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Final Report on
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ORIGIN OF MOON AND METEORITE INFLUX RATE

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ELEMENTS DEPLETED ON LUNAR SURFACE: IMPLICATIONS FOR
ORIGIN OF MOON AND METEORITE INFLUX RATE*

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Abstract. Compared to terrestrial basalts and eucrite meteorites, Apollo 11 and 12 basalts are consistently depleted in siderophile elements (Ir, Pd, Ag, Au) and volatile elements (Zn, Cd, In, Tl, Bi, Br), by factors of 10^{-1} to 10^{-2} . The depletion of siderophiles suggests that the Earth and Moon segregated their metal and silicate in two discrete events, contrary to the fission hypothesis. Moreover, if the Earth-eucrite pattern is typical of independently-formed planetary bodies, the greater depletion of the Moon speaks against an independent origin, as required by the capture hypothesis. The depletion of volatiles implies that the Moon either formed at higher temperatures (510°K vs. 470°K for the Earth and eucrites), or had a 100-fold lower growth rate in the terminal stages of accretion. This might be expected if it formed in the Earth's neighborhood.

The coarse-grained, 13-cm layer of core 12028 shows extreme enrichment in Bi and Cd (38 and 22 ppm), some 10^3 to 10^5 times the content of Apollo 11 and 12 crystalline rocks and soil. Such material must be rare on the Moon, judging from the low Bi content of all soil and breccia samples examined to date. Sample 12013, on the other hand, seems to represent a more abundant rock type. Relative to Apollo 12 basalts, it is enriched in Rb, Cs, Tl, Zn, and Cd by factors of up to 10^2 . About 10-20% of such material is required to account for the high Rb, Cs, and Cd content of nine Apollo 12 soils. Rock 12013 fits various trace element correlations for Apollo 11, 12 rocks, which suggests a close genetic relationship to mare basalts, and a local rather than highland origin.

All soil and breccia samples are enriched in elements thought to be largely of meteoritic origin: Ag, Au, Bi, Br, Cd, Ir, Te, Tl, and Zn. The enrichment pattern in most samples is dominated by material of C1 chondrite composition, probably micrometeorites of cometary origin. The average abundance is 1.9% C1 material or equivalent, and the average meteorite influx rate is 4×10^{-9} g cm⁻² yr⁻¹. Soil samples collected on crater rims, and some Apollo 12 breccias, show a smaller amount of meteoritic material, of less primitive composition. Apparently Bench, Head, and Surveyor Craters at the Apollo 12 site were made by ordinary chondrites or irons. An anorthosite sample from Apollo 11 soil shows a similar pattern.

The meteoritic elements in Apollo 11 soil dissolve preferentially upon HNO₃ treatment. Apparently they are located for the most part in small grains or on surfaces.

The glassy exterior of rock 12017 is enriched in "meteoritic" elements (Au, Br, Cd, Ir, etc.) relative to the interior. Apparently the glass represents molten material splashed onto the rock from a crater, not a glazing made in place by a solar outburst, as proposed by Gold.

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We have measured 15 trace elements in lunar samples, using neutron activation analysis procedures described previously (Keays et al., 1971). Results on Apollo 12 samples are shown in Table 1. Some of these have already been published (Ganapathy et al., 1970a; Laul et al., 1970; Morgan et al., 1970). We have also analyzed several Apollo 11 samples since our last publication (Ganapathy et al., 1970b). These results are given in Table 2.

Crystalline Rocks: Siderophile Elements. Figure 1 compares lunar rocks with calcium-rich achondrites (Laul et al., to be published) and terrestrial basalts. The last three, siderophile elements are about equally abundant in terrestrial basalts, eucrites, and the Angra dos Reis meteorite, but are less abundant by some two orders of magnitude in lunar rocks. Very likely the Ca-rich achondrites come from the asteroid belt, not the Moon, and thus give us information on smaller bodies and more remote parts of the solar system (Heymann et al., 1968; Taylor and Epstein, 1970; McCord et al., 1970). The similarity of the terrestrial and meteoritic patterns thus suggests that siderophile elements were removed with equal efficiency during planetary differentiation in bodies a few hundred to a few thousand km in radius, between 1 and ~ 2.5 a.u. from the sun. If the terrestrial-meteoritic pattern is typical of independently-formed planetary bodies, the greater depletion of the Moon suggests some unique circumstance during its formation, perhaps proximity to the Earth. In any case, the singular pattern of the Moon is hard to reconcile with the capture hypothesis.

The contrast between the lunar and terrestrial patterns speaks against the fission hypothesis, as already noted in our earlier paper (Ganapathy et al., 1970b). If the Moon had lost its siderophiles while still part of the Earth, it should show a terrestrial siderophile pattern.

Crystalline Rocks: Volatile Elements. Apart from occasional deviations by rock 12013 (inverted triangles), the first four, volatile elements in Figure 1 show consistently greater depletion in the Moon and eucrites than in terrestrial basalts. This is also true of Tl, not shown here. Presumably these elements were left behind in the solar nebula during accretion. Thallium in lunar rocks correlates with alkali metals and uranium, even in rock 12013 (Laul et al., 1970), and since these elements largely concentrate in the crust during planetary differentiation, fairly reliable estimates of whole-planet abundances can be obtained from element ratios. Volatilities increase in the order $U < Cs < Tl$. For the Earth, Moon, and eucrites Tl/Cs and Tl/U ratios (both normalized to C 1 chondrites = 1) are: 0.25, 0.018, 0.17, and 2.7×10^{-2} , 2.7×10^{-4} , 8.5×10^{-4} .

For the interpretation of these numbers, it is necessary to know how the volatiles were acquired. Two limiting cases may be considered within the framework of the Larimer and Anders (1967) model.

(1) If temperatures remained constant throughout accretion, the volatile content reflects both the proportion of low-temperature to high-temperature material and the accretion (or equilibration) temperature of the low-temperature material. The Cs/U (or K/U) ratio probably indicates the overall content of low-temperature material, and the Tl/Cs ratio, the accretion temperature. Average temperatures derived from Tl/Cs, Bi/Cs, and In/Cs ratios are: Earth $470^\circ K$, Moon $510^\circ K$, eucrites $470^\circ K$, all for a total nebular pressure of 10^{-4} atm.

These are similar to the accretion temperatures of L-chondrites, which range from 460-560°K (Keays et al., 1971). If the total pressure were 10^{-2} or 10^{-6} atm, these temperatures would be raised by 80 to 100° or lowered by 60 to 80°.

(2) If the nebula cooled during accretion, the bulk of the volatiles would be acquired only toward the end, when temperatures had fallen low enough to permit their condensation. In the most extreme case, the volatiles may have been brought in entirely during the final stages of accretion, as a thin veneer of carbonaceous-chondrite-like material (Turekian and Clark, 1969). The nominal mass fraction of such material is equal to the Tl/U ratio, i.e., Earth 2.7%, Moon 0.027%, eucrites 0.085%.

A higher accretion temperature of the Moon, as derived in case (1), suggests a distant origin and might thus be regarded as an argument in favor of the capture theory. However, from the data available it seems that the temperature gradient in the inner solar nebula was essentially flat between 1 and ~2.5 a.u. For dynamical reasons, the capture theory requires that the Moon initially was in an Earth-like orbit, with semi-major axis close to 1 a.u. It does not seem likely that a temperature difference of 40° could have developed over so short a distance. We therefore believe that case (2) is closer to the truth, the lower volatile content of the Moon reflecting a lower accretion efficiency in the terminal stages of growth rather than a higher formation temperature.

We have previously suggested that a lower accretion efficiency might reflect accretion of the Moon in the Earth's neighborhood (Ganapathy et al., 1970b). Singer and Bandermann (1970) have shown, however, that nothing like the required difference in accretion rate can develop in the absence of gas. The lower capture cross section arising from the orbital motion of the satellite is more than offset by the increasing concentration of dust in the neighborhood of the central planet. However, it is generally believed that gas was present during accretion, and this could radically alter the situation.

Rocks 12013 and 12008. We have already discussed our results on rock 12013 in a separate publication (Laul et al., 1970). As far as our 15 elements are concerned, this rock fits in well among the ordinary Apollo 11,12 basalts. It shows a typical lunar abundance pattern, quite unlike the terrestrial or tektite pattern. Its description as "tektite glass" by O'Keefe (1970) therefore seems inappropriate, as already noted by King et al. (1970). The enrichment of Rb, Cs, and U in Apollo 12 soils compared to A,B rocks seems to be due to admixture of 10-20% material similar to 12013. This, too, suggests that 12013 represents a fairly abundant, local rock type rather than a chance fragment of highland origin. Data on 12013 enabled us to recognize a correlation between Cd and alkalis in lunar rocks, which seems to have no parallel on Earth (Laul et al., 1970).

The ilmenite-rich rock 12008 shows no noteworthy compositional trends, at least insofar as the elements measured by us are concerned.

Cores 12025 and 12028. The 13-cm layer of core 12028 contains very little meteoritic material, but is spectacularly enriched in Bi and Cd, by factors of 10^4 to 10^5 . We have already discussed the implications of this observation (Ganapathy et al., 1970a). One significant conclusion is that the turnover rate of the regolith

must be orders of magnitude slower than previously estimated, because we saw no evidence for vertical spreading of the Bi-, Cd-rich layer. This conclusion is supported by subsequent analysis of a sample from near the top of the core (12025,72). It shows only a very slight enrichment of Cd and Bi, 10^{-3} and 10^{-4} times the content of the 13-cm layer. However, our argument loses much of its force if the Bi-, Cd-rich material analyzed by us is an atypical freak, rather than a representative sample of a widespread material.

Meteoritic Component. All Apollo 12 soils and breccias are enriched in elements thought to be largely of meteoritic origin: Ag, Au, Bi, Br, Cd, Ir, Te, and Zn. We have once again attempted to characterize the composition of the meteoritic component by subtracting the average composition of AB rocks (with 15% 12013) from the gross abundances in soils and breccias. The most informative elements are Ir, Au, and Bi (Figure 2).

Two types of pattern show up. Contingency soil 12070 shows the flat pattern characteristic of primitive meteorites (C 1,2 or E 3,4), which had previously been seen in Apollo 11 soils and breccias. Again, a meteoritic component equivalent to about 1.8% C 1 material seems to be present. Soils 12032, 12037, 12033, and breccia 12073 show a step pattern characteristic of differentiated meteorites (irons or ordinary chondrites). The enrichment of Bi is much less than that of Ir and Au, and may in fact be zero within the uncertainty of the correction for indigenous lunar Bi. And the amount of meteoritic material is only about one-half that in the other samples: 0.9% to 1% C 1 equivalent (corresponding to 0.86% L chondrites, 0.60% H chondrites, or 0.17% group 1 irons).

The abundance pattern alone is not sufficient to establish the exact nature of the meteoritic material in the last four samples. However, a further clue can be obtained from cratering theory. From the equations of Öpik (1961) we find that the above percentages of meteoritic material correspond to impact velocities of 8, 11, and 24 km/sec for the three types of projectiles. A velocity as high as 24 km/sec is fairly improbable for an iron meteorite, although a single iron meteor with $V_G = 30$ km/sec has been observed (Ceplecha, 1966). On the other hand, velocities of 8 and 11 km/sec for chondrites are close to the mean geocentric velocity for stony meteorites, 14 km/sec (Millman, 1969, and earlier references cited therein).

All three soil samples that showed a "differentiated" meteorite pattern were collected on crater rims, whereas those showing a "primitive" pattern were taken at greater distances. Apparently the soil far away from craters is heavily contaminated with micrometeorite material of C 1 composition, that falls on the lunar surface in a steady rain. Material on crater rims is less contaminated, and still shows the abundance pattern of the projectile. The effect disappears at distances of only a few tenths of a crater diameter from the rim. Three samples associated with Surveyor Crater illustrate this sequence. Breccia 12073, part of the contingency sample, has a pronounced "differentiated" pattern, with no detectable meteoritic Bi. It may be an uncontaminated ejectum formed mainly from bedrock, not soil. The lower (31 and 37 cm) layers of core 12028 still show a vestigial step pattern, while the upper layers and the contingency soil sample already display a C 1 pattern.

It thus seems that all three major craters at the Apollo 12 landing site were made by differentiated meteorites, probably ordinary chondrites.

Anorthosite. Two anorthosite samples from Apollo 11 soil showed very low alkali contents, coupled with an enrichment of meteoritic elements. The meteoritic component cannot be accurately characterized because the composition of the non-meteoritic component is not known. However, uncorrected data for sample 10085,107-1 show Ag/Au and Ag/Ir ratios of only 13 to 15% the C 1 value. Corrections for non-meteoritic Au and Ir are almost certainly negligible, and thus any correction for Ag will only make the ratios smaller. Evidently the meteoritic component in anorthosite was less primitive than C 1 chondrites. Irons or ordinary chondrites appear suitable, as they have Ag/Au and Ag/Ir ratios some 3 to 10% the C 1 value.

The highlands regolith must contain planetesimal debris from the final stages of the Moon's accretion. However, we cannot determine from the present data whether the meteoritic component in our anorthosite samples represents this exceedingly interesting material, or merely the remains of a more recent projectile.

Glass-Coated Rock 12017. As we reported elsewhere (Morgan et al., 1970), the glassy coating of this rock is enriched in meteoritic elements (Ir, Au, Ag, Zn, Cd, Br, and Bi), in proportions implying addition of $0.5 \pm 0.1\%$ C 1 material. The glazing seems to represent splashed-on ejecta from a nearby impact, not in situ melting by a sudden increase in solar luminosity as proposed by Gold (1969). However, Gold's hypothesis applies specifically to rocks located in small craters; we do not know whether rock 12017 was found in such a crater. (See also Science 168, 608-611, 1970.)

Acid Leaching of Soil. In order to learn more about the physical and chemical state of the meteoritic component, we treated a 482-mg sample of Apollo 11 soil with HNO_3 according to Silver's (1970) procedure (Table 2). All the meteoritic elements (Ir, Au, Zn, Cd, Ag, Bi, Tl) showed substantial solubility ($>15\%$) in the first acid leach. However, the separation was not clear-cut; several elements of non-meteoritic or mixed origin were also enriched in the first fraction. Whereas most of the meteoritic elements showed up in their customary (C 1) proportions in the first two fractions, corresponding to 0.5 and 0.4% C 1 material, Zn, Cd, and Pb^{204} (Silver, 1970) were present in 2 to 7 times greater amounts. Apparently lunar Zn, Cd, and Pb reside largely in acid-soluble phases. This must also be true of the clearly non-meteoritic U and Th, which appear in the first leach fraction in significant amounts (Silver, 1970). Cs and Rb, on the other hand, show only slight acid solubility, and this seems to be true of lunar Tl as well. Judging from Tl/Au, Tl/Ir, and Tl/Cs ratios, the first three fractions contained mainly meteoritic Tl, and the residue a mixture of lunar and meteoritic Tl.

The high acid-solubility of the meteoritic elements is not surprising, because much of the meteoritic material appears to be present as small particles or surface coatings. We had previously shown that these elements were enriched in the finest (~ 325 mesh) size fraction of the soil (Ganapathy et al., 1970b), while Barber et al. (1970) have recently observed micron-sized particles with high track densities, which appear to be meteoritic. Moreover, some part of the meteoritic material must be present as vapor-deposited surface coatings on larger grains.

Other Apollo 11 Samples. Compositionally our sample of 10017 resembles a breccia. We are investigating the possibility of a sample mixup. Sample 10047,65, consisting of fragments, gave much lower abundances for many elements than a powdered sample of the same rock (10047,32) distributed by LRL. This confirms our suspicion that the powder was heavily contaminated during preparation at LRL. Another powdered sample, 12038,57 (Table 1) also gave suspiciously high results. We believe that the practice of powdering lunar samples at LRL should be discontinued, as it results in severe contamination.

We were not able to confirm the high Au values of 8.7 ppb and 1.6 ppb for 10017 and 10057 (Wänke et al., 1970). Our values were one to two orders of magnitude lower (Table 2). A recheck of 10072,23 gave a far more reasonable Ir value (0.022 ppb) than our earlier result (4.02 ppb) which we had attributed to contamination.

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Table 1. Abundances in Apollo 12 Lunar Samples^a

Sample Number	Type ^b	Ir (ppb)	Au (ppb)	Zn (ppm)	Cd (ppb)	Ag (ppb)	Bi (ppb)	Tl (ppb)	Br (ppb)	Te ^c (ppb)	Se (ppb)	Ga (ppm)	Rb (ppm)	Cs (ppb)	In (ppb)	Co (ppm)	Ref.
12002,126	B	0.62	0.024	0.70	1.4	0.81	1.4	0.25	10	10	141	2.4	0.97	39	1.9	-	1
12008,11	AB Ilm.	0.06	0.074	1.04	1.3	1.17	0.26	0.34	11		139	3.2	0.62	28	28	60	
12017,17	AB Int.	0.20	0.072	1.02	1.1	1.45	0.25	0.34	16		156	2.9	1.06	45	2.0	32	2
12017,20	AB Glass	2.64	1.23	3.30	5.4	2.81	0.59	0.88	49		182	3.3	2.30	87	5.1	44	2
12038,57	A Powder	0.04	0.36	2.09	5.2	80	0.76	0.76	10		120	4.3	0.41	15	77	25	
12040,28	B	0.17	0.012	0.78	3.3	0.41	0.03	0.06	4		58	1.9	0.29	13	0.4	54	
12051,45	AB	0.09	0.008	0.52	1.2	0.82	0.53	0.36	16	10	201	4.6	1.03	40	2.0	-	1
12051,45	AB	0.54	0.007	0.54	1.1	0.80	-	0.37	16	16	204	4.3	1.06	42	1.2	-	1
12065,35	AB	0.078	0.013	0.93	-	1.37	0.30	0.53	22		200	3.8	1.15	67	2.2	43	
12065,35	AB	≤0.05	0.011	0.67	1.2	-	-	-	-	-	180	-	1.05	49	-	42	
Average ^d	AB	0.104	0.034	0.81	1.59	1.00	0.50	0.31	13		149	3.3	0.97	41	2.2	43	
12013,10,06	High-K	4.6	3.10	4.10	34	31.4	0.63	1.9	114		99	6.4	13.5	820	380	31	3
12013,10,15	High-K	0.047	0.21	2.06	91	0.88	0.46	18	26		54	6.3	66.5	2670	32	16	3
12013,10,18	High-K	0.72	0.46	1.94	44	0.68	0.55	18	48		30	5.9	49.4	2280	2.9	21	3
12013,10,35	High-K	0.19	13.2	3.04	40	3.80	0.52	7.2	54		75	6.0	26.7	1260	3.9	27	3
12013,10,37+24	High-K	0.50	2.37	2.85	64	3.49	1.04	18	47		68	6.0	50.0	2370	2.8	34	3
12013,10,41	High-K	10.0	0.45	2.21	300	0.44	≤0.9	34	40		420	5.9	98.7	4030	6.6	34	3
12013,10,44	High-K	0.84	0.34	2.44	24	1.17	0.55	4.8	36		40	6.0	20.7	1010	3.1	21	3
Average ^e	High-K	0.434	0.353	2.77	71	1.65	0.60	12.8	58		94	6.1	42	1900	3.7	26	
12010,22 ^f	C	2.7	0.82	7.96	34	3.70	0.32	4.3	130		193	4.1	8.75	255	7.0	38	
12073,37	C	4.5	1.98	6.49	19	2.73	0.46	2.8	130		186	4.5	9.24	385	6.5	35	
Average	C	3.6	1.40	7.22	26	3.2	0.39	3.6	130		190	4.3	9.0	320	7	36	

Table 1. Abundances in Apollo 12 Lunar Samples (continued)

Sample Number	Type ^b	Ir (ppb)	Au (ppb)	Zn (ppm)	Cd (ppb)	Ag (ppb)	Bi (ppb)	Tl (ppb)	Br (ppb)	Te ^c (ppb)	Se (ppb)	Ga (ppm)	Rb (ppm)	Cs (ppb)	In (ppb)	Co (ppm)	Ref.
12025,72	Core	1.7	5.9	2.53	6.11	70	28	3.53	2.2	140	215	3.9	6.0	254	77	39	
12028,66	Core	13.2	0.08	0.63	1.47	22000	301	38500	0.26	16	86	2.7	0.32	23	42	-	1
12028,90	Core	18.9	8.1	1.65	5.1	53	140	2.1	0.51	141	80	5.2	8.6	345	294	-	1
12028,121	Core	31.2	8.7	2.07	5.4	48	3.6	1.2	2.2	124	30	5.0	9.0	359	9.2	-	1
12028,145	Core	37.2	9.2	2.01	4.3	49	7.2	1.4	2.3	116	90	5.2	10.8	342	25.6	-	1
12032,33	D	3.9	3.9	1.50	6.45	26	3.43	0.63	2.5	180	200	5.1	7.6	400	9	34	
12032,33	D	4.6	1.43	4.97	16	-	-	-	-	-	190	-	7.5	374	-	43	
12033,20	D	3.9	1.64	5.06	27	7.45	0.30	2.1	130	164	164	4.7	8.0	380	24	26	
12033,20	D	4.4	1.38	4.88	22	-	-	-	-	185	-	-	8.6	424	-	41	
12037,25	D	3.5	1.57	6.33	-	5.14	0.72	5.2	140	190	190	3.4	5.0	200	27	49	
12037,25	D	5.0	1.50	5.88	35	-	-	-	-	219	-	-	5.1	280	-	60	
12057,78	D	5.0	5.72	6.92	34	43	1.63	1.7	100	188	188	3.5	5.1	215	1280	125	
12070,69	D	8.5	2.39	6.9	45	46	2.4	1.6	123	100	259	4.3	6.3	248	218	-	1
Average ^g	D	6.45	2.32	5.72	42	9.14	1.70	2.26	133	217	217	4.52	7.44	310	9	58	
BCR-1	Terr. Bas.	0.012	0.84	118	124	31.5	46	278	-	95	95	22	45	890	91	36	
BCR-1	Terr. Bas.	4.0	0.41	116	127	26.3	49	290	31	94	94	21	46	925	96	35	3
BCR-1	Terr. Bas.	0.06	-	130	120	25.5	46	282	60	85	85	22	46	900	88	37	
BCR-1	Terr. Bas.	0.05	0.35	108	140	-	-	-	-	95	95	-	47	910	-	-	

^aDoubtful values are shown in italics. They include all of the higher In and Ag values (contamination from vacuum gaskets in sample containers and LRL); most results on 12038,57 (powder prepared at LRL) and a few unusually high Ir and Au values, where contamination during cutting or handling was suspected.

^bDepths given for core samples represent nominal distances from top of core tube (LSPET, 1970). These are smaller than the true depths, owing to compression during sampling (Carrier III et al., 1970). For comparison, the estimated true depths (cm) are given in parentheses: 1.7-2.5 (2.0-2.8); 13.2-14.4 (17.8-19.4); 18.9-19.7 (25.8-26.9); 31.2-32.2 (44.5-46.2); 37.2-38.2 (55.6-57.2).

^cTe samples are being recycled, because of possible Se contamination. Numbers given here are preliminary.

^dExcluding Ir, Au, Zn, Cd, Ag, Bi, Tl, and Br in 12017,20 which appear to be largely of meteoritic origin.

^eExcluding Ir and Au in 12013,10,06 which appear to be largely of meteoritic origin.

^fAppears to be borderline case between crystalline rock and breccia (LSPET, 1970).

^gExcluding 12028,66 which consists mainly of fragments of crystalline rock.

References: 1. Ganapathy et al. (1970a); 2. Morgan et al. (1971); 3. Laul et al. (1970).

Table 2. Abundances in Apollo 11 Lunar Samples

Sample Number	Type	Ir (ppb)	Au (ppb)	Zn (ppm)	Cd (ppb)	Ag (ppb)	Bi (ppb)	Tl (ppb)	Br (ppb)	Se (ppb)	Ga (ppm)	Rb (ppm)	Cs (ppb)	Ref.
10017, 87	AB		0.72	20	60	16	1.15	6.16	190	215	5.1	6.6	186	
10047, 65	B Fragments		0.029	1.9	2.7	1.89	0.16	0.28	29	250	-	1.54	60	
10047, 32	B Powder	0.240	0.33	5.76	255	24.7	2.15	0.57	133	-	5.35	1.25	44.6	1
10057, 41	A	0.009	0.013	1.75	3.5	-	-	-	-	181	-	-	-	
10057, 41	A	0.023	0.017	1.71	3.15	0.69	0.27	1.09	25.2	-	13.5	3.68	159	1
10072, 23	A	0.022	0.10	1.72	14	-	-	-	-	188	-	-	-	
10072, 23	A	4.02	0.14	1.81	6.5	17.3	0.73	0.92	36	-	4.73	5.98	159	1
10084, 49-4 ^a	D	1.73	0.76	7.3	29	2.36	0.90	0.29	-	-	0.35	0.08	3.4	
10084, 49-5 ^a	D	1.74	0.77	3.4	6	1.78	0.22	0.27	-	-	0.74	0.15	5.9	
10084, 49-6 ^a	D	0.82	0.52	3.6	4	1.77	0.20	0.30	-	-	1.30	0.25	8.2	
10084, 49-7 ^a	D	3.80	0.72	6.6	5	3.05	0.24	0.74	-	143	2.48	2.50	86	
10084, 49-S ^a	D	8.1	2.77	21	44	8.96	1.56	1.60	-	-	4.87	2.98	103	
10084, 49	D	7.4	2.72	19	49	8.56	1.68	1.69	90	326	4.80	2.80	97	
10084, 49, 1-1 ^b	D Anorth.	3.3	1.06	2.2	17	1.65	0.59	0.28	47	90	4.60	1.75	74	
10085, 107-1 ^c	D Anorth.	3.6	1.47	1.5	9	0.49	0.42	0.61	42	29	3.20	0.70	24	
BCR-1	Terr. Bas.	0.01	0.44	116	123	26.3	48	270	-	90	22	47	930	

^aSubsamples of 10084, 49 used in HNO₃ leaching experiment, according to the procedure of Silver (1970): 4 -

stirred 15 min at 25°C, centrifuged 15 min; 5 - stirred 30 min at 70°C, centrifuged 15 min; 6 - stirred 7 hr at

70°C, centrifuged 1 hr; 7 - Residue, fused with NaOH-Na₂O₂; S - Sum of fractions 4 to 7. All abundances were calculated relative to original weight of sample, 481.8 mg.

^b21.4 mg of light fragments, hand-picked by Mrs. J. Morgan from a >100 mesh fraction of 10084, 49 soil.

^c5 anorthosite fragments totalling 41.1 mg from 1-10 mm fraction of fines; hand-picked at LRL.

Reference: Ganapathy *et al.* (1970b).

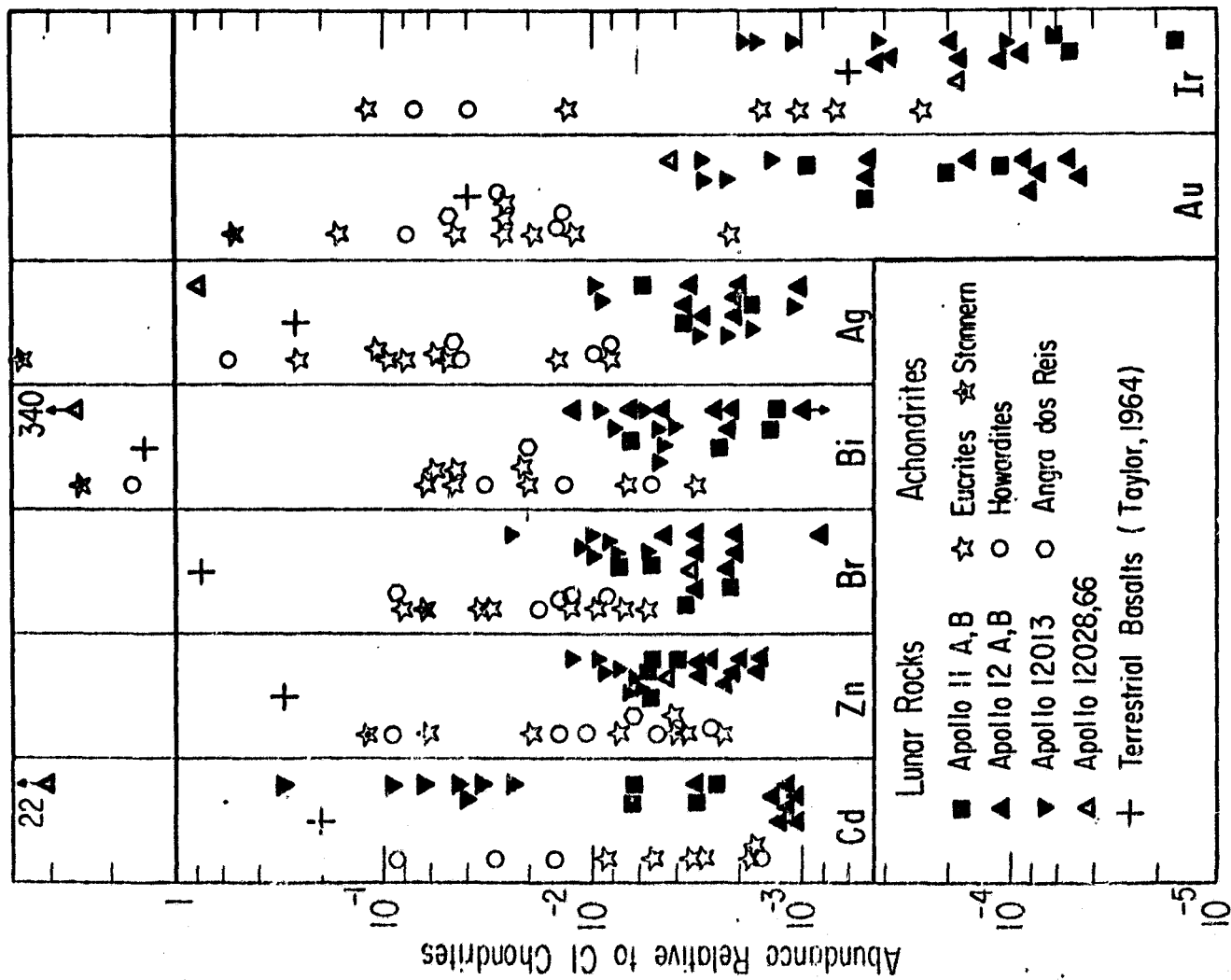


FIGURE 1. Abundance of 7 trace elements in Apollo 12 crystalline rocks and calcium-rich achondrites. See text for discussion.

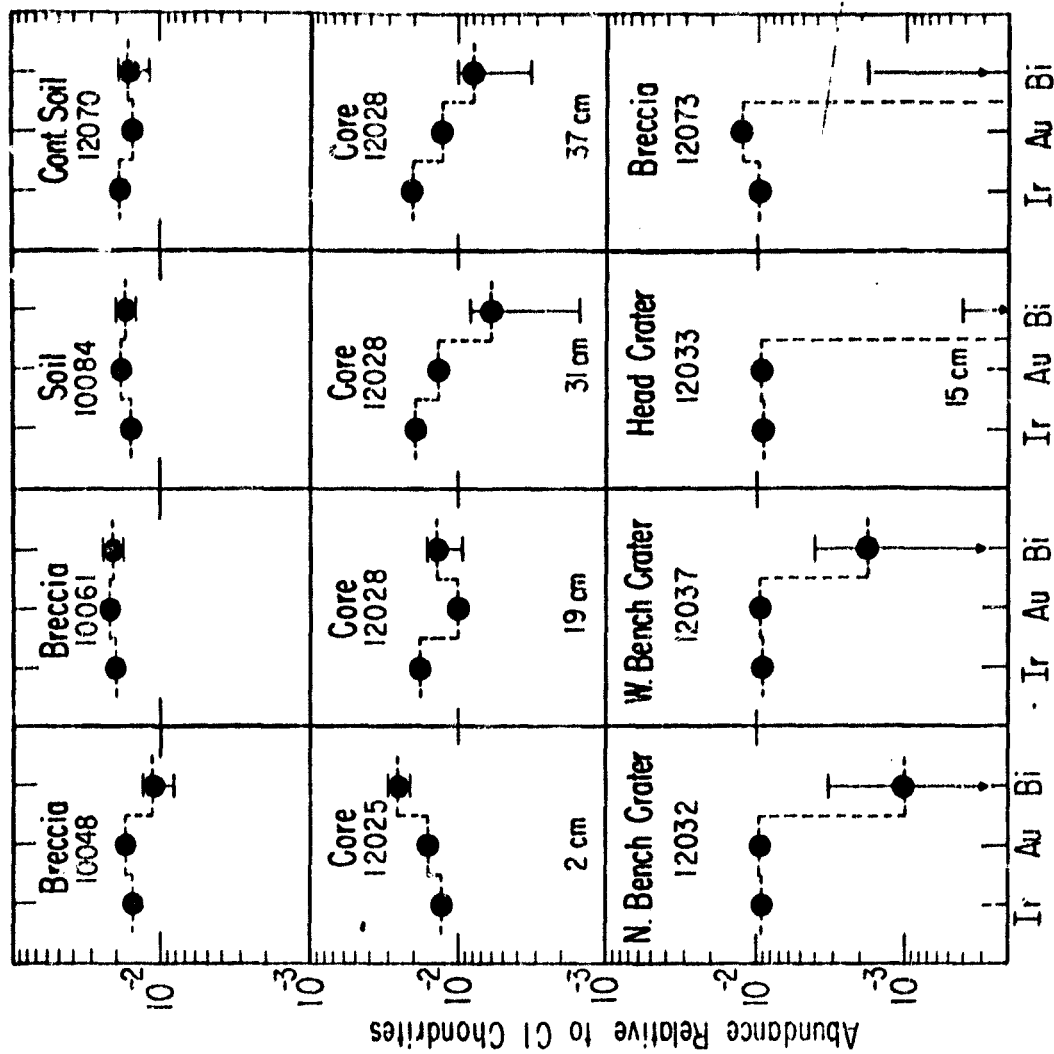


FIGURE 2. Abundance of three meteoritic elements in lunar soils and breccias, corrected for indigenous Ir, Au, and Bi. The first four samples show a flat pattern, characteristic of primitive meteorites. Apparently micrometeorites of carbonaceous chondrite composition comprise the dominant meteoritic component in these samples. The last four samples, all collected on or near crater rims, show a "step" pattern characteristic of less primitive meteorites (ordinary chondrites, irons). Apparently the projectiles that produced the three large craters at the Apollo 12 landing site were ordinary chondrites or irons.