A STUDY OF GARDENING IN THE LUNAR REGOLITH USING ^{53}Mn,

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^{53}Mn ($t_{1/2}$ = 3.7 m.y.) activities have been determined in samples from the upper 48 g/cm^2 of the Apollo 16 drive tube 60010. ^{53}Mn activities were also measured in the 18 to 37 g/cm^2 region of the Apollo 15 and Apollo 16 deep drill stems. These new data along with previous work (1, 2, 3, 4) are intended to determine the depositional histories of specific lunar sites and the distribution of such histories on the time scale measurable by ^{53}Mn.

The double core tube used to collect 60010 has been shown by Carrier et al (5) to induce considerably less disturbance in sampling than some earlier core tubes; in addition, the ^{22}Na data of Fruchter et al (6) suggest that 60010 was not disturbed during sampling and subsequent handling. The ^{53}Mn profile for 60010 (Fig. 1) suggests gardening to a depth of 7 g/cm^2 in the last ∿7 m.y. The depth integrated ^{53}Mn activity to 7 g/cm^2, excluding sample #232 in the 3.8-4.8 g/cm^2 region, is 11% over that calculated by Reedy and Arnold (7). This excess suggests addition of solar cosmic ray (SCR) exposed material to this site within the last ∿10 m.y., perhaps as the result of the filling of a small crater. The surface samples from the top 1 g/cm^2 of 60010 were measured at 0.2 g/cm^2 intervals. The improved depth resolution shows a slight decrease in the ^{53}Mn activity at the surface; this low activity implies gardening in the 1 g/cm^2 region within the last 2 m.y. A slight decrease in the ^{53}Mn activity in the 1-3 g/cm^2 region is a common feature in the sites studied by our group (Fig. 2); this result is in good agreement with the ^{26}Al data of Fruchter et al (6). They conclude that substantial mixing through at least the 4-6 g/cm^2 region on a million year time scale is a common process on the lunar surface.

The samples from 60010 contain on the average 4.3% Fe, 31 ppm Co, and 0.05% Ni; however, 60010,232 from the 3.8-4.8 g/cm^2 region contains 6.7% Fe, 210 ppm Co, and 0.32% Ni. This suggests that this section of the core contains meteoritic materials which are probably metallic fragments. The chemical excess in sample #232 normalized to 100% Fe, Co, and Ni yields Fe = 89%, Co = 0.65%, and Ni = 10%. This result is in adequate agreement with the chemical composition of a 1 mm shiny metallic fragment found in 60010,40 from the 5.7-8.6 g/cm^2 region. This fragment was determined by Ali and Ehmann (8) to contain Fe = 93.2%, Co = 0.363%, and Ni = 6.41% normalized to 100% Fe, Co, and Ni. Our sample #228 in the 5.7-6.7 g/cm^2 region (the same depth region which contained their metal fragment) showed no such chemical excess. The higher Co and Ni content of the material in our sample #232 might be due to an admixture of taenite. The ^{53}Mn activity of 514 dpm/kg Fe found in sample #232 is much greater than the expected value of ∿410 dpm/kg Fe estimated by interpolation from the adjacent samples. The ^{53}Mn activity due to the meteoritic component is calculated to be ∿700 dpm/kg Fe; this high activity requires the meteoritic fragments to be surface material from a recent impact event. The SCR produced ^{53}Mn activity within the first 0.5 mm of a meteorite is calculated to be ∿1000 dpm ^{53}Mn/kg Fe; assuming the fragments had this

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value, the meteorite fell within the last 2 m.y. Measuring individual grains in the 4-10 g/cm^2 section of this core should produce new information concerning this meteoritic material; we plan to do so.

In our previous ^{53}Mn work (3), we concluded that the Apollo 16 drill stem, 60007, had been gardened to $\geq$14 g/cm^2 in the last ∿10 m.y. Our recent ^{53}Mn measurements in the 18 to 37 g/cm^2 region of this core now indicate gardening to $\geq$19 g/cm^2 within the last ∿12 m.y. (Fig. 1). The depth integrated activity to 19 g/cm^2 is 50% over that calculated by Reedy and Arnold (7). ^{53}Mn measured in the 25 g/cm^2 section is at the predicted activity level and therefore shows no evidence of additions of near surface material to this depth on a time scale measurable by ^{53}Mn.

The Reedy-Arnold (7) theoretical production rate for ^{53}Mn as a function of depth indicates that the saturation activity should be nearly constant between 20 and 100 g/cm^2. We have previously renormalized the theoretical galactic cosmic ray (GCR) curve for ^{53}Mn in the lunar soil to the values obtained in this depth interval (4). Fourteen points in the 20 to 100 g/cm^2 region from four cores have been measured to date (Fig. 2). These cores have been gardened to various depths, and in at least one case, material was lost during sampling and subsequent handling; however, the theoretical renormalized GCR curve fits nicely all points in the 20 to 100 g/cm^2 region.

The impact gardening model of Arnold (9) predicts a typical disturbance depth on the order of 10-20 g/cm^2 over the mean life of ^{53}Mn; this is in agreement with our data. Based on this model, a gardened profile for the moon-wide average of ^{53}Mn as a function of depth has been derived. Of the four cores studied by our group, 12025, 60007, and 60010 fall above this new curve. Because of suspected loss of 3-4 g/cm^2 of material from the surface of 15006 (6), it is difficult to predict whether the integrated ^{53}Mn activity would be high or low; however, even allowing for the loss, the data for this core lie below the gardened profile. ^{53}Mn measurements in more cores are required to test the accuracy of the average gardened profile.

References:

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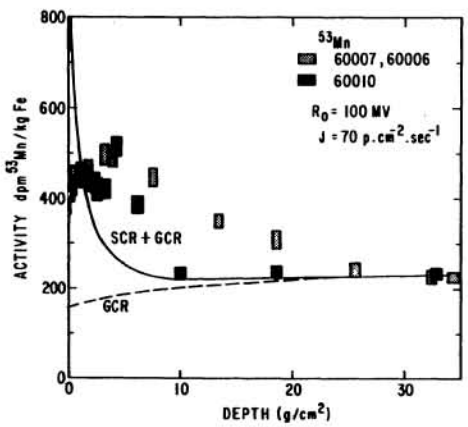

Figure 1.

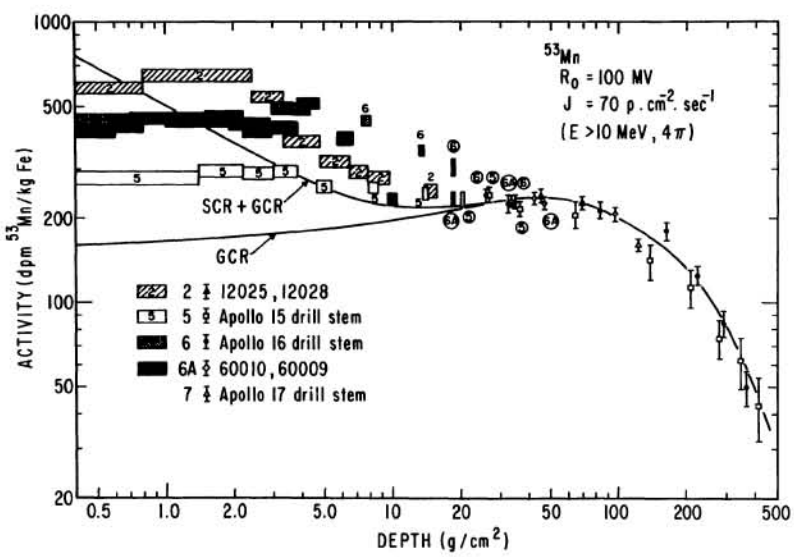

Figure 2.
(60010 and circled numbers measured in this work.)