[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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References and Notes

1. Lunar Sample Preliminary Examination Team, *Science* **165**, 1211 (1969).
2. M. Honda and J. R. Arnold, *ibid.* **143**, 203 (1964); J. P. Shedlovsky, P. J. Cressy, T. P. Kohman, *J. Geophys. Res.* **72**, 5051 (1967).
3. R. S. Clarke, Jr., unpublished data.
4. M. Honda and J. R. Arnold, in *Handbuch der Physik* (Springer, Berlin, 1967); T. P. Kohman and M. L. Bender, in *High Energy Nuclear Reactions in Astrophysics*, B. S. P. Shen, Ed. (Benjamin, New York, 1967).
5. A. L. Turkevich, E. J. Franzgrote, J. H. Patterson, *Science* **165**, 277 (1969).
6. See, for example, K. Fuse and E. Anders, *Geochim. Cosmochim. Acta* **33**, 653 (1969); E. L. Fireman, *ibid.* **31**, 1691 (1967).
7. We thank K. C. Hsieh and Prof. J. A. Simpson and his group for making available their preliminary data from IMP-4. Any errors in the interpretation of these data are, of course, our responsibility.
8. S. Tanaka and M. Furukawa, *J. Phys. Soc. Jap.* **14**, 1269 (1959); I. R. Williams and C. B. Fullmer, *Phys. Rev.* **162**, 1055 (1967).
9. It is important to bear in mind that the orientation of a large sample relative to the detectors may have a significant effect on the result for a radionuclide which is not homogeneously dispersed throughout that sample, as would be the case for the solar particle-induced reaction discussed here.
10. J. P. Shedlovsky, M. Honda, R. C. Reedy, J. C. Evans, Jr., D. Lal, R. M. Lindstrom, A. C. Delany, J. R. Arnold, H.-H. Loosli, J. S. Fruchter, R. C. Finkel, *Science* **167**, 574 (1970); R. W. Perkins, L. A. Rancitelli, J. A. Cooper, J. H. Kaye, N. A. Wogman, *ibid.*, p. 577; G. D. O'Kelley, J. S. Eldridge, E. Schonfeld, P. R. Bell, *ibid.*, p. 580.
11. Supported by grants from AEC and NASA.

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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 which were then stored in light-tight boxes at 5°C for 14 days, developed, and covered for permanent mounts. Sites of ^{65}Zn-deposition show up microscopically as small black spots (*3*).

The site of ^{65}Zn-deposition is on the upper surface and within the upper layers of the community; the control section is clear (Fig. 1). The fact that the ^{65}Zn is present mainly on the surface and in decreasing amounts within the community indicates that radionuclide uptake in these communities is largely a surface phenomenon and that there is a diffusion gradient within the periphyton.

Whitford and Schumacher (*4*) have discussed the interactions of currents and diffusion gradients in determining mineral uptake by algae. Our results extend this relation to entire algal communities. Cushing (*5*) found significant correlations among various limnological factors and ^{32}P- and ^{65}Zn-accumulation by periphyton when data were expressed on an areal rather than gravimetric basis, even though the periphyton had colonized clean substrates and were exposed to the radionuclides throughout their growth period. Neal *et al.* (*6*) present data showing high activity-densities (dpm/mg) when periphyton biomass was low, and low activity-densities when biomass was high. They suggest that uptake may be linear over a certain range of biomass but as the mass increases, proportional accumulation diminishes; they refer to this as a hyperbolic "weight dilution" effect. Harvey and Patrick (*7*) and Watts and Harvey (*8*) give data relating uptake of radionuclides, expressed on a gravimetric basis, in batch and continuous flow systems. In general, uptake was higher in the batch cultures, and the authors attributed this to a biological dilution effect due to the increased growth rate in the continuous flow system. Harvey suggests that cell division in the lower layers of a periphyton community would tend to dilute the activity per cell, hence per unit weight, and that upper layers would have more radioactivity (*9*). This is similar to the interpretations of Neal *et al.* (*6*), and this hypothesis would be consistent with the present findings and those of Cushing (*5*). Whittaker (*10*) reported results of ^{32}P uptake by weight of sessile algae communities in "spiked" aquaria, but the combination of varying ambient concentration, as a result of cycling, and new growth during the extended time of the study confuse the interpretation of the periphyton uptake data.

Data from short-term nutrient-cycling experiments, including ^{14}C-productivity studies, involving the "spiking" of intact periphyton communities should be expressed on an areal rather than gravimetric basis. Caution is advised in interpretation of data from studies of periphyton exposed to radionuclides during all or part of their growth period or when significant growth occurs during an experiment.

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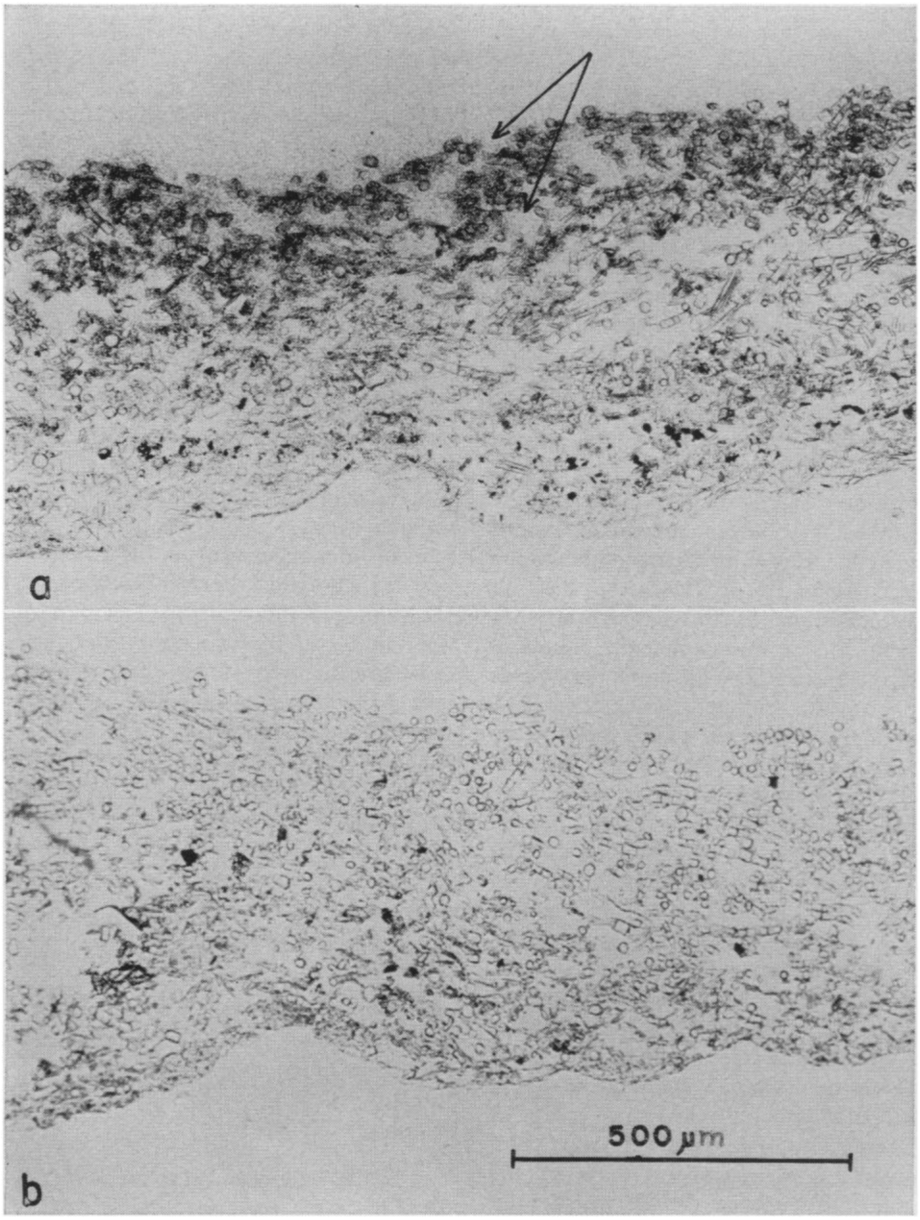

Fig. 1. Autoradiographs of periphyton communities. (a) Community exposed to ^{65}Zn; (b) control community, not exposed to ^{65}Zn. Paraffin substrates were at bottom edge of both communities. Arrows indicate darkened band of ^{65}Zn deposition.

References and Notes

1. D. Nelson, N. Kevern, J. Wilhm, N. Griffith, *Water Res.* **3**, 367 (1969).
2. C. Cushing and F. Rose, in preparation.
3. The nuclear tracks are a result of the Auger electron decay of ^{65}Zn. N. Dockum, *Hanford Biology Research Annual Report for 1961* (Hanford Atomic Products Operation, Richland, Wash., 1962), p. 97.
→ L. Whitford and G. Schumacher, *Limnol. Oceanogr.* **6**, 423 (1961).
5. C. Cushing, *Hydrobiologia.* **29**, 125 (1967).
6. E. Neal, B. Patten, C. DePoe, *Ecology* **48**, 918 (1967).
7. R. Harvey and R. Patrick, *Biotechnol. Bioeng.* **9**, 449 (1967).
→ J. Watts and R. Harvey, *Limnol. Oceanogr.* **8**, 45 (1963).
9. R. Harvey, personal communication.
→ R. Whittaker, *Ecol. Monogr.* **31**, 157 (1961).
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