rectangular. The transition between compacta and spongiosa is sharply marked in the domestic animals; wild specimens show less abrupt transition.

At present, we feel that we must limit ourselves to describing the differences we have observed, since we do not feel that sufficient research has been done to suggest that the underlying causes can be more than tentatively explained. However, it seems obvious that this approach is of value to the study of prehistory. Our results suggest that there are fundamental differences in the microstructure of bone of wild and domestic animals and that these differences are evident at the earliest stages of animal husbandry.

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3. The soils from Suberde and Erbaba consist of calcite, quartz, kaolinite, and montmorillonite, in approximate order of decreasing abundance. Soil from Erbaba is somewhat higher in calcite and lower in clay minerals than soil from Suberde. Both soils test alkaline, with a pH of about 8. Soil from Zawi Chemi Shanidar contains quartz, illite-montmorillonite interlayered clay and magnesian calcite; the pH is about 7. Analyses by emission spectroscopy of bones from the three sites, without attempting to remove the nonintegral mineral concretions observed microscopically, yielded the following averages: copper, 0.0001 percent for Erbaba and Suberde, 0.02 percent for Zawi Chemi Shanidar; iron, 0.08 and 0.06 percent, respectively, for Erbaba and Suberde, in excess of 0.5 percent for Zawi Chemi Shanidar; magnesium, 0.1 and 0.05 percent, respectively, for Erbaba and Suberde, in excess of 1 percent for Zawi Chemi Shanidar; manganese, 0.02 and 0.01 percent for Erbaba and Suberde, 0.5 percent for Zawi Chemi Shanidar; sodium, 0.1 percent for both Erbaba and Suberde, 0.05 percent for Zawi Chemi Shanidar; silicon, 0.2 and 0.3 percent for Erbaba and Suberde, in excess of 1 percent for Zawi Chemi Shanidar. [These elements are among those listed as biologically important in *Trace Mineral Studies with Isotopes in Domestic Animals* (International Atomic Energy Agency, Vienna, 1969), p. 147.]
4. The slices of friable bone were first impregnated with plastic under vacuum. M. Rev, who made all the thin sections for this study, reported that the bones from Suberde, in contrast to those from Erbaba, were particularly resistant to penetration of the plastic.
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8. We thank R. S. Solecki (Columbia University) for initiating these investigations and for continued interest. Partially supported by the Sackler Fund, and by NSF grant GS 2828. J. Curtis and M. Friedman assisted with the spectrographic analyses. B. C. Hesse assisted with the initial study of the fauna of Suberde and Erbaba.

7 October 1970

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Potassium-Uranium Systematics of Apollo 11 and Apollo 12 Samples: Implications for Lunar Material History

Abstract. *Apollo 11 and Apollo 12 lunar rock suites differ in their potassium-uranium abundance systematics. This difference indicates that relatively little exchange of regolith material has occurred between Mare Tranquillitatis and Oceanus Procellarum. The two suites appear to have been derived from materials of identical potassium and uranium content. It appears unlikely that bulk lunar material has the ratio of potassium to uranium found in chondrites. However, systematic differences in the potassium-uranium ratio between Apollo samples and crustal rocks of the earth do not preclude a common potassium-uranium ratio for bulk earth and lunar material.*

Extensive studies (*1, 2*) have shown that the K/U ratios of most igneous rocks on the earth are within 50 percent of 1.0×10^4, despite the fact that differentiation has produced rocks with a range of K and U concentrations that covers 3½ orders of magnitude (*3*). The Apollo 11 samples exhibit K/U ratios that are systematically lower than those of earth rocks (*4*) and, on the average, the K/U ratios obtained for Apollo 12 samples are lower than those for the Apollo 11 samples (*5*).

In Fig. 1 we have plotted K content versus U content for earth rocks (*1, 2, 6, 7*), and for *all* the Apollo 11 and Apollo 12 moon samples as reported by the Lunar Sample Preliminary Examination Teams (*4, 5*). For comparison, we have also plotted averages of values reported by several investigators for chondrites and achondrites [see (*3*)] and for tektites (*8*).

Within each Apollo suite, the samples appear to be members of a single family defining their own trend line, which represents the correlation between their K and U contents. The two suites exhibit different K-U correlation trends, although membership of individual samples in one suite or the other cannot be established by their K or U contents alone. Potassium and uranium enrichment in the Apollo samples must be regarded as the result of magmatic differentiation. Many lunar samples are as high in U as average earth basalt, and at least 50 times as high as chondrites (normally regarded as possessing approximately primordial solar-system relative abundances of nonvolatile elements). We conclude that rock suites from the Mare Tranquillitatis (Apollo 11) and Oceanus Procellarum (Apollo 12) sites represent two distinct populations with respect to their igneous derivation.

The fact that breccias and fines appear to be members of the corresponding K-U trend lines defined by local igneous rocks is in agreement with other evidence (*9*) for local derivation of the regolith. "Bracketing" of these fragmental materials (in Fig. 1) by igneous members of each suite may be fortuitous, however, in view of the small number of samples and the subjective factors involved in sample selection. We conclude that the K-U systematics of Apollo samples argues against moonwide transport and exchange of regolith materials subsequent to the formation of Oceanus Procellarum.

The two trend lines in the Apollo data appear to diverge from a common cluster of points on Fig. 1, which suggests that the two suites represent two separate differentiation sequences originating from materials of identical K and U content. According to material balance requirements, if the two suites exhibit different enrichment trends, complimentary portions of the suites must exist which exhibit different depletion trends. This might cause the two trend lines to appear to cross at a point corresponding to the U and K contents of the starting material. But within the severe limitations of the sampling represented by the two Apollo suites, no such crossover is obvious. Thus, it appears likely that large masses of depleted phases may be "hidden" at great depth or elsewhere on the lunar surface. For example, if the highlands are indeed anorthositic, as suggested by Olsen (*10*) and Wood *et al.* (*11*), measurement of the K/U ratio of "anorthositic" fragments, identified by Wood *et al.* in returned mare breccia, might be informative. Even if the highlands are found to be enriched in K and U, as is the mare material, the possibility will remain that both highland and mare material were enriched in K and U at the expense of a huge reservoir of ultramafic "depleted" phases whose K/U ratio is unknown.

The considerations bear strongly on the important question of whether or not the bulk K/U ratio of the moon could be identical with that of the earth or that of meteorites, or both. The tektite point in Fig. 1 falls almost exactly on the "enriched" portion of the earth's K-U trend line and supports the hypothesis that tektites originated from crustal material of the earth. Both high-calcium and low-calcium achondrites exhibit K/U ratios that are intermediate between those of earth rocks and Apollo 11 and Apollo 12 samples.

Chondrites, in contrast, are clearly not members of the earth or moon trend lines. This is particularly clear since potassium contents greater and less than the potassium content of normal chondrites are represented on the earth and moon trend lines (Fig. 1). It appears that both the moon and the earth possess bulk K/U ratios much lower than those of chondrites.

These differences may reflect differences between the early history of chondritic material and that of the material that formed the earth and the moon. There is abundant evidence from meteorite studies that dispersed-state modification of solar-system material (*12*) occurred prior to planetary accretion. This may explain the observation that the uncompressed density of Mercury (~5.2 g/cm^3) (*13*) appears to be much higher than that of the earth (~4.1 g/cm^3). If the primitive sun served as a heat source for dispersed-state modification, then more preferential volatization of silicate (relative to metal) might be expected for Mercury, at ~0.4 astronomical unit, than for the earth. The uncompressed densities of Mars and the densities of chondrites (*14*) are lower than that of the earth. These considerations suggest that average solid material at 1.0 astronomical unit was more depleted in K relative to U than chondritic material (originating at least at asteroidal distance in the cloud) by early dispersed-state modification. The K-U systematics of Apollo material indicates possibly even greater K depletion for the moon than for the earth. This reasoning is in conflict with the hypothesis that the moon accreted in the portion of the cloud from which chondrites accreted and was subsequently captured by the earth.

Does evidence from the K-U systematics of Apollo material preclude the possibility that the earth and the moon possess the same bulk K/U ratio? In order to reconcile the Apollo trend lines with that of the earth rocks (Fig. 1), two requirements must be satisfied:

1) The overall trend line of lunar material, the "enriched" portion of which is represented in the Apollo suites, must cross that of the earth at some material balance point.

2) Possibly this material balance point for the earth-moon system should lie close to a line designating the normal chondritic U content, if one assumes that normal chondritic abundances of nonvolatile elements (for example, U) approximate the abundances in primordial solar-system material. It is unlikely that the initial U content of that material could have been greatly altered by dispersed-state modification. Thus, the bulk concentrations of U in the earth and the moon might be expected to be roughly that of chondrites, even though bulk K concentrations might be much lower than that of chondrites.

We conclude that there is enough K-U fractionation evident *among* Apollo samples to suggest the possibility that analogous fractionation has occurred between the Apollo suites and the moon as a whole. Thus differences between the K/U ratios of Apollo samples and crustal rocks of the earth do not preclude the possibility that the moon and the earth were derived from materials possessing the same K/U ratio.

Subsequent to publication of the measurements of the Lunar Sample Preliminary Examination Team on

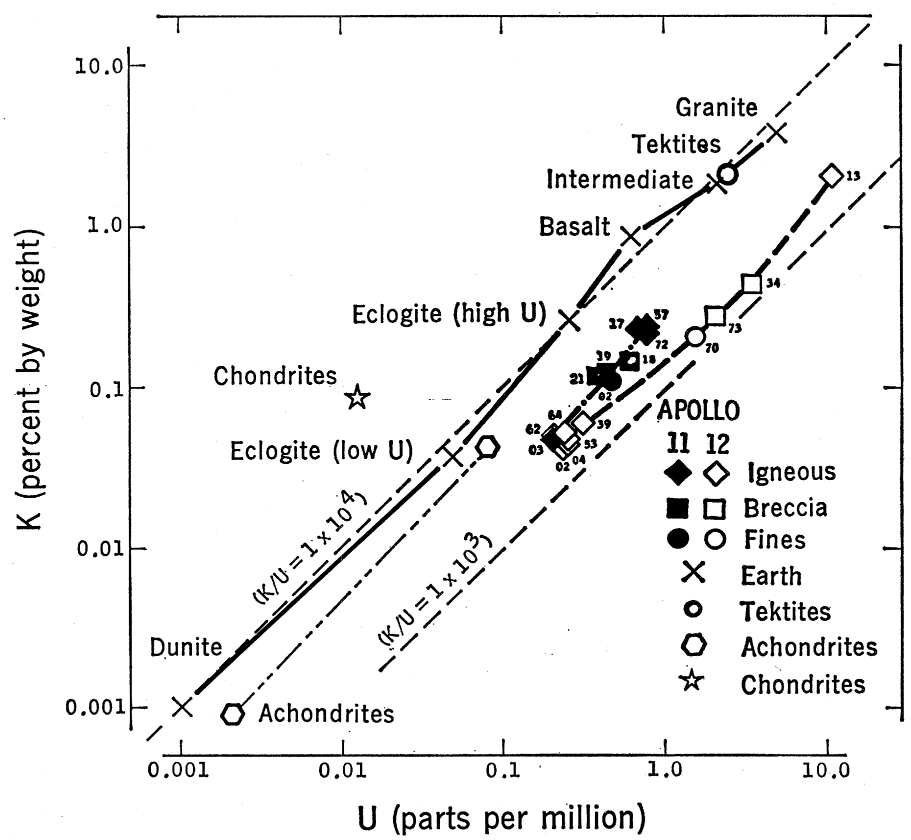

Fig. 1. Comparative trends in potassium-uranium abundance for earth rocks, meteorites, and Apollo 11 and Apollo 12 moon rocks. Earth data points are average values of multiple samples; the data are from the following sources: granite (*1*), intermediate material (*6*), basalt (*1*), eclogites (*1, 2, 7*), and dunite (*2*). Data for meteorites are from the following sources: chondrites and achondrites [results of seven groups of investigators, see (*3*), table 1], and tektites (*8*). Apollo 11 and Apollo 12 data are from the analyses of the Lunar Sample Preliminary Examination Team (*4, 5*); *all* data of the Preliminary Examination Team are plotted. Numbers adjacent to data points are the last two digits of the Lunar Receiving Laboratory sample numbers. Error bars are approximately contained within the symbols; curves are hand-fitted to the points. Diagonal dashed lines are lines of constant K/U ratios of 1 × 10^4 and 1 × 10^3. If values of K/U at any time in the past were plotted, after correction for U decay, all points would be similarly affected, and neither the appearance of the figure nor our conclusions would be altered.

Apollo 11 rocks, additional measurements of K and U on subsamples of individual Apollo 11 rocks by members of the Preliminary Examination Team (*15*) and other investigators (*16*) have been reported. The final results of O'Kelley *et al.* (the Preliminary Examination Team) (*16*), based on longer counting times and more refined analytical techniques, would plot close to the Apollo 11 and Apollo 12 trend lines (Fig. 1) and show even less scatter than the preliminary results.

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17. This report presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract No. NAS7-100, sponsored by the National Aeronautics and Space Administration.

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Environmental Control of Photosynthetic Enhancement

Abstract. *The transition from granular to homogeneous chloroplasts in vivo in* Egeria densa *caused by environmental conditions was paralleled by a decrease in photosynthetic enhancement from 30 percent to nearly zero. The drop in enhancement can be explained either by a change in the partitioning of light energy between the two photosystems or a change to a single photosystem.*

Chloroplasts of higher plants are known to have grana at some times and at others to be homogeneous when observed in the light microscope in vivo (*1*). The transformation from the granular to the homogeneous state can be effected by illumination in red light and is reversed by illumination in blue light or incubation in darkness (*2*). This reversible change in appearance is probably due to a change in fine structure which in turn ought to have an effect on the photosynthetic reactions occurring in the chloroplasts. In order to test this presumed relation between structure and function, photosynthetic enhancement was measured with leaves from plants that had been illuminated with red light long enough to cause the chloroplasts in most of them to become homogeneous. Enhancement decreased from its maximum value of 20 to 30 percent to nearly zero in response to these environmental conditions.

Egeria densa (*Elodea densa* or *Anacharis densa*) was grown under daylight supplemented with fluorescent light. The growth jars contained soil with added nitrate, phosphate, and iron and medium consisting of 200 μM KCl, 100 μM $MgSO_4$, and 200 μM $CaCl_2$. In these experiments 4 to 6 cm of the apical ends of the intact plants in growth jars supplied with 5 percent CO_2 in air and kept at 17°C were first illuminated for 6 to 12 hours with high-intensity red light (2.4×10^4 erg/cm^2-sec). For measurements of enhancement of photosynthesis a leaf was then excised, examined in a light microscope under oil immersion, placed adaxial surface up on a platinum oxygen electrode covered with a Teflon membrane similar to that described by Fork (*3*), and fastened in place with dialysis membrane. The electrode was polarized at -0.55 volt with a circuit powered with an alkaline manganese battery (*4*). The electrode current was measured with an F-1-7 differential amplifier (Computer Techniques Ltd.) used as a d-c microammeter and recorded on a 10-mv potentiometric recorder. The response of the microammeter recorder combination was linear over at least four orders of magnitude. Monochromatic light was produced with Balzer B-40 interference filters and Calflex C heat filters. The wavelengths used were the pairs 482 and 700 nm or 647 and 700 nm which have been reported to give maximum enhancement (*5*). The light intensity was controlled with neutral density filters. The rates of oxygen evolution as a function of illumination (Fig. 1) could be extrapolated linearly to the origin. Thus, there were no detectable systematic errors caused by nonlinear light curves (*6*). Periods of 2 to 4 minutes of illumination in monochromatic light, followed by 2- to 4-minute dark intervals, were randomly interspersed between the periods of illumination in light of two wavelengths. Corrected rates of oxygen evolution were calculated from the differences between the oxygen electrode currents in light and in dark measured after the end of the 40- to 70-second electrode-transient periods. Percent enhancement was calculated according to the formula

$$\%E = \left(\frac{PS_{1,2}}{PS_1 + PS_2} - 1\right) \times 100 \quad (1)$$

where $PS_{1,2}$, PS_1, and so forth are defined as the rates of oxygen evolution corrected for the rates of respiration in light of wavelength 1 and 2 together, wavelength 1 alone, and so forth, respectively. This formula gives lower values for enhancement than the formula

$$\%E = \frac{PS_{1,2} - PS_2}{PS_1} \times 100 \qquad (2)$$

and it also avoids the artificial bias toward greater enhancement at high ratios of auxiliary light to 700-nm light. For example, the low enhancements of 1 to 10 percent calculated according to Eq. 1 becomes 3 to 13 percent at low ratios of auxiliary light to 700-nm light and 21 to 35 percent at high ratios when calculated according to Eq. 2. Similarly, the high enhancements of 20 to 35 percent calculated according to Eq. 1 become 35 to 65 percent at low ratios and 65 to 135 percent at high ratios of auxiliary light. The two methods give roughly the same proportionate change in enhancement, however.

The duration of the illumination of the intact plants with red light needed to effect the transformation from granular to homogeneous chloroplasts is variable because it depends on many