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ANALYSES OF APOLLO 11 AND 12 ROCKS AND SOILS BY NEUTRON ACTIVATION

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ABSTRACT

New analyses of Apollo 11 and 12 rocks made by INAA for Na, Mn, Dy, Sm, Lu, La, Yb, Ce, Eu, Tb, Sc, Hf, Cr, Co, Fe, Ti and Ta, and by x-ray fluorescence for Ca, together with radiochemical results for Au, Ag and Mo and fission track U determinations for Apollo 12 rocks are reported. The excess of Au and Ag in soil relative to rocks reported by Ganapathy, Keays, and Anders is confirmed and contamination of a LRL processed rock for Au, Ag and Mo clearly indicated.

The Apollo 12 rocks and samples of regolith sent to us were analyzed using the methods described before for the Apollo 11 materials (Turekian and Kharkar, 1970). Several improvements were made, however, to correct some of the difficulties encountered in our earlier work. The problems of resolution and drift in the analyzer were corrected so that proper background and interference corrections could be made. All samples were processed in a laminar flow hood in a limited access clean room far from the ambient contamination of our general laboratories. X-ray fluorescence assays for Fe, Ti, and Ca were made. The Fe and Ti concentrations so determined were in excellent agreement with the INAA (Instrumental Neutron Activation Analysis) results. The calcium determinations are new in this program.

Because of these improved techniques we reran all the Apollo 11 samples previously reported as well as an additional sample of Apollo 11 "soil" received after the initial work. These results are also presented and supercede our earlier work.

The results of our analyses are presented in Table 1.

The uranium results for the Apollo 11 samples are the same as those

in Turekian and Kharkar. Because there was an indication that our Apollo 11 samples, opened and processed in our earliest work, may have become contaminated, we did not think it advisable to determine Au, Ag and Mo in these samples again. Since the Apollo 12 samples were processed in much more stringently clean areas we believe results on Au, Ag and Mo are not subject to major contamination effects.

Under any conditions it is clear that rock 12021,98 crushed and homogenized at the Lunar Receiving Laboratory is considerably higher in Au, Ag and Mo relative to the other rocks indicating the probability of contamination there when extensive processing has occurred.

Silver and gold have also been reported for Apollo 12 rocks and soils by Ganapathy, Keays and Anders (1970). For the one common sample analyzed, soil 12070, they report 2.39 ppb Au to our 3.23 ppb and 46 ppb Ag to our 78 ppb. We consider this to be reasonable agreement considering that there is some major doubt of <u>any</u> homogeneity for soil samples. Our averages for A and B rocks (ignoring the LRL processed sample) are Au: 0.067 ppb compared to 0.013 for Ganapathy, Keays and Anders; and <1 ppb Ag compared to their 0.81 ppb average. Our average soil values

are 2.87 ppb Au compared to Ganapathy, Keays and Anders' 2.03 ppb and 71 ppb Ag compared to their 5.4 ppb (ignoring their high values of which 12070 is one). Although differences exist between our two sets of analyses they clearly both speak to the excess of Ag and Au in lunar soil relative to lunar rock. The comparisons for Mo are less sure but the data show no recognizable differences among the rocks and soils analyzed except for the highly contaminated 12021 processed at the LRL.

The differences and similarities between the Apollo 11 and 12 rocks and soils have been well stated by the Preliminary Report (The Lunar Sample Preliminary Examination Team, 1970).

Our results are totally compatible with these results. We defer a detailed discussion of lunar surface rock and soil composition in terms of models of origin to a later time.

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Table 1: The composition of Apollo 11 and Apollo 12 rocks and soils.[1]

Sample	Type	Na	Na	%Ca	%Ca	Mn	Mn	%Fe	%Fe	%Ti	%Ti	La	La
10084,57	Soil D	3116±60 3118±61	3142	9.44±.16 8.49±.20	8.97	1587±12 1589±12	1588	11.74±.20 12.44±.20	12.09	4.44±.08 4.00±.08	4.22	17.61±.45 17.33±.45	17.47
10084,139	Soil D	3100±70 3108±68	3104	9.26±.15 8.62±.15	8.94	1588±14 1612±12	1600	10.97±.19 11.41±.18	11.19	4.34±.04 4.31±.04	4.33	16.13±.44 15.88±.44	16.00
10044,27	Vesicular basalt A	3630±66 3630±65	3630	8.19±.15 9.98±.15	9.09	1941±13 1935±13	1938	13.35±.20 13.75±.20	13.55	4.76±.03 5.48±.04	5.12	10.43±.33 10.52±.33	10.48
10049,33	Vesicular basalt A	3800±72 3750±72	3775	8.33±.10 7.07±.12	7.70	1738±12 1732±12	1735	13.64±.18 13.74±.21	13.69	6.98±.04 6.36±.05	6.67	23.89±.45 25.28±.45	24.59
10057,79	Vesicular basalt A	4050±70 4050±71	4050	7.40±.15 8.28±.14	7.84	1781±13 1775±13	1778	13.94±.20 14.97±.22	14.46	7.80±.08 6.79±.08	7.30	22.63±.50 23.56±.50	23.10
10020,27	Gabbro B	2700±70 2680±71	2690	9.55±.10 7.91±.15	8.73	1958±14 1952±14	1955	13.09±.20 14.27±.22	13.68	6.35±.08 5.22±.06	5.79	6.67±.34 6.56±.34	6.62
10056,21	Gabbro B	2800±65 2827±64	2814	9.53±.15 8.24±.12	8.89	2070±16 2063±16	2067	13.06±.20 13.19±.20	13.13	4.98±.07 5.16±.07	5.07	11.95±.27 10.57±.27	11.26
10062,25	Gabbro B	2995±62 3000±62	2998	9.09±.12 7.53±.13	8.31	2023±17 2016±18	2020	14.25±.15 13.67±.15	13.96	6.91±.08 6.81±.08	6.86	11.21±.28 11.73±.27	11.47
10021,33	Breccia C	3470±60 3472±61	3471	9.77±.15 9.37±.15	9.57	1582±11 1577±11	1580	12.14±.15 12.33±.15	12.24	5.54±.08 5.04±.08	5.29	17.82±.45 17.73±.45	17.78
10046,24	Breccia C	3720±65 3680±65	3700	8.73±.14 8.95±.15	8.84	1636±13 1631±13	1634	12.13±.20 12.13±.15	12.13	5.29±.07 5.54±.07	5.42	18.36±.50 18.80±.47	18.58

Table 1 (continued):

Sample	Type	Ce	Ce	Sm	Sm	Eu	Eu	Dy	Dy	Tb	Tb	Yb	Yb
10084,57	Soil D	39.41±2.00 40.00±2.00	39.71	9.01±.26 9.01±.27	9.01	1.90±.11 2.20±.11	2.05	23.22±3.28 19.54±2.96	21.38	2.50±.32 2.50±.32	2.50	8.37±.66 8.44±.61	8.41
10084,139	Soil D	38.52±2.10 38.52±2.10	38.52	9.91±.27 9.90±.27	9.91	1.81±.10 2.18±.11	2.00	20.13±3.05 21.45±2.91	20.79	2.47±.34 2.49±.32	2.48	8.72±.60 8.36±.60	8.54
10044,27	Vesicular basalt A	37.21±2.00 38.00±2.00	37.61	11.43±.21 11.42±.21	11.43	2.83±.10 3.18±.10	3.00	27.45±3.54 27.78±3.24	27.62	3.90±.32 3.88±.31	3.89	10.87±.75 9.96±.75	10.42
10049,33	Vesicular basalt A	70.67±3.00 71.60±3.00	71.14	15.65±.25 15.65±.25	15.65	2.00±.10 2.22±.10	2.11	31.61±4.00 29.49±3.43	30.55			14.08±.75 14.36±.75	14.22
10057,79	Vesicular basalt A	68.39±3.00 70.70±3.00	69.55	14.27±.24 14.27±.23	14.27	2.27±.11 2.44±.11	2.36	33.30±4.25 26.52±3.32	29.91			13.16±.74 13.17±.74	13.17
10020,27	Gabbro B	25.00±2.00 24.80±2.00	24.90	9.50±.26 9.50±.22	9.50	1.17±.10 1.67±.10	1.42	18.22±2.54 16.31±2.27	17.27	2.60±.33 2.62±.33	2.61	6.66±.60 6.39±.62	6.53
10056,21	Gabbro B	33.18±2.50 32.24±2.50	32.71	11.06±.20 11.05±.20	11.06	.08±.15 3.06±.16	3.07	30.75±3.98 32.27±3.74	31.51			10.67±.70 10.23±.70	10.45
10062,25	Gabbro B	37.00±2.50 38.10±2.50	37.55	8.73±.20 8.72±.20	8.73	2.34±.11 1.97±.11	2.16	24.34±3.44 24.87±3.49	24.61			7.84±.60 7.81±.61	7.83
10021,33	Breccia C	48.07±3.00 48.50±3.00	48.29	11.13±.25 11.27±.24	11.20	1.90±.15 1.85±.14	1.88	22.36±3.00 19.35±2.50	20.86	3.10±.30 3.10±.30	3.10	10.08±.60 9.75±.60	9.92
10046,24	Breccia C	52.31±3.00 52.31±3.00	52.31	9.91±.26 9.48±.22	9.70	1.95±.10 2.11±.11	2.03	22.14±2.98 17.61±2.47	19.88			9.74±.55 10.74±.60	10.24

Table 1 (continued):

Sample	Type	Lu	Lu	Sc	Sc	Hf	Hf	Ta	Ta	Cr	Cr	Co	Co
10084,57	Soil D	1.64±.06 1.63±.06	1.64	68.05±.36 68.79±.37	68.42	10.84±.99 10.84±.99	10.84	1.11±.30 1.49±.31	1.30	1988±185 2152±201	2070	33.88±.51 33.90±.63	33.89
10084,139	Soil D	1.62±.07 1.71±.08	1.67	72.30±.36 66.03±.36	69.17	10.24±.93 10.24±.94	10.24	1.28±.30 1.54±.30	1.41	2423±206 1841±172	2132	34.00±.54 34.20±.60	34.10
10044,27	Vesicular basalt A	2.06±.08 2.15±.08	2.11	100.00±.40 100.74±.40	100.37	13.68±1.21 14.33±1.26	14.00	1.50±.25 1.55±.26	1.53	1416±132 1419±132	1418	12.84±.46 13.00±.47	12.92
10049,33	Vesicular basalt A	2.60±.08 2.56±.09	2.58	86.77±.39 86.15±.40	86.46	17.34±1.44 17.34±1.45	17.34	1.97±.24 1.91±.23	1.94	2107±196 2082±194	2095	22.25±.52 22.88±.52	22.57
10057,79	Vesicular basalt A	2.45±.09 2.50±.09	2.48	87.46±.41 91.83±.41	89.65	17.25±1.44 18.86±1.56	18.06	1.35±.24 1.94±.24	1.65	2257±210 2328±217	2293	25.90±.53 25.90±.57	25.90
10020,27	Gabbro B	1.48±.05 1.42±.06	1.45	88.52±.40 94.03±.40	91.28	7.85±.83 8.62±.90	8.24	1.08±.30 1.14±.30	1.11	2258±211 2449±228	2354	17.56±.47 18.00±.48	17.78
10056,21	Gabbro B	2.17±.07 1.91±.06	2.04	99.05±.41 100.18±.40	99.62	14.94±1.29 17.62±1.48	16.28	1.65±.30 1.94±.30	1.80	1393±130 1369±128	1381	11.54±.46 11.58±.46	11.56
10062,25	Gabbro B	1.83±.07 1.62±.05	1.73	87.32±.36 85.28±.40	86.30	12.68±1.13 11.16±1.04	11.92	1.99±.30 1.41±.31	1.70	1691±158 1629±152	1660	13.61±.44 12.03±.42	12.82
10021,33	Breccia C	2.94±.09 1.91±.07	2.23	71.82±.41 72.86±.41	72.34	14.00±1.20 12.81±1.11	13.41	1.77±.32 1.77±.29	1.77	2068±193 2138±199	2103	26.32±.51 28.26±.53	27.29
10046,24	Breccia C	1.90±.08 1.95±.08	1.93	72.31±.40 72.31±.39	72.31	12.71±1.11 14.09±1.21	13.40	1.41±.25 1.41±.25	1.41	2137±199 2165±202	2151	27.60±.52 26.93±.60	27.27

Table 1 (continued):

Sample	Type	Na	Na	%Ca	%Ca	Mn	Mn	%Fe	%Fe	%Ti	%Ti	La	La
12070,80	Fines D	3372±64 3450±67	3411	8.56±.15 8.20±.15	8.38	1654±11 1634±13	1644	12.21±.20 11.96±.20	12.09	2.27±.04 2.03±.04	2.15	33.42±.45 33.29±.54	33.36
12044,20	Fines D	3379±69 3342±81	3357	8.63±.15 9.49±.10	9.06	1718±12 1705±14	1712	12.15±.20 12.30±.20	12.23	2.58±.04 2.30±.04	2.44	32.98±.47 32.34±.52	32.66
12001,46	Fines D	3347±105 3425±108	3386	8.25±.15 8.54±.14	8.40	1619±11 1617±11	1618	12.36±.07 12.31±.07	12.34	2.18±.03 2.35±.04	2.27	31.85±.42 32.13±.47	31.99
12021,98	Crushed & homogenized B	2025±54 1999±65	2027	7.94±.14 8.09±.10	8.02	1984±12 2078±14	2031	14.78±.08 14.59±.08	14.66	2.66±.04 2.37±.04	2.52	6.36±.18 6.16±.28	6.26
12052,54	Rock A	1844±77 1887±80	1866	7.99±.15 7.99±.15	7.99	1980±12 1990±12	1985	14.74±.08 14.68±.08	14.71	2.40±.04 2.14±.04	2.27	6.64±.17 6.82±.29	6.73
12009,41	Rock A	1827±78 1869±80	1848	7.18±.15 6.74±.15	6.96	2040±13 2144±;5	2092	15.40±.08 15.49±.09	15.45	2.17±.04 2.40±.04	2.29	5.25±.15 5.81±.22	5.53
12020,41	Rock A	1460±59 1495±61	1478	5.58±.15 5.62±.15	5.60	2061±13 2119±15	2068	15.76±.09 15.94±.09	15.85	2.08±.03 2.25±.04	2.17	5.01±.16 5.06±.21	5.04
120063,116	Rock A	2077±50 2125±52	2101	7.03±.10 7.09±.10	7.06	2040±13 2166±16	2103	15.66±.26 15.56±.25	15.61	3.02±.05 2.69±.04	2.86	5.39±.17 5.63±.30	5.51

Table 1 (continued):

Sample	Type	Ce	Ce	Sm	Sm	Eu	Eu	Dy	Dy	Tb	Tb	Yb	Yb
12070,80	Fines D	74.48±3.00 74.00±3.00	74.24	15.00±.12 15.10±.14	15.05	1.80±.11 1.79±.11	1.80	27.44±3.43 26.04±3.55	26.74	3.26±.30 3.25±.30	3.26	12.77±.75 12.86±.78	12.82
12044,20	Fines D	70.98±3.00 71.87±3.16	71.43	15.23±.12 14.96±.13	15.10	1.80±.11 1.84±.11	1.82	27.45±3.53 26.04±3.64	26.75	3.25±.27 3.23±.29	3.24	12.46±.76 12.19±.73	12.33
12001,46	Fines D	71.00±3.00 70.00±3.00	70.50	15.31±.11 15.12±.12	15.22	1.82±.11 1.81±.11	1.82	25.22±3.18 23.93±3.29	24.57	3.00±.20 3.13±.29	3.07	12.49±.73 12.77±.75	12.63
12021,98	Crushed & homo-genized B	50.00±2.00 48.00±2.00	49.00	3.24±.08 4.13±.06	3.69	1.39±.11 0.99±.10	1.19	14.68±2.19 13.93±3.12	14.31	1.79±.35 1.79±.34	1.79	4.34±.34 4.45±.39	4.40
12052,54	Rock A	45.00±2.00 44.50±2.00	44.75	3.99±.05 3.09±.09	3.54	1.16±.10 1.16±.10	1.16	14.61±2.23 13.86±2.25	14.24	1.78±.34 1.78±.35	1.78	3.18±.36 4.14±.33	3.66
12009,41	Rock A	36.00±2.00 40.00±2.00	38.00	3.32±.05 2.98±.07	3.15	0.86±.09 0.79±.09	0.83	15.18±2.37 14.41±2.38	14.80	1.75±.33 1.78±.35	1.77	3.28±.29 3.54±.33	3.41
12020,41	Rock A	40.00±2.00 43.00±2.00	41.50	2.97±.05 2.69±.07	2.83	0.71±.09 0.89±.09	0.80	14.58±2.38 13.83±2.38	14.21	1.73±.32 1.75±.31	1.74	3.30±.29 3.25±.32	3.28
120063,116	Rock A	44.50±2.00 44.50±2.00	44.50	3.99±.09 3.82±.09	3.91	1.09±.11 1.22±.11	1.16	14.89±2.61 14.13±2.59	14.51	1.53±.32 1.75±.32	1.64	4.94±.43 5.61±.39	5.28

Table 1 (continued):

Sample	Type	Lu	Lu	Sc	Sc	Hf	Hf	Ta	Ta	Cr	Cr	Co	Co
12707,80	Fines D	1.75±.06 1.75±.07	1.75	39.30±.12 40.08±.12	39.69	14.02±1.00 14.40±1.00	14.21	1.83±.36 1.76±.34	1.80	2446±61 2355±65	2401	43.49±.73 41.56±.71	42.53
12044,20	Fines D	1.72±.06 1.79±.07	1.76	40.43±.12 40.84±.12	40.64	14.56±1.04 14.00±1.00	14.28	1.97±.36 1.96±.36	1.97	2410±69 2409±75	2410	41.36±.70 42.03±.71	41.70
12001,46	Fines D	1.66±.06 1.71±.06	1.69	38.49±.11 38.87±.11	38.68	13.99±.97 13.44±.91	13.72	2.00±.39 1.93±.36	1.97	2418±90 2443±75	2431	40.64±.50 40.17±.48	40.41
12021,98	Crushed & homogenized B	0.82±.04 0.84±.04	0.83	55.46±.15 55.30±.15	55.38	4.25±.53 4.23±.51	4.24	0.83±.25 0.75±.24	0.79	2413±50 2367±62	2390	30.57±.56 33.96±.61	32.27
12052,54	Rock A	0.84±.04 0.93±.04	0.89	51.90±.14 53.36±.15	52.63	4.05±.49 4.42±.52	4.24	1.01±.26 0.75±.24	0.88	3124±68 3161±67	3143	38.49±.64 40.58±.69	39.54
12009,41	Rock A	0.85±.04 0.86±.04	0.86	45.76±.13 45.78±.13	45.77	3.65±.47 4.25±.50	3.95	0.56±.22 0.54±.21	0.55	4336±89 4326±90	4331	51.89±.86 52.84±.87	52.37
12020,41	Rock A	0.75±.03 0.86±.04	0.81	44.04±.13 43.30±.13	43.67	3.60±.46 3.50±.47	3.55	0.44±.21 0.67±.23	0.56	4157±87 4177±87	4167	56.84±.93 58.58±.96	57.71
120063,116	Rock A	0.92±.04 1.09±.05	1.00	57.75±.16 58.57±.16	58.16	4.01±.52 4.94±.56	4.48	0.63±.24 0.60±.23	0.62	2700±57 2702±57	2701	40.49±.71 42.30±.73	41.40

Table 1 (continued):

Sample	Type	U	U	Mo + U	(Mo)	Au (ppb)		Ag (ppb)	
12070,80	Fines	1.15±.06	1.12	1.21±.12	.06	3.66	3.23	78	78.5
	D	1.08±.05		1.29±.13	.21	2.80		79	
12044,20	Fines	1.36±.07	1.36			2.50	2.54	79	79.0
	D	1.36±.07				2.57		--	
12001,46	Fines	1.25±.06	1.23	1.34±.13	.09	3.03	2.85	42	56.5
	D	1.20±.06		1.42±.14	.22	2.67		71	
12021,98	Crushed & homogenized B	0.31±.02	0.30	0.81±.08	.50	1.00	0.89	256	274.0
		0.29±.02		0.76±.08	.47	0.78		292	
12052,54	Rock	0.31±.02	0.29	0.35±.03	.04	0.07	0.075	<1ppb	<1
	A	0.27±.02		0.33±.03	.06	0.08		<1ppb	
12009,41	Rock	0.25±.02	0.24	0.38±.04	.13	0.05	0.055	<1ppb	<1
	A	0.23±.02		0.35±.04	.12	0.06		<1ppb	
12020,41	Rock	0.26±.02		0.39±.04	.13	0.09	0.085	<1ppb	<1
	A			0.36±.04		0.08		<1ppb	
12063,116	Rock	0.20±.02		0.28±.03	.08	0.05	0.050	<1ppb	<1
	A			0.24±.02		0.05		<1ppb	

Table 1 (continued):

[1] The coefficients of variation based on the pooled estimates of duplicate analyses are as follows:

Na 2.2%; Mn 2.3%; Dy 4.7%; Sm 8.7%; Lu 5.7%; Sc 1.1%; Hf 7.7%; Cr 1.0%; Co 3.5%; Fe 0.9%; La 2.7%; Yb 6.1%; Ce 2.9%; Eu 8.8%; Tb 2.4%; Ti 9.0%; Ca 3.0%; Au 12%; Ag 19%; Ta 11%; U 5.0%. The errors shown after each number are solely the counting errors.

[2] The uranium concentrations for the Apollo 11 materials, as reported in our previous study, are valid here. They are (in ppm):

10084,57 (0.29); 10044,27 (0.41); 10049,33 (0.74); 10057,79 (0.47); 10020,27 (0.22); 10056,21 (0.35); 10062,25 (0.28); 10021,33 (0.39); 10046,24 (0.69).