CARBON-14 IN LUNAR SOIL, E. L. Fireman, J. DeFelice, and J. D'Amico, Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts 02138

Measurements of the carbon-14 temperature release from lunar surface soils give measurable amounts of carbon-14 released between 600 C and 1000°C; however, no carbon-14 was released at these temperatures for subsurface soils (1,2,3). We assigned a solar-wind origin to the 600-1000°C component of carbon-14. If so, this carbon-14 component in surface soils should exhibit the same type of inverse grain-size dependence (i.e., surface correlation) as the rare gases (4,5). Des Marais et al. (6) observed an inverse grain-size dependence for the carbon concentration for size fractions of < 100 μM. We therefore undertook a study of the grain-size dependence of the 600-1000°C released carbon-14.

We were allocated ~1.0-g splits of the < 10, 10-30, 30-37, 37-74, 74-125 μM fractions of 10084 soil separated by King et al. (7). King et al. (7) sieved 14.63 g of 10084 soil and obtained 1.34 g of the < 10 μM, 3.74 g of the 10-30 μM, 1.31 g of the 30-37 μM, 2.51 g of the 37-74 μM, 1.86 g of the 74-125 μM, and 3.83 g of the > 125 μM sized grains.

Our procedures for carbon extraction, conversion of the extracted compounds to CO_2, and CO_2 purification have not changed (1). We extract the carbon compounds from a lunar soil sample in a molybdenum crucible, by raising its temperature with resistance heating and then holding its temperature constant for 4 hr while the gases are removed with an automatic toepler pump. The temperatures were 400, 600, 800, and 1000 °C. We heat the sample above its melting point for 4 hr by induction heating and remove the gases. We then repeat the melting at a higher (>1500°C) temperature and remove the gases again. The collected gas is passed over CuO at 650°C, which converts the carbon compounds to CO_2. The CO_2 is condensed in a trap at -196°C, recovered from the trap at -78°C, and measured in a standard volume. To purify the CO_2 from radon, the CO_2 is converted to CO over Zn at 300°C. The gases that condense from CO at -196°C are removed. The purified CO is then reconverted to CO_2 over CuO. On the basis of stoichiometry, no carbon is lost in the Zn purification.

The amounts of CO_2 obtained from an extraction ranged between 0.11 and 2.1 cm^3 STP. The CO_2 is put into a small proportional counter, the CO_2 pressure is kept under 1 atm and argon is added to the counter until the pressure of the gas is 1.5 atm. In our previous measurements (1,2), only counters of 0.7 cm^3 volume were used, and, on occasion, we had to count aliquots. We have constructed similar counters of 2.5 cm^3 volume and the more appropriately sized counter is now used for counting total amount of CO_2. Counters of both sizes have energy resolutions of 20%. The counter backgrounds were determined with similar gas fillings using CO_2 from a petroleum source. The 0.7 and 2.5 cm^3 counters had backgrounds of approximately 3 and 6 counts/day, respectively, above 7 keV energy. Carbon-14 activity is distinguished most easily from the counter background above 7 keV. When filled with less than 0.5 atm of CO_2, the efficiencies for counting carbon-14 above 7 keV are 25 and 35 ± 3% for the smaller and larger counters, respectively. The backgrounds and efficiencies rise with CO_2 pressure above 0.5 atm. When the CO_2 pressure is above 1.0 atm, the operating voltages approach 2500 V and breakdown pulses occur.

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Table 1 gives the 400-1000°C temperature-released carbon-14 from the 10084 samples that we analyzed. There was little carbon-14 released at 400°C from any of the size fractions. At 600°C, there was significant carbon-14 released from the <10 μM fraction but not from the larger fractions. At 800°C, the <10 μM fraction released 26.5 dpm/kg of carbon-14, which was three times the amount released from the 10-30 μM and six times the amount released from the 30-37 μM fractions. However, at 1000°C, the <10 μM fraction released about the same amount of carbon-14 as the 30-37 μM fraction and less than that released from the 10-30 μM fraction. The sum of the 600-1000°C releases are 40.4 ± 2.5, 26.0 ± 2.5, 7.8 ± 1.7, and 3.7 ± 1.7 dpm/kg of carbon-14 for the <10, 10-30, 30-37, and 74-125 μM fractions, respectively. Within the accuracy of the measurements, the 600-1000°C carbon-14 is inversely proportional to the mean grain diameters.

The carbon-14 in the melts that followed the 1000°C heatings and the remelts are also given in Table 1. The amount of carbon-14 in the melt of the <10 μM fraction, 36.0 ± 2.7 dpm/kg, was similar to the amount obtained from the 74-125 μM fraction, 30.1 ± 5.0 dpm/kg. There were smaller amounts of carbon-14 from the melts of 10-30 and 30-37 μM fractions; however, on the basis of remelts, not all the carbon-14 was extracted from the 30-37 μM fraction. Reedy and Arnold (8) calculated the spallation production rates for carbon-14 from galactic cosmic rays to be 19 dpm/kg. Begemann et al. (9) measured the total carbon-14 in bulk 10084 soil to be 39 ± 4 dpm/kg. The total carbon-14 in the <10 μM fraction is twice the bulk value and four times the value calculated for galactic cosmic rays.

References

(1) Fireman E. L., DeFelice J., and D'Amico J. (1976) Earth Planet. Sci. Lett., 32, pp. 185-190.
(2) Fireman E. L., DeFelice J., and D'Amico J. (1976) Proc. Lunar Sci. Conf. 7th, pp. 525-531.
(3) Fireman E. L., DeFelice J., and D'Amico J. (1977) Proc. Lunar Sci. Conf. 8th, pp. 3749-3754.
(4) Eberhardt P., Geiss J., Graf H., Grögler N., Krähenbuhl U., Schwaller H., Schwarzmüller J., and Stettler A. (1970) Proc. Apollo 11 Lunar Sci. Conf., pp. 1037-1070.
(5) Hintenberger H., Weber H. W., Voshage H., Wänke H., Begemann F., and Wlotzka F. (1970) Proc. Apollo 11 Lunar Sci. Conf., pp. 1269-1282.
(6) DesMarais D. J., Hayes J. M., and Meinschein W. G. (1973) Proc. Lunar Sci. Conf. 4th, pp. 1543-1558.
(7) King E. A. Jr., Butler J. C., and Carman M. F. Jr. (1971) Proc. Lunar Sci. Conf. 2nd, pp. 737-746.
(8) Reedy R. C. and Arnold J. R. (1972) J. Geophys. Res., 77, pp. 537-555.
(9) Begemann F., Vilcsek E., Rieder R., Born W., and Wänke H. (1970) Proc. Apollo 11 Lunar Sci. Conf., pp. 995-1005.

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Table 1. Carbon-14 temperature-release patterns.

Sample	10084.941	10084.1519	10084.939	10084.937
Weight (g)	1.26	1.01	1.28	1.00
Grain size (μ)	<10	10-30	30-37	74-125
Temp. °C	^{14}C (dpm/kg)	^{14}C (dpm/kg)	^{14}C (dpm/kg)	^{14}C (dpm/kg)
400	2.1 ± 0.9	2.3 ± 1.4	0 ± 0.8	2.2 ± 1.2
600	8.9 ± 0.9	0 ± 1.1	0.5 ± 0.8	2.4 ± 1.2
800	26.5 ± 2.0	8.0 ± 1.2	4.2 ± 1.3	1.5 ± 1.2
1000	5.0 ± 0.8	18.0 ± 1.8	3.6 ± 1.0	-0.2 ± 1.2
Sum (600-1000)	40.4 ± 2.5	26.0 ± 2.5	7.8 ± 1.7	3.7 ± 2.1
Melt	36.0 ± 2.7	21.3 ± 2.1	4.0 ± 1.5	30.1 ± 5.0
Remelt	5.8 ± 2.3	3.6 ± 2.1	11.0 ± 1.0	-3.0 ± 2.5