P.819

COSMONUCLIDES IN LUNAR ROCKS , Y.Yokoyama, R.Auger, R.Bibron, R.Chesselet, F.Guichard, C.Léger, H.Mabuchi, J.L.Reyss and J. Sato, Centre des Faibles Radioactivités, C.N.R.S., Gif-sur-Yvette, 91, France

Lunar samples bear fossil records of cosmic radiation. From studies of Apollo 11 samples, clear evidence was obtained for the long term bombardment by solar particles in the region of tens of MeV per nucleon (1). Studies of Apollo 12 samples (2) showed a similarity of the depth profile of 7.4×10^5 yr Al-26 to that of 2.6 yr Na-22. Thus the flux of the solar particles averaged over 10^6 years has been similar to that observed recently. The profile for 3.7×10^6 yr Mn-53 suggests a possibility of either an erosion rate of 0.2 mm per million years or the variation of the solar cosmic flux (2).

The aim of the work reported here comprises experimental measurement of the depth variation of radionuclides, theoretical calculations of the expected profiles and comparison of these results. Unfortunately we have received samples late (on 21 Sept. and 5 Nov. 71) and radiochemical analyses are yet in process. We report here therefore mainly the results of the theoretical calculation. The calculation of the expected production by solar particles is carried out as follows. We consider here only the interactions of the primary protons. The production by α-particles will be reported later. The spectrum of incident solar protons is assumed to decrease exponentially with their rigidity :

$$N(R)\,dR = k\, e^{\frac{-R}{R_o}}\, dR \qquad (1)$$

where $N(R)\,dR$ is the number of particles having rigidities between R and $R + dR$, and R_o is the characteristic slope (MV). By using the relation between the rigidity and the energy,

$$R^2 = E^2 + 1876\,E \qquad (2)$$

the rigidity spectrum is converted in the energy spectrum :

$$N(E)\,dE = \frac{k}{R}\,(E + 938)\, e^{-\frac{R}{R_o}}\, dE \qquad (3)$$

where $N(E)$ is the number of particles having energies between E and $E + dE$ MeV, and 938 is the rest mass of proton in MeV. To calculate the depth variation of the proton flux, we have used a range-energy relation expressed by

$$P = \frac{2.21}{S}\, E^{1.8} \qquad (4)$$

where P is the range (mg/cm^2) of a proton of energy E (MeV) and S is the relative mass stopping power which depends on the chemical composition of the material and is 1 for air, 0.91 for the rock 14305, and 0.88 for the rock 12002. Then the incident energy E of the particle coming with a zenith

© Lunar and Planetary Institute • Provided by the NASA Astrophysics Data System

P.820

angle Θ and having an energy E_D at a given depth D (mg/cm^2) is calculated by

$$E = \left(\frac{S.D.}{2.21 \cos \Theta} + E_D^{1.8}\right)^{1/1.8} \quad (5)$$

The incident flux is assumed to be isotropic. Incident angles are divided in ten parts, of which cos Θ's are comprised between 0 to 0.1, 0.1 to 0.2 and so on, in order that each part has equal solid angle. Then each part is represented by its mean cos Θ, namely cos Θ = 0.05, 0.15 and so on. The differential flux of particles having Energy E_D at a given depth D is then obtained by integrating the flux of particles having initial energy E (E being a function of cos Θ) over all angles ;

$$N(E_D)\, dE_D = \frac{k}{Z^2} \sum_{\cos \Theta} \frac{E + 938}{R} e^{-\frac{R}{R_o}} \left(\frac{E_D}{E}\right)^{0.8} dE_D \quad (6)$$

where E should be determined by the equation (5) as the function of E_D, D , cos Θ ; R does by the equation (2) from E, and summation should be done for cos Θ = 0.05, 0.15, ... to 0.95 . The results are shown in figure 1.

The production rate is calculated in integrating $N(E_D)\sigma(E_p)\, dE_p$ for all energies, where $\sigma(E_p)$ is the excitation function of a given reaction. We have used the excitation functions selected from experiment, corrected for the adopted values of the monitor reactions, of decay schemes, and synthesized by Tobailem and de Lassus St-Genies (3). The calculation of the expected production by galactic cosmic rays is carried out by a method described in detail in a separate paper. Figure 2 shows the calculated profiles for Al-26 and observed value obtained preliminary by us with non-destructive γ-γ coincidence spectrometry on the rock 14305 (Table 1). This rock was thought to be turned recently, from the photographic studies of its situation on the lunar surface and from the pits counting. This was confirmed by our results , showing more activities of Al-26 at the bottom than at the top. In Fig.3, a preliminary result of the measurement of Fe-55 of the rock 14305 is shown. The result of our calculation for the rock 12002 is in good agreement with that of Finkel et al. (2), figure 4.

Table 1 - Non-destructive γ-ray measurements of the rocks 14305 and 14302

SAMPLES	Weight (g)	Th (ppm)	U (ppm)	Al-26 (dpm/Kg)
this work 14305 top(0-3mm)	2.7	14.6 ± 0.9	3.8 ± 0.4	63 ± 34
bottom (0-3mm)	1.45	13.3 ± 0.9	3.8 ± 0.5	160 ± 60
LSPET (4) 14302 *	381	14.3 ± 1.4	3.8 ± 0.6	85 ± 17

* 14302 was a part of 14305 at the lunar surface.

© Lunar and Planetary Institute • Provided by the NASA Astrophysics Data System

P. 821

1. See the references cited in the reference (2).
2. R.C.Finkel et al., Proceedings of the Apollo 12 Lunar Science Conference (1971)
3. J. Tobailem and C.H. de Lassus St-Genies, to be published
4. Apollo 14 preliminary science report, NASA SP-272 (1971)
5. SHRELLDALFF, Proceedings of the Apollo 11 Lunar Science Conference 1503 (1970)

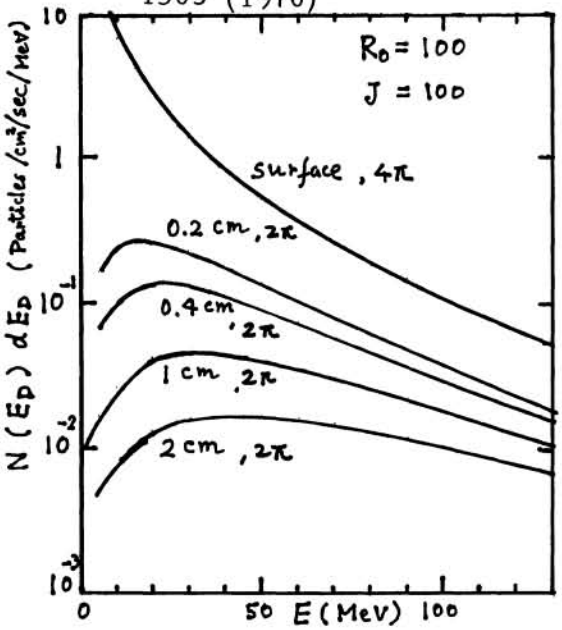

Fig. 1 Differential flux of solar protons as a function of depth

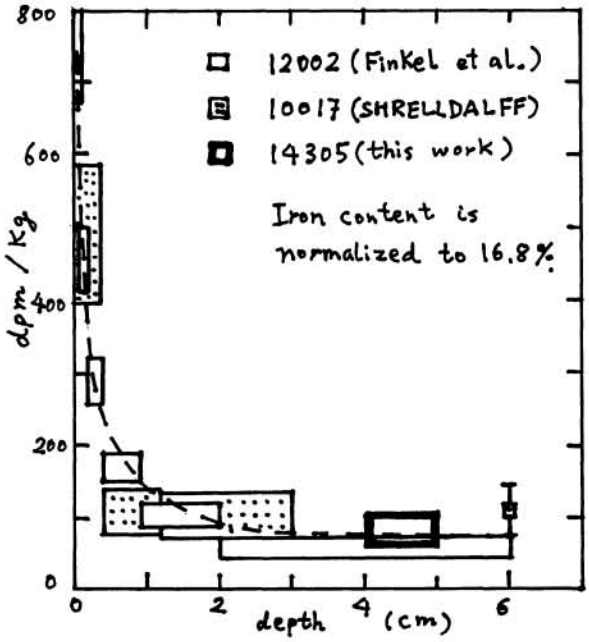

Fig. 3 Fe-55 in lunar rocks

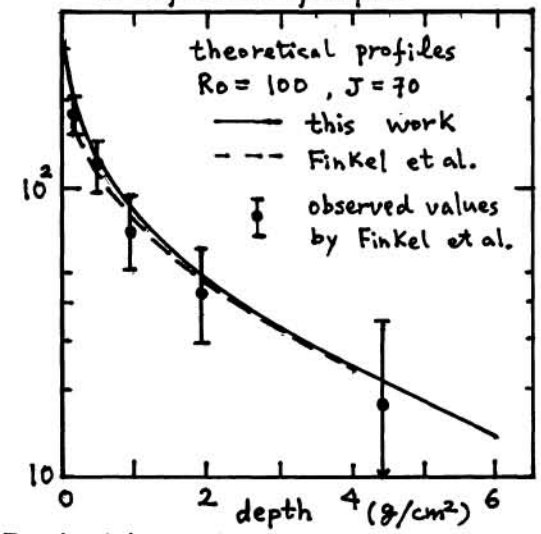

Fig. 4 Solar production of Al-26 in rock 12002

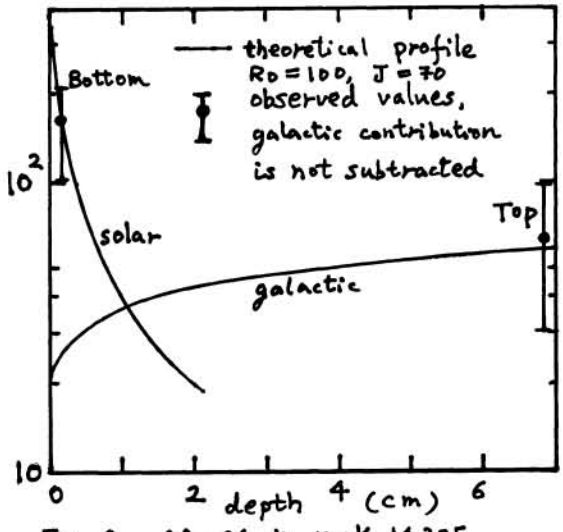

Fig. 2 Al-26 in rock 14305

© Lunar and Planetary Institute • Provided by the NASA Astrophysics Data System