K-Ar AGES AND DEPOSITIONAL CHRONOLOGIES OF APOLLO 15 DRILL CORE FINES, R. O. Pepin, J. R. Basford, and J. C. Dragon, School of Physics and Astronomy, and M. R. Coscio, Jr. and V. R. Murthy, Department of Geology and Geophysics, University of Minnesota, Minneapolis, Minnesota 55455.

Rare gas isotopic compositions and abundances, and concentrations of K, Rb, Sr and Ba were measured in suites of four grain-sized fractions of 25 mg soil samples taken from the base of each of the six Apollo 15 drill stem sections. K-Ar ages were determined from correlations of $^{40}Ar/^{36}Ar$ *vs.* $K/^{36}Ar$ over grain-sized separates of each sample(1). Isotopic compositions of surface-correlated rare gases, and concentrations of spallogenic isotopes, were deduced from intercepts and slopes of ordinate intercept correlations, corrected for spallation target element variations where data were available (2,3). We limit this report to discussion of Ar data.

The distribution of K-Ar age with depth in the drill core is shown in Fig. 1. The data are consistent with (a) a roughly uniform age of 2.9±0.2 AE for the section between 65 gm/cm^2 and 340 gm/cm^2, with the deep sample 15001 older at ≃ 3.3 AE; or (b) progressively older material at increasing depth, with the age increasing by ~ 450 my. down the lower 350 gm/cm^2 of the core. Although the data are not sufficiently precise to rule convincingly between these alternatives, one central conclusion seems evident: the soils comprising the regolith penetrated by the drill string were outgassed in a major thermal event ~2.9 AE ago, or in a series of such events spanning a few hundred million years around 2.9 AE. Among the comparatively few soils studied by the K-Ar isochron method or by similar techniques, there is now evidence from five of the eight sampled lunar sites for large-scale thermal energy input into regolith materials during the period 2.5 - 3 AE ago(4,5).

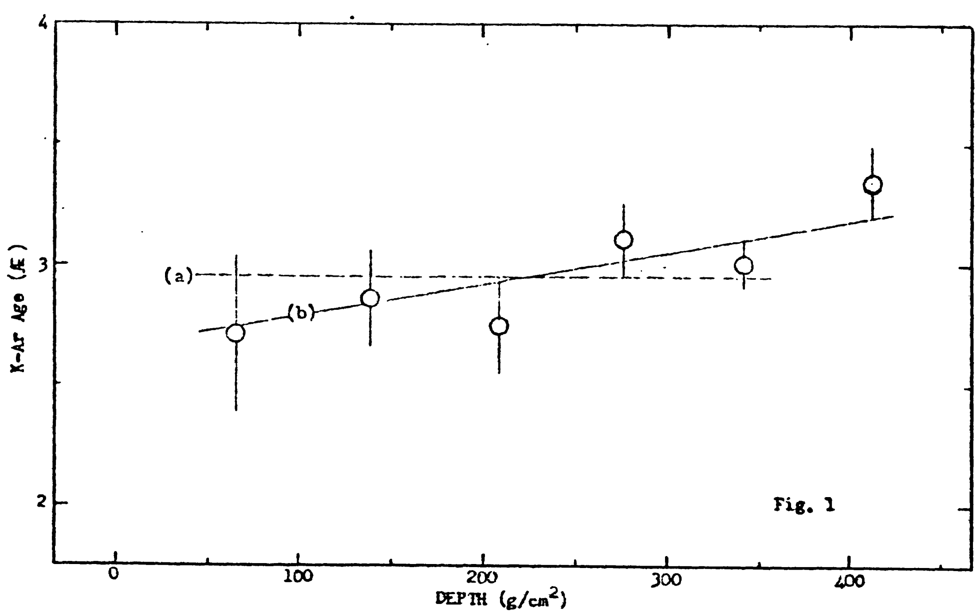

Fig. 1

CHRONOLOGIES OF APOLLO 15 DRILL CORE FINES

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Measurements of isotopic variations in Gd and Sm with depth in the Apollo 15 drill core fines have revealed smoothly varying neutron fluences which are in quantitative accord with a depositional history consisting of rapid deposition of pre-irradiated regolith, *in situ* irradiation of the section for the past ~450 my., and recent addition of a surface layer of thickness ~35 g/cm^2 (6). We have examined the concentrations of spallation-produced ^{38}Ar as a function of depth for additional clues to the depositional chronology. $^{38}Ar_{sp}$ varies smoothly down the section, as shown in Fig. 2. The depth dependence differs from that of the neutron fluence data, plotted for comparison in Fig. 2; the shallower peak is entirely consistent with production by higher energy galactic-cosmic-ray secondary particles than the <0.18eV neutrons to which Gd is sensitive, as expected (7).

In calculating the integrated $^{38}Ar_{sp}$ production profiles expected for various depositional models, we have assumed that the production rate of $^{38}Ar_{sp}$ *vs.* depth is the same as that recently calculated for ^{37}Ar (7), to within a constant scaling factor. For the "instantaneous deposition" model, profiles were calculated as functions of TP_s^{38} (the product of post-accumulation *in situ* irradiation time T and the $^{38}Ar_{sp}$ *surface* production rate P_s^{38}), N_o (the concentration of $^{38}Ar_{sp}$ produced by pre-accumulation irradiation of these regolith materials, assumed constant throughout the section), and t_s (thickness of a possible surface slab of regolith deposited very recently at the drill core site). Calculated profiles converge strongly to the measured profile for $TP_s^{38} \rightarrow 28 \times 10^{-8}$ ccSTP/g, $N_o \rightarrow 15 \times 10^{-8}$ ccSTP/g, and $t_s \rightarrow 45$ g/cm^2 (Fig. 2). There are no fits for the cases $N_o = 0$ and/or $t_s = 0$. P_s^{38} was estimated by assuming that a typical sampled lunar soil has been irradiated at or above a regolith depth of ~1 m; the average $^{38}Ar_{sp}$ production rate $\langle P^{38} \rangle$ is then $\cong 1.93 P_s^{38}$, deduced by integration over the

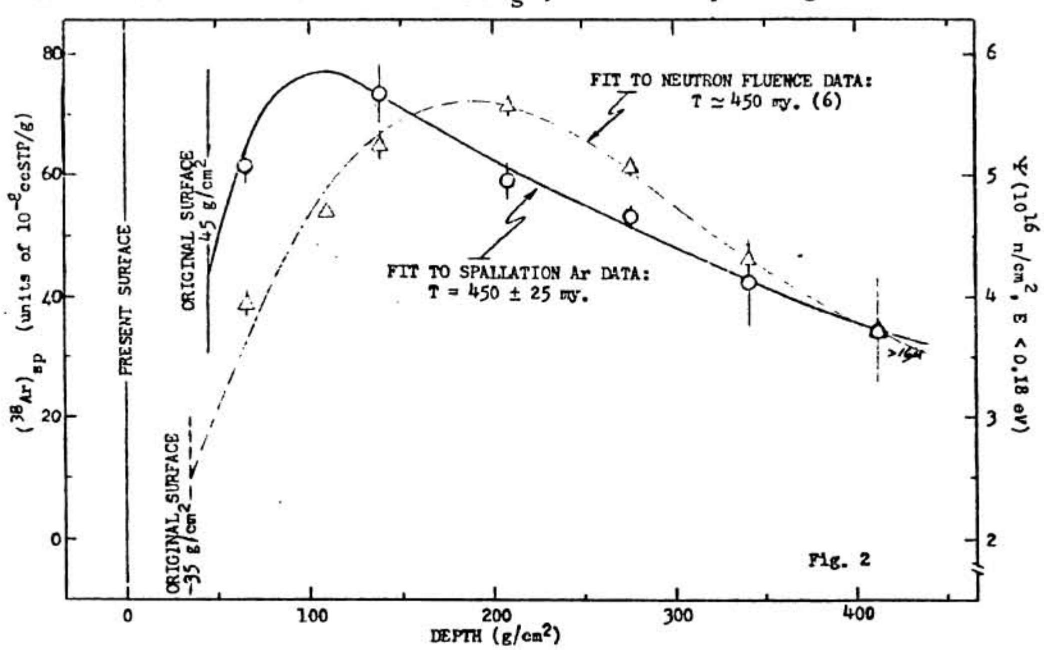

Fig. 2

^{37}Ar production rate profile to this depth. The calculation is insensitive, within comparatively wide limits, to the choice of maximum irradiation depth: $\langle P^{38} \rangle$ is within 10% of $1.93P_s^{38}$ for depths ranging from 30-150 cm. $\langle P^{38} \rangle$ was taken equal to 1.69×10^{-8} ccSTP/g(Ca)-my., the average measured production rate in ~50 Apollo 11 and 12 soils(8). P_s^{38} is then 8.8×10^{-9} ccSTP/g(Ca) -my. = 6.25×10^{-10} ccSTP/g-my. for the drill core samples. With this choice, the *in situ* irradiation time for the lower ~370 g/cm^2 of the drill core is T = 450 ±25 my., where the error reflects the convergence of the calculated and measured profiles in Fig. 2; it does not include uncertainty in P_s^{38}, which may be larger.

Other depositional models are in agreement with measured $^{38}Ar_{sp}$ profile. One we have considered in detail involves steady accretion of initially unirradiated regolith at a rate ρ g/cm^2-my. to a depth ~40 g/cm^2 below the present surface, followed by *in situ* irradiation of the accreted section for time T, and recent deposit of the final surface layer. Here, the best fit of calculated and measured profiles yields ρ = 2.7 g/cm^2-my. ($T_{accretion}$ ~150my.) and T = 520 my. Similar (but not identical) models have been shown to satisfy the neutron fluence data as well(6).

For instantaneous deposition, the detailed histories of the Apollo 15 drill core fines as separately described by model fits to measured neutron fluence and Ar spallation profiles are in impressive agreement. An important element in these coherent chronological descriptions is the fact that the depth dependencies of the two measured profiles are sufficiently different (~100 g/cm^2 between production rate peaks in Fig. 2) that no reasonable probability remains that either profile results from the fortuitous juxtaposition of variably pre-irradiated depositional layers in the core section. It seems clear that the lower 370 g/cm^2 of the core material has experienced no significant vertical mixing for $\geq$ 450 my.

REFERENCES

(1) Venkatesan T.R., Johnson N.L., Pepin R.O., Evensen N., Coscio M.R.Jr. and Murthy V.R.(1974) K-Ar dating of lunar fines: the Apollo 17 dark mantle.†

(2) Eberhardt P., Geiss J., Graf H., Grögler N., Krähenbühl U., Schwaller H., Schwartzmüller J. and Stettler A. (1970)Proc. Apollo 11 Lunar Sci. Conf., *Geochim. Cosmochim. Acta* Suppl. 1, Vol. 2, pp. 1037-1070. Pergamon.

(3) Basford J.R., Dragon J.C., Pepin R.O., Coscio M.R.Jr. and Murthy V.R. (1973). Proc. Fourth Lunar Sci. Conf., *Geochim. Cosmochim. Acta* Suppl. 4, Vol. 2, pp. 1915-1955. Pergamon.

(4) Pepin R.O., Bradley J.G., Dragon J.C. and Nyquist L.E. (1972). Proc. Third Lunar Sci. Conf., *Geochim. Cosmochim. Acta* Suppl. 3, Vol. 2, pp. 1569-1588. MIT Press.

(5) Basford J.R. (1974) Potassium-argon analysis of Apollo 11 regolith. In "Lunar Science V", pp. . The Lunar Science Institute, Houston.

(6) Russ G.P.III, Burnett D.S. and Wasserburg G.J. (1972). *Earth Planet. Sci. Lett.* 15, 172-186.

(7) Reedy R.C. and Arnold J.R. (1972) *J. Geophys. Res.* 77, 537-555.

(8) Bogard D.D., Funkhouser J.G., Schaeffer O.A. and Zähringer J. (1971), *J. Geophys. Res.* 76, 2757-2779.

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