.32	99.62
	Cation Formula Based on 6 Oxygens							
Si	1.958	1.984	1.949	1.918	1.938	1.918	1.960	1.928
Al(IV)	0.019	0.016	0.033	0.078	0.045	0.064	0.034	0.068
Sum T-site	1.977	2.000	1.982	1.996	1.983	1.982	1.994	1.996
Al(VI)	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.000
Ti	0.019	0.014	0.021	0.037	0.025	0.035	0.013	0.030
Cr	0.018	0.012	0.008	0.020	0.013	0.017	0.011	0.016
Fe(2+)	0.468	0.176	0.596	0.288	0.505	0.236	0.212	0.089
Mn	0.007	0.003	0.008	0.008	0.007	0.005	0.005	0.002
Mg	1.470	0.880	1.321	0.859	1.399	0.893	1.718	0.958
Ca	0.045	0.881	0.073	0.782	0.073	0.832	0.051	0.905
Na	0.001	0.011	0.000	0.011	0.001	0.011	0.000	0.008
Sum M1,M2	2.028	1.988	2.028	2.006	2.024	2.029	2.011	2.008
	Cation Ratio Mg/(Mg+Fe) and Molecular Proportions of Wollastonite (Wo), Enstatite (En), and Ferrosilite (Fs)*							
Mg/(Fe+Mg)	0.76	0.83	0.69	0.75	0.73	0.79	0.89	0.91
Wo	2.2	43.4	3.7	38.1	4.1	40.8	2.9	44.4
En	74.2	47.1	66.3	46.4	70.4	46.8	86.4	50.8
Fs	23.6	9.4	29.9	15.5	25.4	12.4	10.7	4.7

* corrected for "others" (<2%)

Table 4. Phosphate Compositions.

	,7037 Apat n=1	,7350 Apat n=17	,7080 Whit n=6	,7350 Whit n=6
	Chemical Composition (Weight Percent)			
P2O5	41.1	41.55	43.66	43.17
SiO2	0.30	0.28	0.06	0.24
Al2O3	0.04	<0.02	0.17	0.00
FeO	0.22	0.04	0.85	0.17
MnO	0.04	<0.01	0.01	0.02
MgO	0.08	0.10	3.36	3.60
CaO	55.69	54.98	41.90	39.52
Na2O	0.02	0.01	0.59	0.23
Y2O3	0.10	0.14	2.04	3.09
La2O3	<0.02	0.06	0.83	1.14
Ce2O3	0.04	0.16	2.10	3.16
Nd2O3			1.35	1.96
Yb2O3			0.09	0.17
Other REE	0.06	0.13	1.69	2.31
F	2.97	3.32		
Cl	0.80	0.71		
Total	101.42	101.50	98.72	98.75
- O = F	1.25	1.40		
- O = Cl	0.18	0.16		
Total	99.99	99.94	98.72	98.75
	Apatite Formula based on 12.5 Ox		Whitlockite based on 56 Oxygens	
P	2.942	2.973	13.901	13.918
Si	0.025	0.024	0.021	0.091
Sum(Tet)	2.967	2.997	13.923	14.010
Al	0.004	0.000	0.077	0.000
Fe(2+)	0.016	0.003	0.266	0.054
Mn	0.003	0.001	0.005	0.006
Mg	0.010	0.013	1.886	2.041
Ca	5.049	4.978	16.886	16.126
Na	0.003	0.001	0.434	0.166
Y+Ln(3+)	0.007	0.017	1.218	1.807
Sum Other	5.092	5.012	20.772	20.201
F	0.796	0.887		
Cl	0.114	0.102		
sum F,Cl	0.910	0.989		
Mg/(Fe+Mg)	0.39	0.82	0.88	0.97

Notes: (1) Apatite ,7037 "other REE" estimated from Y, Ce.
(2) Apatite ,7350 REE determined by ion microprobe [3].
(3) Whitlockite ,7080 "other REE" estimated from Y, La, Ce, Yb.
(4) Whitlockite ,7350 REE determined by ion microprobe [3].

Table 5. Olivine in 14161,7350.

	Oliv n=2
Composition (Wt. %)	
SiO2	39.91
TiO2	0.02
Al2O3	0.01
Cr2O3	0.04
FeO	11.55
MnO	0.13
MgO	48.04
CaO	0.05
Na2O	0.00
Total	99.76
Cation Formula Based on 4 Oxygens	
Si	0.989
Ti	0.000
Cr	0.001
Fe(2+)	0.240
Mn	0.003
Mg	1.775
Ca	0.001
Na	0.000
Sum Oct.	2.021
Mg/(Fe+Mg)	0.881
Molecular Proportions	
Fayalite	11.9
Forsterite	88.0
Ca2SiO4	0.1

Table 6. Spinel and chromite compositions in 14161,7037.

	Sphene n=2	Chromite n=1
SiO2	30.06	0.05
TiO2	38.99	2.20
Al2O3	0.64	6.24
Cr2O3	0.54	57.04
FeO	0.47	30.62
MnO	0.09	0.32
MgO	0.09	2.86
CaO	27.47	0.06
Na2O	0.01	0.00
Total	98.36	99.39
Cation formula based on:	5 Ox.	4 Ox.
Si	0.998	0.002
Al(VI)	0.025	0.262
Ti	0.974	0.059
Cr	0.014	1.606
Fe(2+)	0.013	0.912
Mn	0.002	0.010
Mg	0.005	0.152
Ca	0.977	0.002
Na	0.001	0.000
Sum Other	2.011	3.003
Mg/(Fe+Mg)	0.255	0.143

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