used to separate those animals which, on the basis of their phylogenetic relations, we wish to call mammals from those which we wish to retain in the Therapsida. The groups generally considered to be mammals (5) appear to be more closely related to one another than to advanced cynodonts or other cynodont-derived groups; thus, it should be possible to find features shared by the former but lacking in the latter which can be used to supplement the definition of a mammal. Hopson and Crompton (9) have suggested that the presence of a diphyodont pattern of tooth replacement and possession of cheek teeth of a characteristic pattern be added to the dentary-squamosal contact as criteria for diagnosing what is a mammal. As knowledge of early mammals improves, other, perhaps better, characters can be added to or substituted for these. The problem of mosaic acquisition of these characters will complicate the issue as the record documenting the transition becomes increasingly complete, but we shall also be in an increasingly better position to select the most biologically significant criteria for separating the two classes.

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Radioactivity Induced in Apollo 11 Lunar Surface Material by Solar Flare Protons

Abstract. *Comparison of values of the specific radioactivities reported for lunar surface material from the Apollo 11 mission with analogous data for stone meteorites suggests that energetic particles from the solar flare of 12 April 1969 may have produced most of the cobalt-56 observed.*

Values for the abundances of several radionuclides in eight lunar surface samples returned by the Apollo 11 mission have been reported by the Preliminary Examination Team (PET) (*1*). The preliminary nature of the experimental results was emphasized, and our conclusions must therefore necessarily be considered as tentative also.

One approach to a consideration of these radionuclide results is to compare them with analogous data from stone meteorites. In Table 1 are listed several of the nuclides reported by PET in order of increasing half-life. For each of these, average specific radioactivities in lunar surface material and in typical stone meteorites (*2*), as well as the ratios of these two quantities, are given. Also listed are the types of nuclear reactions by which they may have been formed. Corresponding to each reaction, we present in the last column of Table 1 the ratio of the specific radioactivities, after dividing each by the amount of target element in the sample (*1, 3*). This corrected ratio should be close to unity if the same spectrum and intensity of particles incident on both the lunar surface and the meteorites are responsible for the reaction being considered. It should be borne in mind that, if the relative importance of a given reaction varies greatly between the two classes of materials, the value of this ratio may not be very meaningful.

Perhaps the most striking feature of the PET results is the rather high average ^{56}Co content (≈ 31 dpm kg^{-1}). This ^{56}Co (half-life = 77 days), like most of the other radioactive species reported, is the result of the interaction of energetic particles in space with the lunar surface material; this phenomenon is well known from studies of meteorites and recovered satellites

Table 1. Comparison of specific radioactivities observed in Apollo 11 lunar material and in stone meteorites. d, day; y, year; dpm, disintegrations per minute.

Nuclide	Half-life	Observed specific radioactivities (dpm kg^{-1}): Average lunar samples*	Observed specific radioactivities (dpm kg^{-1}): Typical stone meteorites†	Ratio (lunar/stone)	Possible nuclear reactions	Ratio (lunar/stone)‡
^{56}Co	77 d	31 ± 4	14 ± 2	2.2 ± 0.4	^{56}Fe (p,n)	4.3 ± 0.8
^{46}Sc	84 d	11 ± 1	12 ± 1	0.9 ± 0.1	$^{46}Ti + {}^{48}Ti$ {(p,xpyn) (n,xpyn)}	0.012 ± 0.002
					Fe^{56} {(p,6p5n) (n,5p6n)}	1.8 ± 0.2
^{54}Mn	312 d	29 ± 5	72 ± 7	0.40 ± 0.08	^{54}Cr (p,n)	0.36 ± 0.07
					^{55}Mn {(p,pn) (n,2n)}	0.29 ± 0.06
					^{56}Fe {(p,2pn) (n,p2n)}	0.79 ± 0.16
^{22}Na	2.6 y	43 ± 4	80 ± 8	0.54 ± 0.08	^{23}Na {(p,pn) (n,2n)}	0.96 ± 0.14
					^{24}Mg {(p,2pn) (n,p2n)}	1.6 ± 0.2
					^{28}Si {(p,4p3n) (n,3p4n)}	0.48 ± 0.07
^{26}Al	7.4×10^5 y	80 ± 7	64 ± 6	1.3 ± 0.2	^{26}Mg (p,n)	3.8 ± 0.5
					^{27}Al {(p,pn) (n,2n)}	0.24 ± 0.03
					^{28}Si {(p,2pn) (n,p2n)}	1.1 ± 0.2

* Values from (*1*). † Values from (*2*). ‡ Corrected for target abundance.

[recent reviews are listed in (*4*)]. However, the reported specific activity of the ^{56}Co in the material returned by Apollo 11 is a factor of 2 higher than typical radiochemically determined values in stone meteorites. Iron is by far the most likely element from which this nuclide is produced in these two classes of materials. If Harleton is considered a model stone meteorite, the ^{56}Co content of the lunar surface materials per unit weight of iron (*1, 3*) is high by a factor of about 4. The average specific radioactivity of none of the other species reported by PET is as disparate from that observed in stone meteorites, if differences in the amounts and possible nature of the target material involved in their production are kept in mind.

For example, the comparable specific radioactivities of ^{46}Sc in lunar material and in stone meteorites presumably arise from the presence of the appreciable amount of titanium in the former (*1, 5*), which compensates as target material for the lower iron abundance. The lower amount of ^{54}Mn is probably due to the lower iron content in the Apollo 11 samples (the principal nuclear reactions leading to ^{54}Mn, again, include iron as the target). The lower lunar ^{22}Na content is probably partly due to the lower sodium and magnesium abundances, while the larger amount of ^{26}Al found in the lunar surface material is consistent with the higher aluminum abundance (*1, 3*). Thus, the apparent inversion of the ratio of ^{22}Na to ^{26}Al [which is normally observed as greater than unity in stone meteorites (*6*)] may be due to the relative target abundances in the two classes of materials.

A reasonable explanation for the clear excess of ^{56}Co in the lunar material is production of this nuclide by particles from the solar flare of 12 April 1969. This flare was accompanied by the presence of a very great excess of energetic protons in space for a period of several days, with no major events occurring between this one and the collection of the Apollo 11 samples. The integral flux of these interplanetary solar flare protons is estimated at about 10^9 cm^{-2} for the 10- to 100-Mev energy range, on the basis of data from the IMP-4 satellite (*7*). Protons in this energy range are particularly effective in producing (p,n) nuclear reaction products (such as ^{56}Co) in high specific radioactivity close to the surface of exposed material. They are not as effective in increasing the abundances of the other radionuclides listed in Table 1 under the conditions which prevailed for the Apollo 11 material. From experimental values for the cross section of the $^{56}Fe(p,n)^{56}Co$ reaction (*8*), the abundance of iron in the Mare Tranquillitatis material (*1*), and an approximate energy spectrum for the solar flare particles (*7*), a simplified calculation gives an average of nearly 100 dpm kg^{-1} of ^{56}Co in the first 2 cm of depth of lunar material due to the flare. Since the activity induced by these particles will depend rather strongly on the actual depth from which the samples were obtained and the local topography, as well as on the applicability of the flare intensity experienced by IMP-4 to that on the Mare Tranquillitatis, quantitative agreement is not to be expected. The calculated amount, however, appears to be more than adequate to explain the excess ^{56}Co observed (*9*).

More detailed conclusions must await further analyses and data on more radionuclides from the Apollo 11 rocks and from rocks collected at different times in the solar cycle, as well as more rigorous estimates of the abundances expected to be produced in lunar materials by projectiles of various types.

After we submitted this manuscript, several groups presented results at the Apollo 11 Lunar Science Conference at Houston, Texas, 5 to 8 January 1970. Their conclusions are in accord with ours (*10*).

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Periphyton: Autoradiography of Zinc-65 Adsorption

Abstract. *The major site of sorption of zinc-65 in natural, matlike periphyton is on the upper surface of the community. There is a diffusion gradient within the community. Expression of results from short-term spiking experiments should thus be presented on an areal rather than gravimetric basis.*

Mineral cycling in periphyton communities is conveniently studied with radionuclides as tracers. There are, however, questions as to whether to express rates and quantities on an areal or gravimetric basis. Nelson *et al.* (*1*) present data suggesting that uptake of ^{32}P by periphyton is a community-surface phenomenon; Cushing and Rose (*2*) found that cycling data were more meaningful when expressed on an areal rather than gravimetric basis.

The present experiment was designed to determine, by autoradiographic techniques, whether the entire periphyton community is uniformly exposed to the ambient water or whether there is a diffusion gradient within the community. This information would be important relative to quantifying data in gravimetric or areal terms. Natural periphyton communities from the Columbia River were cultured on paraffin blocks until a mature matlike colony dominated by diatoms was present, as judged by morphological characters. The periphyton community was then placed in a 2-liter beaker containing river water filtered through a 0.45 μm filter with a ^{65}Zn concentration of 10 nc/ml for 24 hours. Water was circulated by a stream of air from an air stone. After having been dried in air the paraffin blocks and periphyton were suspended in large paraffin boats and imbedded in Paraplast Plus under vacuum. This resulted in an essentially intact periphyton community suspended in paraffin. Sections (5 μm thick) were cut, taken to a darkroom, transferred to Kodak NTB nuclear track plates