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13. Finely divided ice was prepared by grinding ice under liquid nitrogen with a mortar and pestle and by condensing water from air at 78°K. The ice was degassed at 230°K and the hydrate was prepared in a vacuum line at temperatures between 200° and 230°K. The temperature was then brought to the desired value, and the equilibrium was approached from both the high- and low-pressure sides of the dissociation pressure. The pressures between 177° and 193°K were measured with a mercury manometer, and the lower pressures were measured with an oil (butyl phthalate) manometer. The temperatures were measured with carbon dioxide and ethylene vapor-pressure thermometers. The dissociation pressure measurements between 153° and 192°K are consistent with those between 195° and 232°K (*6*) and between 239° and 271°K (*9*).
14. This is a least-squares fit of the values between 123° and 173°K given by C. H. Meyers and M. S. Van Dusen [*J. Res. Nat. Bur. Stand.* **10**, 381 (1933)] and which are reproduced in *Handbook of Chemistry and Physics* (Chemical Rubber Publishing Company, ed. 44, Cleveland, Ohio, 1963), p. 2428.
15. The equation used is

$$\ln [(P_0-P_\infty)/(P-P_\infty)] = kt$$

where P_0, P_∞, and P are the initial pressure, the equilibrium pressure, and the pressure as a function of time, respectively, k is the first-order rate constant, and t is time in hours.

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Apollo 12 Lunar Samples: Trace Element Analysis of a Core and the Uniformity of the Regolith

Abstract. *Four core and soil samples from Apollo 12 are enriched in a number of trace elements of meteoritic origin to virtually the same degree as Apollo 11 soil. An average meteoritic influx rate of about 4 × 10^{-9} gram per square centimeter per year thus seems to be valid for the entire moon. A sample from a light gray, coarse-grained layer in the core resembles lunar basalts in composition, but is enriched by factors of 10^4 to 10^5 in bismuth and cadmium.*

In our study of Apollo 11 lunar samples (*1*) we found that lunar soil was enriched in about a dozen siderophile or volatile elements that are abundant in meteorites (Ir, Au, Bi, Tl, and others), while lunar rocks were depleted in these same elements. From these data we concluded that lunar soil contained about 1.9 percent meteoritic material of a composition similar to carbonaceous chondrites and that the moon had formed in the earth's neighborhood (*1, 2*).

Our conclusions hinged on the tenuous assumption that the Apollo 11 samples were typical of the moon as a whole. We now find that the Apollo 12 samples largely confirm our earlier results, though with some important modifications.

Seven Apollo 12 samples (~0.1 g each) were available for the present study: two crystalline rocks (12002 and 12051, the latter measured in duplicate); four samples from core tube 12028, representing depths of 13 to 38 cm below the surface; and a contingency fines sample (12070) collected some 10 m northwest of the landing site. The core tube sample was taken 240 m due south of the landing site, near the southern rim of Halo crater.

The samples were analyzed by neutron activation, with the use of procedures described previously (*1, 3*). A few substitutions were made relative to our Apollo 11 work: Cu and Co were dropped, while Se and Te were added. The data are shown in Table 1. Sample type is indicated in the brassiere-cup notation used by the Lunar Sample Preliminary Examination Team [LSPET (*4*)]: A and B for fine- and coarse-grained rocks, C for breccias, and D for soil.

Before turning to a discussion of the data, we shall note the difficulties encountered for five elements. Several of the In and Ag values were again spuriously high, owing to the widespread use of In-Ag gaskets on Apollo sample containers. The Cd and Te activities contained appreciable contributions from uranium fission, requiring corrections of up to 25 percent. The Pd results determined via ^{111}Ag by the reaction $^{110}\mathrm{Pd}(n,\gamma)\ ^{111}\mathrm{Pd}(\beta^-, \nu)\ ^{111}\mathrm{Ag}$ were most severely affected. The fission contribution was estimated at about 90 percent for rocks and 60 percent for soil. We are, therefore, not reporting individual Pd values for Apollo 12 samples, only upper limits of ≤ 0.5 part per billion (ppb) for rocks and ≤ 20 ppb for soil. Because of this interference, our Pd results for Apollo 11 rocks and BCR-1 basalt (*1*) must also be revised downward to ≤ 0.5 ppb, and those for soil and breccias, to ≤ 5 ppb.

The most striking result is the spectacular enrichment of Cd and Bi in the 13- to 14-cm layer of core 12028. This sample is described as consisting of "a coarse layer of angular rock fragments, minerals, and glass; comprised mostly of olivine grains and olivine-rich gabbro," with a median grain size of approximately 4.9 mm (*4*). The LSPET report notes that this material is fairly abundant at the Apollo 12 landing site and may be of distant origin: "Along many parts of the traverse made during the second period of EVA [extra-vehicular activity], the astronauts found fine-grained material of relatively high albedo. This material is at the surface in some places. It is possible that this discontinuous deposit of light gray material may be the feature that is observed telescopically as a ray of Copernicus."

Compositionally, this sample certainly differs from typical soil in its lower content of elements characteristic of a meteoritic component (Ir, Au, Zn, Br, and Te) or enriched in soil for other reasons (Tl, Rb, and Cs). But its content of Cd and Bi far exceeds that of all lunar samples and all meteorites studied to date.

Its Ag content also is unusually high and apparently not due to contamination from In-Ag gaskets. Contamination from this source consistently gives In ≫ Ag, but in sample 12028,66 In (42 ppb) is less abundant than Ag (301 ppb).

The remaining core samples are of quite uniform composition in regard to both "meteoritic" and "indigenous" elements. The only slight irregularities are the low Tl and Te contents in samples 12028,90 and 12028,121, respectively. This is surprising, in view of the distinct differences in color and grain size [see figure 9 in (*4*); location of our samples is given in footnotes to Table 1].

If we disregard sample 12028,66 and compute averages for the AB rocks and bona fide D samples, we obtain values close to those from Apollo 11. The D averages (lines 5 and 6 from the bottom of Table 1) are especially similar,

Table 1. Abundances in Apollo 12 lunar samples. Doubtful values are italicized. Abbreviations: ppm, parts per million; av., average.

Sample type and No.	Ir (ppb)	Au (ppb)	Zn (ppm)	Cd (ppb)	Ag (ppb)	Bi (ppb)	Tl (ppb)	Br (ppb)	Te (ppb)	Se (ppb)	Ga (ppm)	Rb (ppm)	Cs (ppb)	In (ppb)
B 12002,126	0.62	0.024	0.70	1.4	0.81	1.4	0.25	10.0	10	141	2.40	0.97	39	1.9
AB 12051,45	0.03	0.008	0.52	1.2	0.82	0.53	0.36	16.4	10	201	4.58	1.03	40	2.0
AB 12051,45	0.54	0.007	0.54	1.1	0.80		0.37	16.1	16	204	4.34	1.06	42	1.2
A+D 12028,66*	0.08	0.63	1.47	22,000	301	38,500	0.26	16.4	10	86	2.71	0.32	23	42
D 12028,90*	8.1	1.65	5.1	53	*140*	2.1	0.51	141	80	230	5.23	8.6	345	*294*
D 12028,121*	8.7	2.07	5.4	48	3.6	1.2	2.2	124	30	247	5.02	9.0	359	9.2
D 12028,145*	9.2	2.01	4.3	49	7.2	1.4	2.3	116	90	237	5.19	10.8	342	*26*
D 12070,69	8.5	2.39	6.9	45	*46*	2.4	1.6	123	100	259	4.26	6.3	248	*218*
D 12 av.	8.63	2.03	5.4	49	5.4	1.77	1.65	126	75	243	4.92	8.67	324	9.2
D 11 av.	7.14	2.66	21.1	44	8.72	1.63	2.22	107			4.63	3.10	105	
AB 12 av.	0.33	0.013	0.59	1.2	0.81	0.96	0.33	14.7	12	182	3.74	1.02	40	1.7
AB 11 av.	0.066	0.041	7.4	12.5	1.46	0.33	0.63	22.1	11		4.48	3.58	121	2.9
D 12 excess (%)†	1.88	1.35	1.47	*4.73*	1.18	*0.71*	*1.78*	2.31	2.48					
D 11 excess (%)†	1.60	1.75	*4.15*	*3.08*	1.87	1.14	2.15	1.75						

* Core samples, representing the following depths: 13.2 to 14.4 cm; 18.9 to 19.7 cm; 31.2 to 32.2 cm; 37.2 to 38.2 cm [see figure 9 in (*4*) for description of these samples]. † Apparent meteoritic component = 100 $(D_{av}-AB_{av})/C\text{-}1$ (C-1 = abundance in type I carbonaceous chondrites).

the only significant differences being the lower Zn and higher Rb,Cs content of the Apollo 12 samples. The AB rocks (lines 3 and 4 from the bottom) show greater differences. Some of these are undoubtedly due to limited sampling, but the systematically lower Zn, Cd, Tl, Br, Rb, and Cs abundances in Apollo 12 rocks seem to represent a real and significant trend. The lower alkali content of Apollo 12 rocks has already been noted by other investigators (*4, 5*).

We can again try to determine the meteoritic component in the soil by subtracting the AB average from the D average. This makes sense only for the first nine elements, which are depleted in AB rocks by more than a factor of 100 relative to cosmic abundances, and show a clear enrichment (by more than a factor of 2) in soil. The absolute excesses $(D_{av} - AB_{av})$ have been normalized to C-1 carbonaceous chondrites, so as to give the nominal percentage of C-1 material that must be added to AB rocks to obtain the observed soil composition. The results for Apollo 12 and Apollo 11 are given in the two bottom lines of Table 1.

At both landing sites, the majority of values are essentially constant, even for elements of widely different geochemical character (compare siderophile Ir,Au with volatile Br). This suggests that the meteoritic component consists largely of primitive unfractionated material, similar to C-1 chondrites in composition. If we disregard the italicized values to be discussed below, the average meteoritic components at the two landing sites are 1.8 and 1.7 percent. [The Apollo 11 value rises to 1.9 percent if Ni, Ge, and data on breccias are included; see (*1*).]

The above procedure involves the tacit assumption that the AB average is truly representative of all the rock types that contributed to the soil. Actually, there is good evidence that Apollo 11 soil contained other components differing somewhat from AB rocks in composition: anorthositic material estimated as 4 percent (*6*) to 20 percent (*7*) of the total, and perhaps still another "cryptic" component (*8*). Apollo 12 soil shows even more striking imbalance; alkalis, uranium, and thorium are clearly overabundant relative to AB rocks (*4*).

We have no perfect safeguard against errors from this source. Perhaps the most reliable warning signal is provided by irregularities in the abundance pattern of the excess component. For example, the anomalously high Zn and Cd excesses in Apollo 11 soil and breccias led us to suggest the existence of a cryptic component rich in Zn and Cd. The high Cd value in Apollo 12 soil apparently calls for a similar explanation. At first glance the Bi,Cd–rich sample 12028,66 might appear to be a suitable candidate for such a component. This possibility must be dismissed, however, since Apollo 12 soil shows no overabundance of Bi (in fact, the excess of 0.71 percent is less than expected, probably due to an unrepresentative AB average). Thus the source of the excess Cd remains undetermined. [*Note added in proof*: Samples of the unique alkali- and uranium-rich lunar rock 12013 have Cd contents up to 300 ppb (*9*). Admixture of about 10 percent of such material to the Apollo 12 soil would account not only for the high Rb, Cs, and U contents, but also for the excess Cd.]

Thallium is another element that may have been affected by a cryptic component. The apparent excess of 1.78 percent calculated by our standard procedure looks fairly reasonable, but, since Tl in lunar rocks correlates with alkalis (*1*), the enrichment of Rb and Cs in Apollo 12 soil leads one to expect a comparable enrichment of Tl as well. Judging from the slope of the correlation plot, one-half or more of the apparent excess of Tl may be indigenous rather than meteoritic.

It is interesting that the meteoritic component is virtually identical in two lunar sites separated by 1400 km and in core-tube and breccia samples representing a range of ages. The constancy in space is better established and more significant than the constancy in time, because reworking of the regolith precludes any simple relationship between stratigraphic position and age of core samples. It can safely be said, however, that Apollo 11 breccias and Apollo 12 core-tube samples underlying the 13-cm layer became isolated from the meteoritic influx at some time in the past (10^6 to 10^7 years ago?), whereas Apollo 11 and Apollo 12 soil samples from the surface continued to collect meteoritic material up to 1969.

From cratering theory, the ratio of eroded mass to meteoritic mass is essentially proportional to meteorite velocity and the square root of the crushing strength of the target rock (*10*). Hence the time constancy of the meteoritic component merely implies that the velocity (and composition) of the meteoritic flux has not changed greatly in the recent past—hardly a surprising conclusion for believers in the uniformitarian principle. The spatial constancy, on the other hand, has more interesting implications. It suggests that local variations in the meteoritic component (as might be expected from differences in impact velocity, proximity to impact center, and so forth) are being smoothed out. Such smoothing-out may arise from two causes: stirring of the regolith and preponderance of micrometeorites in the meteorite influx (*11, 1*). Whichever of these factors is dominant, the spatial constancy of the meteoritic component suggests that the influx rate derived from our Apollo 11 data, 3.8×10^{-9} g cm^{-2} yr^{-1} (*1*), is a meaningful average for the entire moon.

We have not calculated a separate influx rate from our Apollo 12 data because the thickness of the regolith is not accurately known. It is supposed to be slightly less than at the Apollo 11 site (*12*), as might be expected from the slightly younger Rb-Sr age of the Apollo 12 rocks (*5*).

The two AB rocks that were analyzed are similar enough to their Apollo 11 counterparts to leave our conclusions (*1*) unaffected. However, sample 12028,66 raises problems. If it represents a major stratigraphic unit, and if the high Bi,Cd content of our sample is typical of that unit, then the moon's depletion in volatile metals cannot be as great as inferred from the Apollo 11 and Apollo 12 basalts. This in turn undermines all our conclusions based on such depletion (*1, 2*).

At the moment we do not have enough evidence to settle this question conclusively. However, there are two lines of evidence suggesting that material of high Bi,Cd content is uncommon. The lack of a Bi,Cd enrichment in surface soil (12070,69) or deeper layers of core 12028 suggests that Bi,Cd–rich material was deposited only once and was not stirred appreciably. One-time deposition might be expected for material of shallow but localized, or deep-seated but wide-spread, occurrence. Either would be exposed only infrequently. Lack of stirring requires that the deposit be of very recent origin.

From Gault's data (*13*), the "turnover time" of the lunar surface layer to a depth of 13 cm seems to be very short: Two turnovers would be expected in 10^6 years and 1.5×10^4 turnovers in 10^9 years. Much of the turning-over is done by infrequent large impacts, and thus the actual survival time of a discrete layer may be longer in some patches. Moreover, it is possible that Gault's times were somewhat too low. Nonetheless, since the 13-cm layer was not even slightly dispersed, much less turned over, it is probably no older than a few million years. This tends to speak against a Copernican origin, as the age of Copernicus, estimated as 10^9 years from crater counts (*14*), is not likely to be 2 to 3 orders of magnitude shorter.

We are therefore inclined to believe that the light gray material typified by sample 12028,66 may be quite rare. An alternative possibility is that this material is common but normally quite poor in Bi and Cd. Our sample may have accidentally contained a grain of a Bi,Cd–rich mineral. In any event, sample 12028,66 raises some interesting questions about statistical problems in lunar sample collection or lunar geochemistry, or both.

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Mercury: The Dark-Side Temperature

Abstract. *The planet Mercury was observed before, during, and after the inferior conjunctions of 29 September 1969 and 9 May 1970 at wavelengths of 3.75, 4.75, 8.6, and 12 microns. The average dark-side temperature is 111° ± 3°K. The thermal inertia of the surface required to fit this temperature is close to that for the moon and indicates that Mercury and the moon have very similar top surface layers.*

Radar measurements have shown that the mercurian day is two orbital periods long. When Mercury is new, the center of the dark hemisphere presented to the earth is at the midnight temperature, and 88 days have elapsed since noon for this point. The noontime temperature at the mean distance of the planet from the sun is about 620°K. A measurement of the midnight temperature will establish the average temperature of the planet, as well as the thermal inertia of the surface. In order to establish the dark-side temperature it is necessary either to observe with sufficient resolution to put one photometer beam on the cold disk without including any of the crescent, or to fill the photometer beam with the planet when the planet is near inferior conjunction and the contribution of scattered light and thermal emission from the crescent can be reduced indefinitely. Murray attempted to measure the dark-side temperature by the first method (*1*), using the 200-inch (508-cm) telescope at Mount Palomar. No signal was observed, and Murray concluded from this that the temperature must be less than 150°K.

We used the second method of observing the entire planet near its new phase. This method has the disadvantage of requiring observations at very small elongation angles from the sun. Fortunately, this can be accomplished much more easily in the infrared region than in the visible, and in September 1969 we observed down to an elongation angle of 3°. Solar heating of the mirror resulting in defocusing can cause a reduction in signal from the planet when observations are made with beam sizes only slightly larger than the apparent angular diameter of the planet. As shown below, it appears that this effect was small although not negligible.