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LUNAR SURFACE DYNAMICS:
SOME GENERAL CONCLUSIONS AND
NEW RESULTS FROM APOLLO 16 AND 17

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ABSTRACT

Exposure ages of Apollo 17 rocks as measured by tracks and the Kr-Kr rare gas method are reported. Concordant ages of 22 ± 1 my are obtained for the station 6 boulder sample 76315. This value is interpreted as the time when the station 6 boulder was emplaced in its present position. Reasonable agreement is also obtained by the two methods for another station 6 boulder, sample 76015. Discordant ages (respectively 5 and 28 my by the track and rare gas methods) are obtained for the station 7 boulder sample, 77135, indicating that the boulder was emplaced at least 5 my ago. The 72 my exposure age of 75035, in general agreement with previous measurements of ∿85 my for another Camelot boulder, may well date the formation of Camelot. Rock 76015 was split and one surface exposed to the sky through a very small solid angle. The solar flare track record in this surface is similar to that previously observed in the Surveyor III glass. Track measurements in the soil collected at station 3 on the rim of Ballet Crater strongly suggest a crater formation age between 5 and 20 my. Analysis of the 29.5-31.5 cm interval in the Apollo 17 deep drill core shows that ∿98% of the crystals were emplaced without prior irradiation in a single event. Future analyses of these crystals should extend the energy range of fossil cosmic ray studies. The deposition of the layer was ∿10 my ago. Either the layer is not associated with Camelot, as has been previously suggested, or the 72 my age of Camelot given above is not correct. A review of experimental rates for lunar dynamical processes is presented. No compelling evidence is found showing a drastically reduced flux of micrometeoroids in the past (as has been suggested by a number of authors).

This paper is divided into two parts. We first give new results on Apollo 17 samples and then discuss certain general aspects of lunar surface dynamics. The exposure ages of Apollo 17 rocks as measured by tracks and rare gases are discussed first. We then describe measurements of a unique rock that will help permit the establishment of the long-term energy spectrum of solar flare heavy particles. The track record of several Apollo 17 soils is treated next. It is shown that the Apollo 17 deep drill stem promises to greatly extend the energy range over which the fossil record of galactic cosmic rays can be studied.

The last part of the paper gives a review of various experimental rates for lunar dynamic processes. Previous authors have suggested that the current flux of micrometeorites may be an order of magnitude higher than the flux averaged over the last million years or so. (For a general review of the status of micrometeoroid measurements, see Hörz et al., 1973.) Our review of the experimental data leads to a lower ratio between past and present fluxes. In fact, we see no compelling evidence at this time that the ancient flux of larger micrometeoroids ($m > 10^{-6}$g) has been markedly different than the current flux.

EXPOSURE AGES OF APOLLO 17 ROCKS

We report here measurements of cosmic ray exposure ages measured by rare gases and by fossil nuclear tracks. The rare gas ages are measured by the Kr-Kr method in which the amount of the radioactive isotope ^{81}Kr determines the production rates of the accumulated cosmogenic stable isotopes of Kr. Provided the sample has been irradiated in a fixed geometry, the Kr-Kr age gives a rigorously correct value for the exposure age. If, however, several episodes of irradiation have occurred, characterized by different production rates, then the "exposure age" does not measure a determinate interval of time.

As we have emphasized in previous publications (Behrmann _et al._, 1973; Drozd _et al._, 1974), a single determination of the apparent exposure age of a rock is not sufficient to establish the age of formation of a specific lunar feature. There are two ways in which the age of a feature can definitively be established. If, as in the case of the North Ray Crater and the South Ray Crater rocks (Behrmann _et al._, 1973; Marti _et al._, 1973; Drozd _et al._, 1974; Lightner and Marti, 1974), numerous samples from different boulders give the same age, then it is reasonable to assume that this age represents the formation of a specific lunar feature.

An independent way to establish the correspondence between an apparent exposure age and the actual age of formation of a specific feature is to obtain concordancy between the rare gas age and the fossil nuclear track age for a single sample. The rare gas effects are produced by galactic protons (and secondary cascade particles) that are capable of penetrating deeply into the lunar surface. In contrast, track ages are determined from the densities of galactic iron nuclei which are rapidly absorbed in lunar materials. There is thus a very different characteristic depth dependence of these two effects. If the track ages are concordant with the rare gas ages, then it is reasonable to assume that the sample has had a simple, one-stage irradiation history.

In work reported at the Fourth Lunar Science Conference (Walker and Yuhas, 1973) we calibrated the track production rates as a function of depth using the Kr-Kr determination of the age of rock 68815 from South Ray Crater. Using this calibration data to determine ages for other rocks that have been exposed for different times on the lunar surface assumes that the proton/iron ratio in the galactic cosmic radiation has not changed in the past. This basic assumption can be verified if concordancy is found for objects of different ages.

Our rare gas data for Apollo 17 rocks are shown in Table 1 and Table 2. The track data are given in Table 3. Also shown in Fig. 1 is a depth profile of the track density in lunar rock 76315.

To the rather limited list of lunar features whose ages of formation are definitely established, we now add the station 6 consortium boulder. Samples taken from 76315 give concordant track and rare gas exposure ages of 22 ± 1 my. We interpret this age as the time when the station 6 boulder was emplaced in its present position. Although it is possible that both rare gas isotopes and tracks accumulated before the boulder rolled down the slope of the North Massif, this seems to us improbable. The removal of as little as 1.5 cm of material in the process of rolling would cause a discordancy between the rare gas and track ages. From the amount of debris along the boulder track, we think it unlikely that less than 1.5 cm was removed in the rolling process and believe, therefore, that the rare gases and tracks were accumulated <u>after</u> the rolling event.

This interpretation is further supported by our work on sample 76015. As shown in Tables 2 and 3, the track age and the rare gas age of this sample are again approximately concordant at ∿20 my. The Kr-Kr age of 76015 is measurably lower than 76315, but this can be attributed to a reduction of shielding (probably by impact spalling) at some time in the past. Rock 76015 was split off from the main boulder and was lying in a loose position. It clearly could not have been in this state at the time the boulder was emplaced. From solar flare track data given in the next section, we estimate that the split occurred ∿1 my ago.

The station 7 boulder sample 77135 gives a Kr-Kr age of 28 my and a track age of ∿5 my. The age of emplacement of the boulder can therefore not be definitely established from our data. The track data suggest that this boulder was emplaced at least 5 my ago. Since track ages can be affected by relatively minor removals of shielding that influence the rare gas ages only slightly, the rare gas age of 28 my may well be the true age of exposure. However, if some spallation krypton was accumulated prior to the time the boulder rolled down the hill, then the Kr-Kr exposure age is higher than the age of emplacement of the boulder. We thus cannot exclude the possibility that the station 6 and 7 boulders were simultaneously emplaced at the time of a large moonquake.

Rock 75035, collected from the rim of Camelot Crater, has a Kr-Kr age of 71.7 ± 1.8 my. This is close to the approximate Ca-Ar age of 85 my reported by Kirsten _et al_. (1973) for rock 75055, also from the rim of this crater. This concordancy allows us to tentatively establish the age of Camelot as 72 ± 2 my. However, we feel that this conclusion is not completely firm at this time. Data on the deep drill stem of Apollo 17, discussed below, suggest that Camelot could be much younger.

UNIQUE SOLAR FLARE TRACK RECORD IN ROCK 76015

Lunar rock surfaces that have been exposed to the sun show a rapidly decreasing density of tracks in the first millimeter of depth. The very high density of tracks and the rapid decrease with depth clearly identify these tracks as having a solar flare origin. However, the depth dependence in most lunar rocks is very much flatter than that which would be expected from measurements of contemporary solar flares.[†] The data for contemporary flares stems primarily from a sample of glass removed from the Surveyor III spacecraft.

The difference between the steep spectrum expected and the flat spectrum measured in older lunar rocks has been attributed by us and others to the effects of microerosion of lunar rock surfaces (Barber _et al._, 1971; Crozaz _et al._, 1971; Fleischer _et al._, 1971a).

Although this is an attractive interpretation, it has not been heretofore possible to prove that the long-term solar flare spectrum averaged over long times was, in fact, the same as the Surveyor spectrum measured over a period of 3 years. The possibility remained that the average solar flare spectrum had differed substantially in the past.

[†] Certain young surfaces, including a vug crystal that was also exposed to a limited portion of the sky, have exhibited steep spectra (Hutcheon _et al._, 1972; Neukum _et al._, 1972; Schneider _et al._, 1972, 1973). However, all these surfaces were exposed in the last 10^3 to 10^5 yrs.

At least two different samples brought back from the moon on Apollo 17 can be used to remove this uncertainty. One of these rocks (72315) has been measured extensively by Hutcheon et al. (1974) and is discussed in their paper in this conference proceedings. The other rock was received relatively recently by us and is described here. Both rocks have the virtue that they have an irradiated surface that was exposed to the sky only through a very small solid angle. As a consequence of the small solid angle factor, the effects of erosion over even long periods of time are minimal. It is thus possible to investigate the solar flare spectrum without the complication of erosion.

A schematic diagram showing the orientation of rock 76015 and its exposure to space is shown in Fig. 2. At some time in the past, rock 76015 was partially split away from the parent boulder. The interior surface was then exposed to space through a narrow solid angle. The effects of this partial exposure can be seen in a striking fashion in Fig., 3 which shows the variation of patination on this interior surface from the top to the bottom of the cleft.

The track data shown in Fig. 4 exhibit a much more rapid decrease with increasing depth than is observed in most lunar rocks; the behavior is similar to that in the Surveyor III glass for depths greater than ∿20 microns. To compare the two results precisely, however, it is necessary to derive an energy spectrum from the rock 76015 data, and this conversion requires a more detailed knowledge of the geometry of irradiation than we currently possess. Although a preliminary analysis indicates reasonable agreement with our previously published Surveyor spectrum, we prefer to defer discussing the details of the long-term energy spectrum until we perform additional measurements.

Our preliminary results also appear to differ somewhat from the more detailed measurements reported by Hutcheon _et al_. (1974) on rock 72315. If these differences persist after additional work, they would suggest directional anisotropies in the average solar flare energy spectrum. Such an anisotropy was reported for one flare by Rancitelli _et al_. (1974) at the Fifth Lunar Science Conference.

Our estimate of the exposure age of the internal surface of rock 76015 is based on our previous measurements in the Surveyor glass. Unfortunately, the Surveyor glass determination of the absolute fluxes is somewhat in question. Determination of an exposure age also depends on knowing the geometry of irradiation; as previously indicated, this is presently not well measured. In principle, an exposure age could be obtained by measuring the track density at a point deep enough in the rock, where the track background would be dominated by galactic cosmic rays and then using the track production rates given by Walker and Yuhas (1973). However, the large track background acquired prior to the splitting of 76015 makes this approach most difficult.

Determination of the absolute rate of solar flare track production is an important problem. In conjunction with impact pit counts, such tracks are used to measure the absolute rate of impact pit formation on young surfaces. In addition to rock 72315 discussed by Hutcheon _et al_. (1974), there appear to be other samples from both the Apollo 16 and 17 missions where independent determinations of the absolute rate of solar flare production appears to be possible (D. Morrison, private communication). These rocks are covered with glass splashes that are sufficiently large to permit Kr-Kr age determinations. The rocks also appear to be unsaturated with impact pits so that erosion effects should be minimal or, in any case, directly measurable from the smooth glass coatings.

TRACK RECORD OF APOLLO 17 SOILS

In Fig. 5,we show measurements of the distribution of track densities in various Apollo 17 soils. All measurements were made in feldspar crystals removed from the > 200 mesh fraction. Etching techniques were identical to those previously used by us. Densities $\geq 10^7$ tracks/cm^2 represent total pit counts made with a scanning electron microscope. On samples where the track density is low ($\leq 10^7$ tracks/cm^2) densities were measured optically. The low track densities indicate exposure at depths > .5 cm where the track production rates of Walker and Yuhas (1973) are applicable.

Soil samples in the sequence 73220 to 73280 were taken from the trench at station 3. The trench was dug into the rim of a 10 m crater (Ballet Crater), exposing a marbled zone of light and medium gray material at the bottom. This marbled zone was covered with a 3 cm thick layer of light material which, in turn, was capped by a 0.5 cm zone of medium gray material. The topmost sample 73220 was taken from this surface layer and appears typical of soils in the region. The second sample, 73240, is from the upper 5 cm of material and appears to be typical of the light material kicked up in several areas near the trench site;

some gray material is probably also present in this sample. The third and fourth samples, 73260 and 73280, are both taken from the marbled zone at a depth 5 to 10 cm below the surface. The former sampled the gray material and the latter the lighter material of the zone.

The combination of track data on these trench samples, coupled with our measurements on rock 73275, suggest strongly that the age of Ballet Crater lies between 5 and 20 my.

It can be seen from Fig. 5 that 73241,16 has the lowest track density of any of the other trench samples studied. While the other samples taken from this same trench have ∿50% of the grains with track densities > 2×10^8 tracks/cm^2, only 15% of the grains studied in 73241 exceed this value. This layer is therefore distinct. The clustering of points at the lower end is what would be expected if the soil contained a component that had been irradiated in situ with no pre-irradiation. There are, however, a few very high track density crystals, and it is clear that there is at least one other pre-irradiated component present.

If we take the maximum depth of the material from 73241 as 5 cm, the minimum track densities observed in this sample give an exposure age of 20 my. Since the crystals may have contained some tracks that were added prior to deposition of this layer, this is a maximum age for the formation of Ballet Crater where the trench was dug.

The light material (73261) and medium gray material (73281) removed from the marbled zone have similar track records; both are more heavily irradiated than the overlying light gray material (73241) but less irradiated than the 0.5 cm medium gray surface layer. This is somewhat different than the irradiation sequence found by Chang et al. (1974) who ordered the trench samples in the following decreasing order of solar wind content: 73261 ≥ 73221 > 73281 > 73241.

The interpretation given by Chang et al. (1974) to explain their results suggests a similar plausible, though not unique, model to explain the track results. The model is illustrated schematically in Fig. 6. Before Ballet Crater was formed, we assume that the region sampled was covered by a layer of light gray material. Subsequent to this, some medium gray material was deposited, covering the original light gray substrate. Ballet Crater was then formed. In the process of cratering, the layers were inverted. The inverted light gray-medium gray interface can now be seen as the marbled layer. Covering this is the light gray zone that was originally at a deeper depth where it accumulated less tracks. As a final step, medium gray material was deposited on the surface subsequent to the formation of Ballet Crater.

This scenario implies that the light gray material 73241 was at least partially irradiated prior to its final emplacement. The model age of 20 my derived above would thus be too old. In this connection it is interesting to note the track age of 5 my (see Table 3) for rock 73275 which was removed from the blocky rim of Ballet Crater close to the trench sample. The combination of the soil data with the data for 73275 suggest strongly that the age of Ballet Crater lies in the range from 5 to 20 my.

If it is assumed that the 0.5 cm medium gray surface layer built up gradually in time as a distinct component, these data fix the rate of accumulation of the material as lying between 0.25 and 1 mm/my.

The data in Fig. 5 shown for the "orange" soil 74220 are for feldspar crystals and not for the orange glass spherules themselves which show much lower median track densities of $5 \times 10^5/cm^2$ (Macdougall et al., 1974). The feldspar crystals were probably derived from the 0.5 cm gray soil covering the orange soil. The gray soil 74241 immediately adjacent to the orange soil is a typical heavily irradiated lunar soil.

Samples 72701 and 73221 were collected near the avalanche region. The soils are both heavily irradiated and, in analogy with other such soils, probably have spallation ages of several hundred million years. If the samples are representative of avalanche material, then the avalanche must date back at least this far.

Sample 72701 as well as sample 76261 collected from the base of the North Massif appear to be somewhat more uniformly heavily irradiated than the other soils. Although similar soils have been found by us and others in previous missions, it is possible that the observed uniformity reflects the topography of the region. Crystals rolling downhill might tend to receive more surface exposure than crystals residing in flat plain areas.

THE UNIQUE TRACK RECORD OF THE APOLLO 17 DEEP DRILL STEM

The upper one-meter section of the Apollo 17 deep drill stem consists of a coarse-grained layer that may have been emplaced in a single event. The Preliminary Science Report suggests that the emplacement of this thick layer may have been associated with the formation of Camelot Crater. Our preliminary track analysis of samples 70008-216, 224, 227, 230, 236, 238, 241 and removed from depths of 29.5-30 cm, 41-41.5 cm, 44-44.5 cm, 49-49.5 cm, 56-56.5 cm, 57.5-58 cm, and 61-61.5 cm respectively showed extraordinarily low numbers of particle tracks. The track densities at the deeper depths were lower than had ever been observed in any lunar samples. The densities also dropped off rapidly with depth. Our initial interpretation of these data was that the one-meter layer had been emplaced as an unirradiated layer and had lain completely undisturbed, at least at the deeper depths, since the time it was laid down. With this interpretation, the samples became extremely interesting. Measurement of the dependence of the track density vs. depth, as well as measurements of the track length distributions, would give information about ancient galactic cosmic rays at much higher energies than had been possible before. Based on the more easily measured higher densities in the 29.5 to 30 cm level quoted in the abstract for the Fifth Lunar Science Conference, we originally estimated the age of emplacement of the single layer as ∿50 my ago.

A more detailed analysis involving ∿500 crystals now indicates a more complicated history for the coarse-grained layer than we had originally envisioned. As shown in Fig. 7, the vast bulk of the crystals do indeed have very low track densities. However, some 2 percent of the crystals removed from the deeper depths have track densities that are much higher than the average.

There are several possibilities for the existence of these "interloper" crystals. They could have been introduced as a contaminant in the handling of the core tube samples either at Houston or in our laboratory. However, this seems to be unlikely. We consider it most probable that these crystals did indeed come from the depths indicated and that they were pre-irradiated prior to their being thrown out in the event that produced the distinct one-meter layer. This would be expected if a small fraction of the crystals had been rather close to the surface prior to their being ejected in the layer-forming event.

This interpretation is supported by the observations of Eberhardt et al. (1974) who measured a spallation age of 560 my for sample 70008,186 removed from a depth of 62 cm below the surface. This simultaneous measurement of an old spallation age in a sample with extremely low average track densities is somewhat surprising. Because of the different depths of penetration of protons and track-producing iron, such a result is possible; however, it has never before been observed in lunar samples. Since the track data are obtained on grains that are typically $\gtrsim$ 75 μm in size, one possibility is that the spallation rare gases are concentrated in a fine-grained fraction. Another possibility is that pre-existing tracks may have been largely removed by mechanical erasure in the event that produced the layer (Fleischer and Hart, 1973a).

In Fig. 7 we show a comparison of the experimental track data with theoretical curves for the expected depth dependence for a simply irradiated layer. Although the statistical quality of the data are poor, the densities measured in most crystals removed from the 40 cm to 60 cm interval appear to follow the predicted behavior. The interloper, high density, crystals, of course, lie off the theoretical lines. The point at the 29.5 to 30 cm depth also falls considerably above the lines defined by the 40 to 60 cm data.

These data suggest, but do not prove, that the crystals at the deepest depths consist of two components, one that was pre-irradiated prior to deposition and the other that started recording tracks when the layer was formed. If this is true, then the second class of crystals can be used to study the ancient record of cosmic rays.

The absolute track densities measured in the low-density component in the 40-60 cm depth interval lead to an estimated deposition time of $\sim$10 my. If this layer is indeed associated with Camelot, as suggested in the Apollo 17 Preliminary Science Report, this would be the age of Camelot Crater and not the 72 my age determined by the Kr-Kr method described above.

Although the issue cannot be resolved at present, the generally eroded appearance of the Camelot ejecta suggests that the older age is more probably correct. If this is true, the origin of the 1 meter layer remains an open question.

COMMENTS ON LUNAR SURFACE DYNAMICS

Various authors have suggested that the past flux of micrometeoroids was as much as a factor of ten lower than present-day values (for early references, as well as a summary of the lunar measurements made by various groups, see Hörz et al., 1973). In this section we give an independent review of the experimental data for the rates of several dynamical processes. Comparison with the calculated rates suggest that the striking discrepancies previously noted may have been more apparent than real.

Consider first the question of the survival lifetimes of lunar surface rocks. Gault et al. (1972) originally estimated that rocks in the 1 to 10 kg range would survive on the lunar surface for an average of 2 to 6 my before being catastrophically ruptured by micrometeoroid impacts. They noted that typical surface exposure ages measured by track methods were considerably higher than this.

In Table 4 we give a summary of all surface exposure ages of lunar rocks measured by track techniques through the Apollo 16 mission. Several rocks from Apollo 17 measured by us are also included. Six methods of age determination are listed. Methods A, B, and D rely on single-point determinations. They assume that all the tracks measured were accumulated while the rock was exposed in a single geometry. They are thus maximum surface exposure ages. This is not the case in method C, where a detailed profile of track density vs. depth is measured. Only the part of the profile that gives the expected depth dependence using the actual geometry of the rock measured is employed. At present we consider this the best method for determining the true surface exposure ages of lunar rocks. Method E, which is included here for completeness, is the "sun-tan" method originally described by Bhandari et al. (1972a,b). This method is sensitive to small changes in surface topography and ages derived this way are not included in what follows. Method F, the sub-decimeter age, is a model age that estimates the time the rock was irradiated while below the surface (Bhandari et al., 1972a,b).

The average surface exposure age for 24 selected rocks that fall in the 1 to 10 kg range is 13 my. Although this is higher than the

2 to 6 my calculated by Gault et al. (1972), it must be realized that most of the ages that go to make up this average were determined by methods A, B, and D and are thus maximum ages. As is also indicated in Table 4, most rocks when measured turn out not to have been irradiated in a single stage with fixed geometry, as is assumed in methods A, B, and D. In the several cases where detailed depth profiles have been measured, the average drops to ∿8 my. All in all, there appears to be no large discrepancy between experimental and predicted surface lifetimes.

Lunar erosion rates ranging from 0.5 mm to 2 mm/my have been calculated from present-day micrometeoroid fluxes (Hörz et al., 1973). These calculations refer to impacts that remove material primarily in steps of tens to many hundreds of microns - a process that we have previously called "mass-wastage" erosion (Crozaz et al., 1971). These rates have been erroneously compared to microerosional rates determined by measurements of solar flare tracks in lunar rocks (see Crozaz et al., 1971, for a fuller discussion of this point). Some authors have quoted very small rates of microerosion, and this led to the view that the experimental values were considerably lower than the predicted ones.

Although the current best estimate for microerosion lie in the range 0.3 to 0.8 mm/my (see Fleischer et al., 1974a,for a detailed discussion of this point), this is irrelevant. The calculated values should properly be compared to experiments that measure mass-wastage erosion. One such method is to compare galactic track ages measured in the interior portions of rocks with proton spallation ages. Typical values of 0.5 to

2 mm/my are determined in this fashion (Fleischer *et al.*, 1974a), although one extremely low value of $\lesssim 0.3$ mm/my has been reported (Fleischer *et al.*, 1971b). The depth profiles of radioisotopes in lunar rocks can also be used to measure mass-wastage rates, leading again to estimates ranging from 0.5 to several mm/my for different rocks (Finkel *et al.*, 1971; Wahlen *et al.*, 1972).

In summary, erosion measurements and predictions based on current micrometeoroid flux data seem to be in good agreement.

Comparison of the predicted and measured rates of impact pitting have also been used as arguments for a reduced micrometeoroid flux in the past. Table 5 shows a summary of impact pit and age data for rocks that have not been saturated with impact pits (such rocks are said to be in a production state). The data indicate an experimental rate of impact pit production of 1 to 3 craters/cm^2.my for craters with a central pit diameter $\geq$ 500 μm in size. Independent impact pit counts by our group on several well-dated surfaces give rates approximately twice as high when extrapolated to the 500 μm size (Crozaz *et al.*, 1971; Behrmann *et al.*, 1973). The experimental values are considerably smaller than the $\sim$8 pits/cm^2.my estimated by Hörz et al. (1973). However, it should be noted that most of the rock surfaces in Table 5 are older than 1 my. For such surfaces erosional effects on 500 μm size pits should be important. The surfaces may not be in a pure production state as was assumed. Although there appears to be a real difference between calculated and predicted rates, some or all of this may be due to the effects of erosion.

Gault _et al_. (1972) originally estimated that the first 6 cm of the lunar regolith would be turned over once, on the average, in a million years with present micrometeoroid fluxes. This prediction was in striking disagreement with the experimental measurements of the rates of turnover of lunar soil samples summarized in Tables 6 and 7. These data show that layers of 4 to 5 cm in thickness can remain relatively undisturbed for up to 20 my. However, the original estimates of turnover rates have been considerably modified; the revised estimates of Gault _et al_. (1974) reported at the Fifth Lunar Science Conference now agree with the experimental values.

There is a natural tendency to play with numbers until agreement with prediction is obtained; we may well be guilty of this tendency in our analysis. On the other hand, there is a responsibility on those who would demonstrate a particularly interesting effect, in this case dramatic changes in the interplanetary dust concentrations in the past, to prove their case. We hope that our conservative view of the situation given here will help to better define the current state of the problem.

Perhaps the best evidence for past fluctuations in the rate of micropitting is the recent work by Hartung _et al_. (1974) reported at the Fifth Lunar Science Conference. Using solar flare tracks to date individual microcraters, these authors found many more young pits than old ones. This interesting line of investigation certainly deserves to be pursued. However, the particles measured by Hartung _et al_. (1974) were typically much smaller than those responsible for most of the dynamic effects discussed above. Thus even if their observations were confirmed, it might turn out to be a separate problem from the one discussed here.

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Table 1. Krypton data (84 ≡ 100.).

	[84]†	78	80	81	82	83	86
73275	17.7	32.47 ±0.42	92.90 ±1.15	0.233 ±0.004	137.74 ± 1.55	176.31 ± 2.15	11.28 ±0.17
75035	24.8	12.14 ±0.05	35.58 ±0.07	0.174 ±0.005	64.69 ± 0.09	81.59 ± 0.11	21.12 ±0.01
76015	12.2	5.47 ±0.07	15.58 ±0.15	0.252 ±0.003	36.58 ± 0.25	41.63 ± 0.39	28.23 ±0.04
76315	5.59	8.74 ±0.23	23.85 ±0.54	0.347 ±0.013	48.24 ± 0.76	57.13 ± 1.12	26.95 ±0.06
76535	8.78	25.21 ±0.05	81.18 ±0.19	0.151 ±0.004	122.75 ± 0.29	161.68 ± 0.35	6.56 ±0.09
77135	6.52	9.25 ±0.21	28.51 ±0.54	0.327 ±0.009	54.28 ± 0.76	66.53 ± 1.11	24.08 ±0.13

† Concentrations of ^{84}Kr are given in 10^{-11}cm^{3}STP/g and are reliable to 10%.

Table 2. Krypton spallation spectra (83 ≡ 100.) and exposure ages.[†]

	78	80	81	82	84	$[U]_{ppm}$	P_{81}/P_{83}	Exposure Age (my)
73275	18.8 ±0.5	53.6 ±1.5	0.136 ±0.005	77.6 ±2.1	45.3 ±1.2	1.2[a]	0.623 ±0.012	139. ± 5.
75035	17.2 ±0.1	48.3 ±0.3	0.249 ±0.006	75.3 ±0.4	50.1 ±0.5	-	0.587 ±0.003	71.7 ± 1.8
76015	20.9 ±0.4	51.2 ±1.1	1.068 ±0.022	78.8 ±1.7	43.7 ±0.9	2.0[c]	0.617 ±0.010	17.5 ± 0.5
76315	20.4 ±0.8	51.0 ±2.0	0.856 ±0.041	78.3 ±2.9	43.0 ±1.4	-	0.614 ±0.017	21.7 ± 1.2
76535	15.3 ±0.3	49.2 ±1.0	0.085 ±0.002	75.2 ±1.5	62.4 ±1.3	0.054[b]	0.591 ±0.009	211. ± 7.
77135	17.2 ±0.6	49.9 ±1.6	0.638 ±0.023	76.1 ±2.3	46.2 ±1.5	1.42[c]	0.599 ±0.013	28.6 ± 1.4

[†] ^{81}Kr-Kr exposure ages and spallation spectra were calculated as described by Drozd *et al*. (1974). Errors (1σ) include uncertainties due to unknown U concentrations where applicable.

[a] Eldridge *et al*., 1974.

[b] Keith *et al*., 1974.

[c] Apollo 17 Preliminary Science Report, 1973.

Table 3. Nuclear track data for Apollo 17 rocks.

Rock #	Weight (grams)	[§]Orientation & Description	[§§]Depth (cm)	Track Density $10^6 t/cm^2$	[§§§]Track Age (my)
76015	2819	η=75°, β=90° Station 6 boulder	1.3	4.4	18. ± 3.[†]
			2.4	3.1	
			3.5	2.30	
			3.7	2.45	
			4.3	2.0	
			5.0	2.0	
			6.3	2.2	
76315	671	η=90°, β=0° Station 6 boulder	0.7	8.6	21. ± 3.[†]
			2.0	4.5	
			3.2	3.2	
75035	1235	β=90° Station 5 boulder	2.0	3.2	7.3 ± 3.[*]
73275	430	β=90°	2.9 ± .4	1.5	4.7 ± 1.[*]
77135	337	β=0° Station 7 boulder	1.0 ± .2	2.0	5.4 ± 1.[*]
76535	155	Unoriented	1.5 ± .5	1.2 ± .3	2.0 ± 1.[*]

[§] η is the angle of the track column relative to lunar vertical and β is the angle between the plane of observation and the nearest rock surface. See, for example, Bhandari _et al_. (1971).

[§§] Statistical error on the measured track densities and error on the depth assignments are $\lesssim$ 10% unless noted explicitly.

[§§§] Ages are determined using the track production spectrum of Walker and Yuhas (1973) and erosion rates of 1 to .5 mm/my depending on lunar orientation. The bulk of the error arises from both geometrical and erosional uncertainties.

[†] Fit to track profile demonstrates single stage exposure

[*] Single point determination at depth shown gives maximum surface exposure.

Table 4. Surface exposure histories of lunar rocks

Rock	Rock Type	Weight (grams)	Surface Exposure Ages ($\times 10^6$ yr) A	B	C	D	E	F	Spallation Age ($\times 10^6$ yr)	Exposure History[†] SS-single stage MS-multistage	Comments
10003[a]	Crystalline	213.	10(4π)	-	-	-	-	-	129 ± 11[aa]	MS?	
10003[j]			-	-	-	-	5	-			
10017[b]	Crystalline	973.	11(4π)	-	-	-	-	-	450-510[aa,bb]	MS?	Gradient small but possible single stage exposure to VH nuclei.
10017[c]			6(4π)	-	-	-	-	-			
10017[d,g]			10(4π)	-	-	-	4	-			
10017[a]			10(4π)	-	-	-	-	-			
10044[c]	Crystalline	247.5	-	4	-	-	-	-	70 ± 17[cc]	MS?	
10047[b]	Crystalline	138.	16(4π)	-	-	-	-	-	86 ± 4[bb]	MS?	
10049[c,f]	Crystalline	193.	30(4π)	-	-	-	-	-	25[dd]	SS	Close agreement between tracks and spallation gives low limit on erosion.
10057[b]	Crystalline	919.	-	-	28	-	-	-	52 ± 2[aa] 47 ± 2[bb]	SS?	Erosion could account for difference in track and spallation ages.
10057[j]			-	-	-	-	8.5	0			
10057[c]			29(4π)	-	-	-	-	-			
10058[b]	Crystalline	282.	13(4π)	-	-	-	-	-	60[ee]	MS?	
10058[j]			-	-	-	-	4	-			

Rock	Rock Type	Weight (grams)	Surface Exposure Ages ($\times 10^6$ yr)						Spallation Age ($\times 10^6$ yr)	Exposure† History SS-single stage MS-multistage	Comments
			A	B	C	D	E	F			
12002[f]	Crystalline	1529.5	–	24	–	–	–	–	94 ± 6[ff]	MS	Small gradient.
12002[g]			–	–	–	–	2	35			
12013[h]	Breccia	82.3	14(4π)	–	–	–	–	–	40-47[gg] 48[hh]	MS	
12017[f]	Crystalline	53.0	–	2	–	–	–	–		?	Possible single stage exposure to VH nuclei.
12017G[f]	–	–	.01(2π)	–	–	–	–	–		SS	This is a glass splash. Age assumes galactic production only at 1 mm depth.
12018[g]	Crystalline	787.0	–	–	–	–	1.7	0	195 ± 16[ff]	MS	Small grad from 1 to 4 cm.
12020[g]	Crystalline	312.0	–	–	–	–	2.6	25	71[ii]	MS?	
12021[f]	Crystalline	1876.6	13(4π)	–	–	–	–	–	303 ± 18[ff]	MS?	
12022[i]	Crystalline	1864.3	10(2π)	–	–	–	–	–	220[dd]	MS?	Measurable gradient. Possible single stage exposure to VH nuclei.
12022[j]			–	–	–	–	4	0			
12038[g]	Crystalline	746.0	–	–	–	–	1.3	0	150-190[dd]	MS?	Measurable gradient. Possible single stage exposure to VH nuclei.
12040[h]	Crystalline	319.0	5(2π)	–	–	–	–	–	225 ± 11[aa]	?	
12063[h]	Crystalline	2426.0	5	–	<1.5 < .7	–	–	–	95 ± 5[ff]	MS	Rock pitted on all sides. Careful measurement shows small gradient.
12063[j]			–	–	–	–	2.8	0			
12064[h]	Crystalline	1214.3	1.5(2π)	–	–	–	–	–	190-220[ii]	SS?	Lowest track density observed at 1 cm depth. Possible single stage exposure to VH nuclei.

Rock	Rock Type	Weight (grams)	Surface Exposure Ages (x 10^6 yr) A	B	C	D	E	F	Spallation Age (x 10^6 yr)	Exposure[†] History SS-single stage MS-multistage	Comments
12065[f]	Crystalline	2109.0	14(2π)	–	–	–	–	–	180-200[ii]	MS?	
14047[k]	Breccia	242.01	–	–	–	3.4	–	–	<45[jj]	SS?	
14055[k]	Breccia	110.99	–	–	–	0.05	–	–		?	
14066[k]	Breccia	509.80	–	–	–	0.49	–	–	24 ± 2[kk]	SS?	
14068[l]	Breccia	35.47	–	–	–	–	–	15	(25)[ll]	SS?	
14270[k]	Breccia	25.59	–	–	–	1.4	–	–		?	
14301[l]	Breccia	1360.60	–	–	–	–	–	8	102[mm]	MS	Disagreement between groups on variability of ρ and absolute value of ρ min.
14301[k]			–	–	–	.34	–	–			
14303[l]	Breccia	898.40	–	–	–	–	2.5	0	29[nn]	MS	
14305[l]	Breccia	2497.50	–	–	–	–	–	35		SS?	Possible single stage exposure to VH nuclei.
14307[o]	Breccia	155.00	–	–	5	–	–	–	(125)[ll]	MS	
14310[m]	Crystalline	3439.00	–	15	1-3	–	–	–	265[oo]	MS	Most completely studied rock. Three orthogonal rock sections studied by five groups. Gradients generally very small. For details see Yuhas et al. (1972).
14310[n]			10-30	–	–	–	–	–			
14310[l]			–	–	–	–	1	–			

Rock	Rock Type	Weight (grams)	Surface Exposure Ages (x 10^6yr)						Spallation Age (x 10^6yr)	Exposure History† SS-single stage MS-multistage	Comments
			A	B	C	D	E	F			
14311[k]	Breccia	3204.40	-	-	-	1-3	-	-	661[oo]	MS	
14311[l]			-	-	-	-	-	12			
14321[m]	Breccia	8998.0	-	25	-	-	-	-	23-27[pp]	SS?	Basic disagreement on variation of ρ in large crystals. One group finds large variations, others do not.
14321[k]			-	-	-	8	-	-			
14321[o]			-	23	-	-	-	-			
14321[l]			-	-	-	-	2-4	-			
15058[p]	Crystalline	2672.5	25	-	-	-	-	-		MS	Sun-tan age 1 to 2 my using solar flare tracks. Small gradient.
15058[q]			-	-	-	-	2	10			
15058[v]			10(2π)	-	-	-	-	-			Grain mount analysis. Small depth variation.
15058[w]			-	7	-	-	-	-			Time since last major shock.
15085[q]	Crystalline	458.9	-	-	-	-	<1	-		?	
15118[q]	Crystalline	27.6	-	-	-	-	1.3	-		?	
15233[k]	Breccia	3.8	-	-	-	0.3-7	-	-		?	
15265[q]	Breccia	314.1	-	-	-	-	<1	-		?	
15388[q]	Crystalline	9.0	-	-	-	-	<1	-		?	
15405[s]	Breccia	513.1	-	-	-	0.5	-	-		?	

Rock	Rock Type	Weight (grams)	Surface Exposure Ages ($\times 10^6$ yr)						Spallation Age ($\times 10^6$ yr)	Exposure[†] History SS-single stage MS-multistage	Comments
			A	B	C	D	E	F			
15426[q]	Breccia	223.6	–	–	–	–	–	15		?	Soil clod.
15426[x]			0.5	–	–	–	–	–			
15475[v]	Crystalline	406.8	–	–	15.5	–	–	–	473 ± 20[oo]	MS	Peculiar depth variation implies at least two-stage surface exposure.
15505[w]	Crystalline	1147.4	0.6	–	–	–	–	–		MS	Age since last shock.
15535[q]	Crystalline	404.4	–	–	–	–	<1	<10		?	
15555[q]	Crystalline	9613.7	–	–	–	–	1	26	81^{+17}_{-7}[qq]	MS	Although a multistage history, the measured gradient suggests that exposure history is still relatively simple.
15555[r]			34	–	15	–	–	–			
15555[p]			26	–	–	–	–	–			
15557[q]	Crystalline	2518.0	–	–	–	–	<1	–		?	
61016[y]	Crystalline	11745.	20	–	–	–	–	–			Inclusion of erosion raises age to 40 my. Plum Crater samples
61175[y]	Breccia	543.	–	20	–	–	–	–			
62235[v]	Crystalline	320.	4	–	2	–	–	–	153.3 ± 6.5[oo]	SS?	Large grain-to-grain track density variations (30%-40%).
67915[v]	Breccia	255.	–	–	50	–	–	–	50.6 ± 3.0[oo]	SS	Boulder sample associated with North Ray Crater. 1 mm/my erosion rate gives agreement between track and rare gas age.

Rock	Rock Type	Weight (grams)	Surface Exposure Ages ($\times 10^{6}$ yr)						Spallation Age ($\times 10^{6}$ yr)	Exposure[†] History SS-single stage MS-multistage	Comments
			A	B	C	D	E	F			
68415[v]	Crystalline	371.	4(2π)	-	-	-	-	-	92.5 ± 13.3[oo]	SS?	Age estimate is sensitive to topography and erosion.
68815[t]	Breccia	1789.	-	-	2.0	-	-	-	2.0[oo]	SS	Because of simple exposure history, this rock is used as cosmic ray track standard.
69935[v]	Breccia	128.	-	-	2.3	-	-	-	1.99 ± .37[oo]	SS	Boulder sample. Same track age as 68815.
73275	Breccia	430.	4.7(2π)	-	-	-	-	-	139. ± 5.	?	
75035	Crystalline	1235.	-	7.3	-	-	-	-	71.7 ± 1.8	SS?	Station 5 boulder sample.
76015	Breccia	2819.	-	-	18	-	-	-	17.5 ± .5	SS	Station 6 boulder sample.
76315	Breccia	671.	-	-	21	-	-	-	21.7 ± 1.2	SS	Station 6 boulder sample.
76535	Breccia	155.	-	-	-	2.0	-	-	211. ± 7.	?	Large background of dislocations.
77135	Breccia	430.	5.4(2π)	-	-	-	-	-	28.6 ± 1.4	?	Station 7 boulder sample.

Age A - Single point determination. Sample not at center so 2π or 4π irradiation must be assumed. This gives maximum surface age.
Age B - Single point determination at rock center. This age gives maximum time rock could have been exposed at surface in present configuration.
Age C - Determined from gradient measurement in rock. This is probably the best approximation to true "sun-tan" exposure.
Age D - Single point determination taking minimum track density measured in a number of crystals from same location. Applicable to breccias with pre-irradiation histories and to shocked rocks. This is also a maximum surface age.
Age E - Single point determination at a depth of 1 mm. This age is sensitive to surface topography and to rock erosion; it may be higher or lower than true surface exposure age.
Age F - Sub-decimeter age. See text for explanation.

[†] Single stage irradiation refers to track record only. Thus a rock which had been buried at 1 meter where the track production rate was very small would be considered to have a single stage exposure if it had recently been brought to the surface. The primary criteria for a single stage exposure is a steep track gradient or an agreement between track and spallation ages.

[a] Price and O'Sullivan (1970)
[b] Crozaz *et al*. (1970)
[c] Fleischer *et al*. (1970)
[d] Lal *et al*. (1970)
[f] Fleischer *et al*. (1971b)
[g] Bhandari *et al*. (1971)
[h] Crozaz *et al*. (1971)
[i] Barber *et al*. (1971)
[j] Lal (1972)
[k] Hart *et al*. (1972)
[l] Bhandari *et al*. (1972a)
[m] Crozaz *et al*. (1972)
[n] Berdot *et al*. (1972b)
[o] Berdot *et al*. (1972a)
[p] Poupeau *et al*. (1972)
[q] Bhandari *et al*. (1972b)
[r] Behrmann *et al*. (1972)
[s] Fleischer and Hart (1972)
[t] Yuhas and Walker (1973)
[u] Behrmann *et al*. (1973)
[v] Yuhas (unpublished)
[w] Fleischer *et al*. (1973)
[x] Fleischer and Hart (1973c)
[y] Fleischer and Hart (1974)
[aa] Schwaller (1971)
[bb] Marti *et al*. (1970a,b)
[cc] Hohenberg *et al*. (1970)
[dd] Bogard *et al*. (1971)
[ee] Burnett *et al*. (1971)
[ff] Marti and Lugmair (1971)
[gg] Kaiser (1971)
[hh] O'Kelley *et al*. (1971)
[ii] Hintenberger *et al*. (1971)
[jj] Megrue and Steinbrunn (1972)
[kk] Kaiser (1972)
[ll] Bogard and Nyquist (1972)
[mm] Crozaz *et al*. (1972)
[nn] Kirsten *et al*. (1972a,b)
[oo] Drozd *et al*. (1974)
[pp] Lugmair and Marti (1972)

Table 5. Selected surface exposure ages and crater counts for craters > 0.05 cm in diameter.

Rock	No. of Craters Counted	ρ_c (cm^{-2})	Surface Exposure Age (my)	Cratering Rates cm^{-2} my^{-1}
12017	12[a]	2.3	$\lesssim 0.7$[f]	$\gtrsim 3.3$
12038	30[a]	3.6	$\lesssim 1.3$[g]	$\gtrsim 2.8$
12054	4[b]	0.4	0.05 to 0.5[h]	$\lesssim$ 0.8 to 8
14301	54[c]	2.5	> 1.5[i]	$\lesssim 1.7$
14303	10[d]	2.3	$\lesssim 2.5$[j]	$\gtrsim 0.9$
14310	30[b]	2.0	1.5 to 3[k]	$\gtrsim$ 0.7 to 1.3
60315	14[e]	3.4	> 1.5[ℓ]	$\lesssim 2.3$
61175	196[e]	13.2	> 1.5[m]	$\lesssim 8.8$
62295	34[e]	4.0	$\lesssim 2.7$[n]	$\lesssim 1.5$
68415	57[e]	2.3	> 1.5[o]	$\lesssim 1.5$

[a] Hörz *et al.*, 1971.

[b] Hartung *et al.*, 1972.

[c] Morrison *et al.*, 1972.

[d] Hartung *et al.*, 1973.

[e] Neukum *et al.*, 1973.

[f] Fleischer *et al.*, 1971b.

[g] Bhandari *et al.*, 1971.

[h] Schönfeld, 1971.

[i] Keith *et al.*, 1972.

[j] Bhandari *et al.*, 1972a.

[k] Crozaz *et al.*, 1972.

[ℓ] Clark and Keith, 1973.

[m] Eldridge *et al.*, 1973.

[n] Bhandari *et al.*, 1973.

[o] Rancitelli *et al.*, 1973.

Table 6. Lightly and (rather) simply irradiated soil samples.

Sample	Depth	Model Age
12028[a] Coarse-grained layer in core	4 cm thick at 18 cm depth	$\lesssim$ 15 my (slightly stirred)
14141[b,c,d,e] Conelet Crater	Scoop sample ($\sim$4 cm)	8 to 15 my
15401[f] Green glass	Scoop sample ($\sim$4 cm)	0.5 my (stirred at least once)
73241[g] Trench sample	0 to 5 cm	$\sim$20 my
74220[f] Orange glass	5 to 7.5 cm	4 to 7 my (slightly stirred)

[a] Crozaz *et al.*, 1971.

[b] Bhandari *et al.*, 1972a.

[c] Crozaz *et al.*, 1972.

[d] Hart *et al.*, 1972.

[e] Phakey *et al.*, 1972.

[f] Fleischer and Hart, 1973b.

[g] Fleischer *et al.*, 1974b.

Table 7. Typical layer model ages in lunar cores.

Modeling Method	Sample	
Minimum density	Apollo 12 double core[a]	Layers 2 to 4 cm have typical ages of 6 to 30 my
Minimum density	Apollo 15 deep drill[b]	Layers 0.5 to 2 cm have ages of 0.5 to 5 my
Median density	Apollo 12 double core[c]	Layers 2 to 10 cm have ages of 5 to 40 my
Median density	Apollo 15 deep drill[d].	Layers 1.5 to 5 cm have ages of 1 to 40 my

[a] Fleischer and Hart, 1973a.

[b] Fleischer and Hart, 1973b.

[c] Arrhenius *et al.*, 1971.

[d] Bhandari *et al.*, 1972b.

FIGURE CAPTIONS

Fig. 1 The measured track density vs. depth curve for rock 76315. The fit to the data (solid line) gives a 21 my exposure age, using a π geometry and .05 mm/my erosion rate.

Fig. 2 Schematic depicting the shielding geometry of 76015. Uncertainty in shielding stems from the incomplete documentation of the part of the boulder which was not sampled.

Fig. 3 Patination gradient of 76015 which is very dark at A, the most exposed portion, to very light at B, the least exposed portion. The corresponding positions are also indicated on Fig. 2. The arrow indicates the approximate location of the track sample, the data for which are shown in Fig. 4.

Fig. 4 Solar flare track density vs. depth curve for 76015. The slope is ∿-2 while most lunar rocks yield a value of ∿-1 in the same depth interval.

Fig. 5 Distribution of track densities in feldspar crystals of Apollo 17 soil samples. Data shown are total pit counts as measured in a scanning electron microscope. For densities < 10^7 tracks/cm^2 optical scanning was employed.

Fig. 6 Schematic diagram of a plausible, though not unique, model to explain the track data in the trench samples of station 3 (following Chang _et al_., 1974).

Fig. 7 Track densities in individual feldspar and pyroxene grains of section 70008 of the Apollo 17 deep drill core (right-hand vertical scale). Soil depths are expressed in cm of equivalent rock. The grains are all larger than 130 μm. The left vertical scale shows the calculated track production rate for a one my exposure interval. The two smooth curves correspond to the track production rate as a function of depth for two extreme orientations of the grains with respect to the surface. F and P stand for feldspar and pyroxene. The number of tracks actually observed in more than 25 crystals at each level are in parentheses. The points on the upper right represent individual crystals with high track densities noted in parentheses when higher than $10^6/\text{cm}^2$.

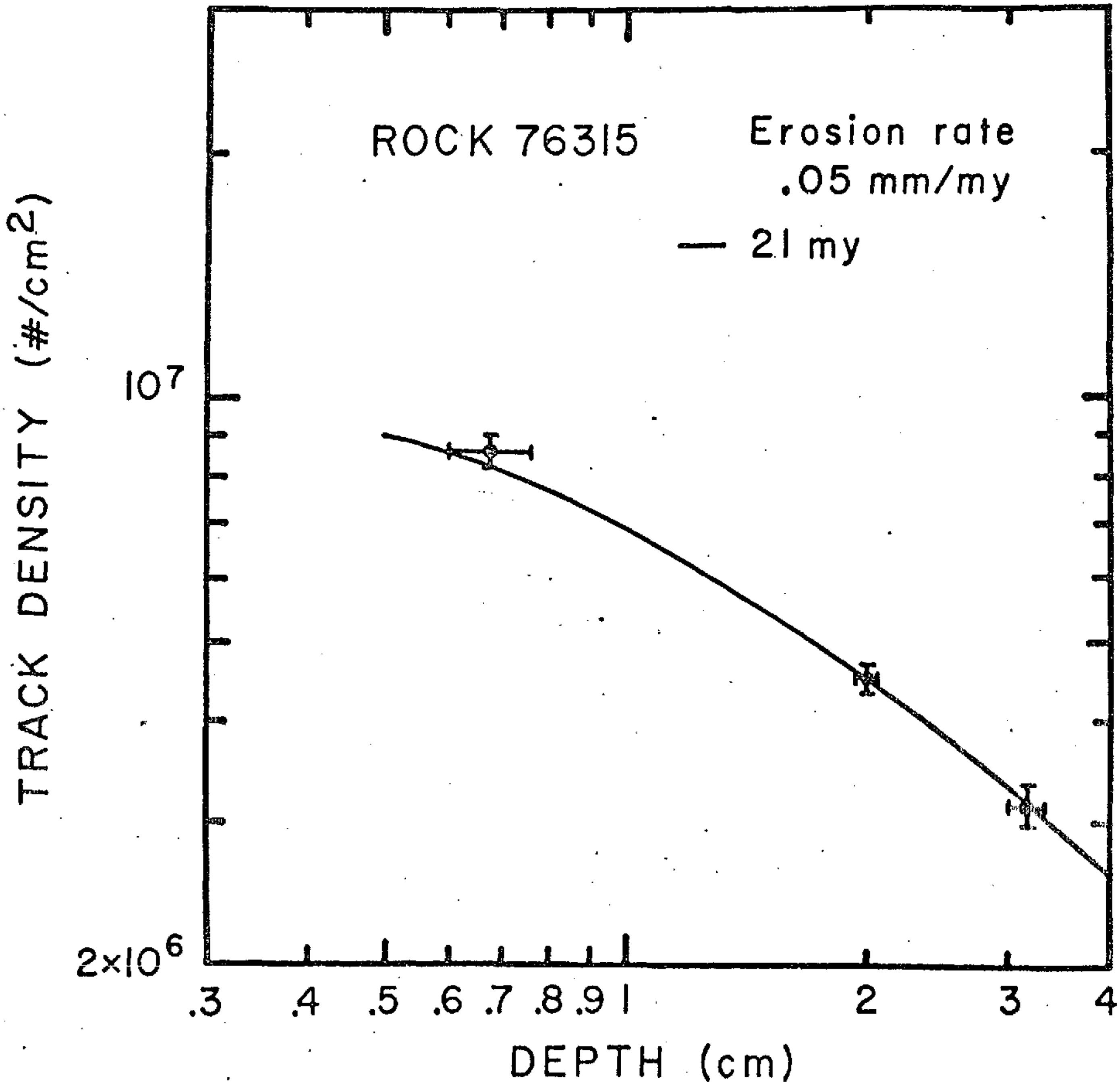

ROCK 76315
Erosion rate
.05 mm/my
— 21 my
TRACK DENSITY (#/cm^2)
10^7
2×10^6
.3
.4
.5
.6
.7
.8
.9
1
2
3
4
DEPTH (cm)

FIG. 1

SCHEMATIC OF 76015 EXPOSURE GEOMETRY

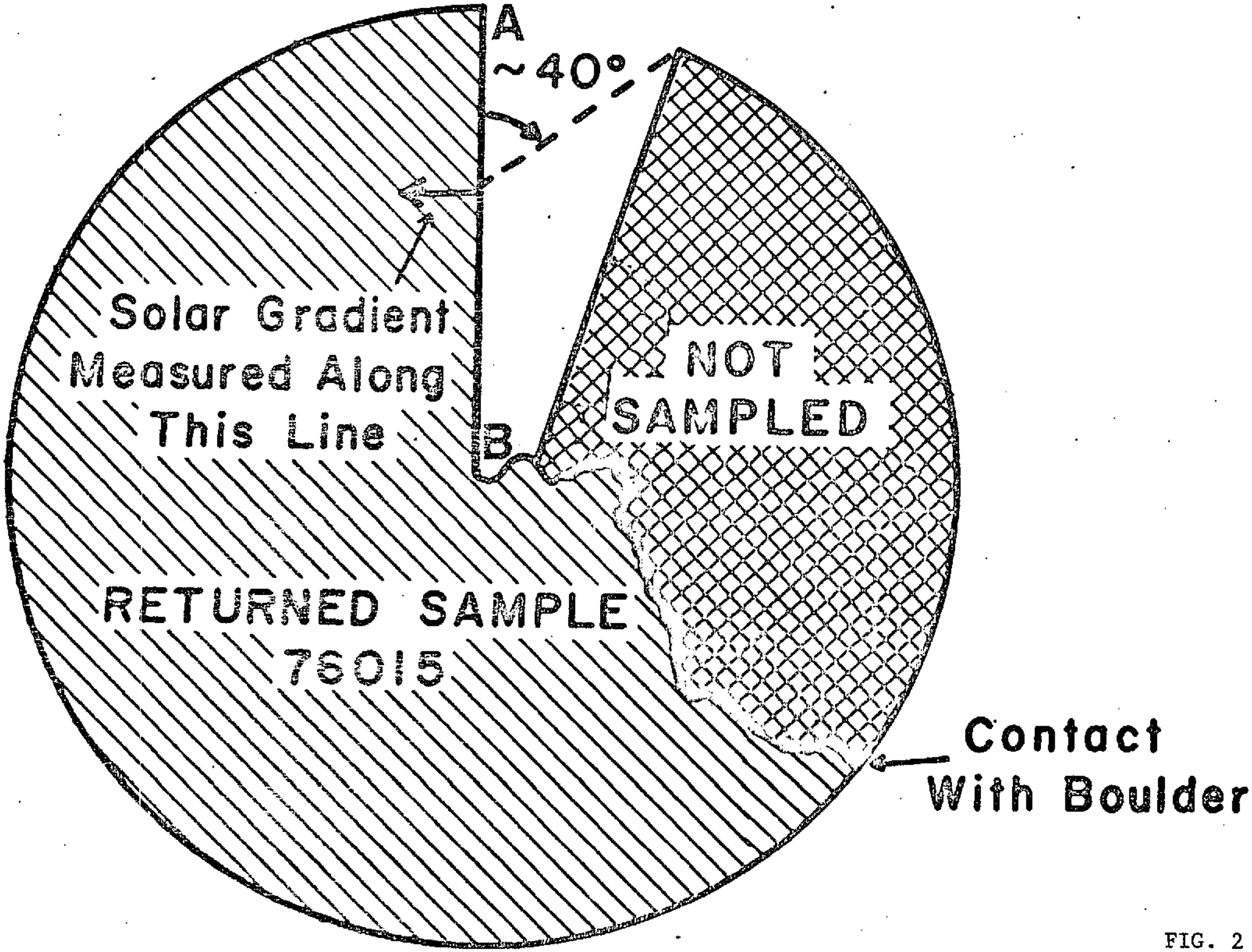


FIG. 2

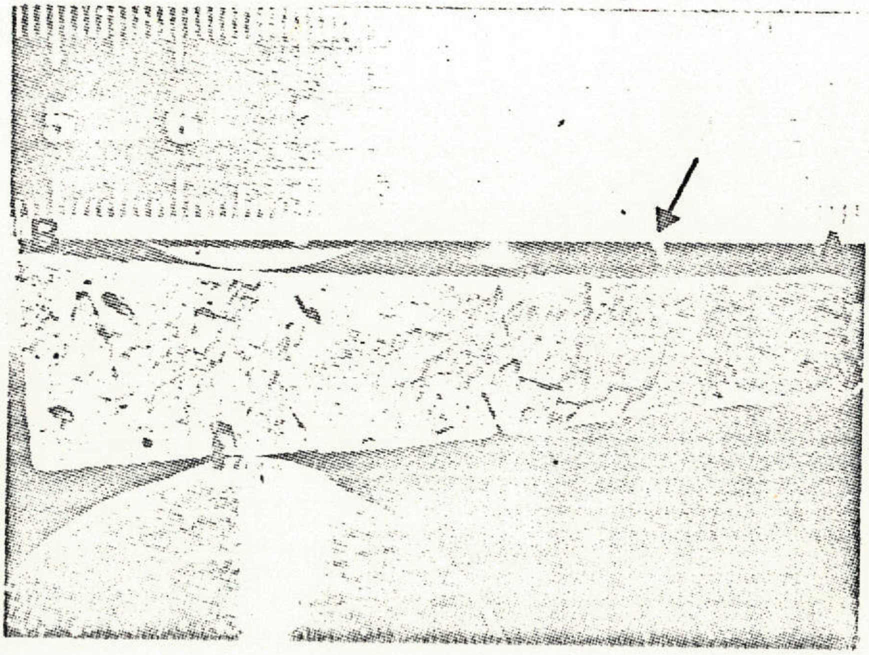
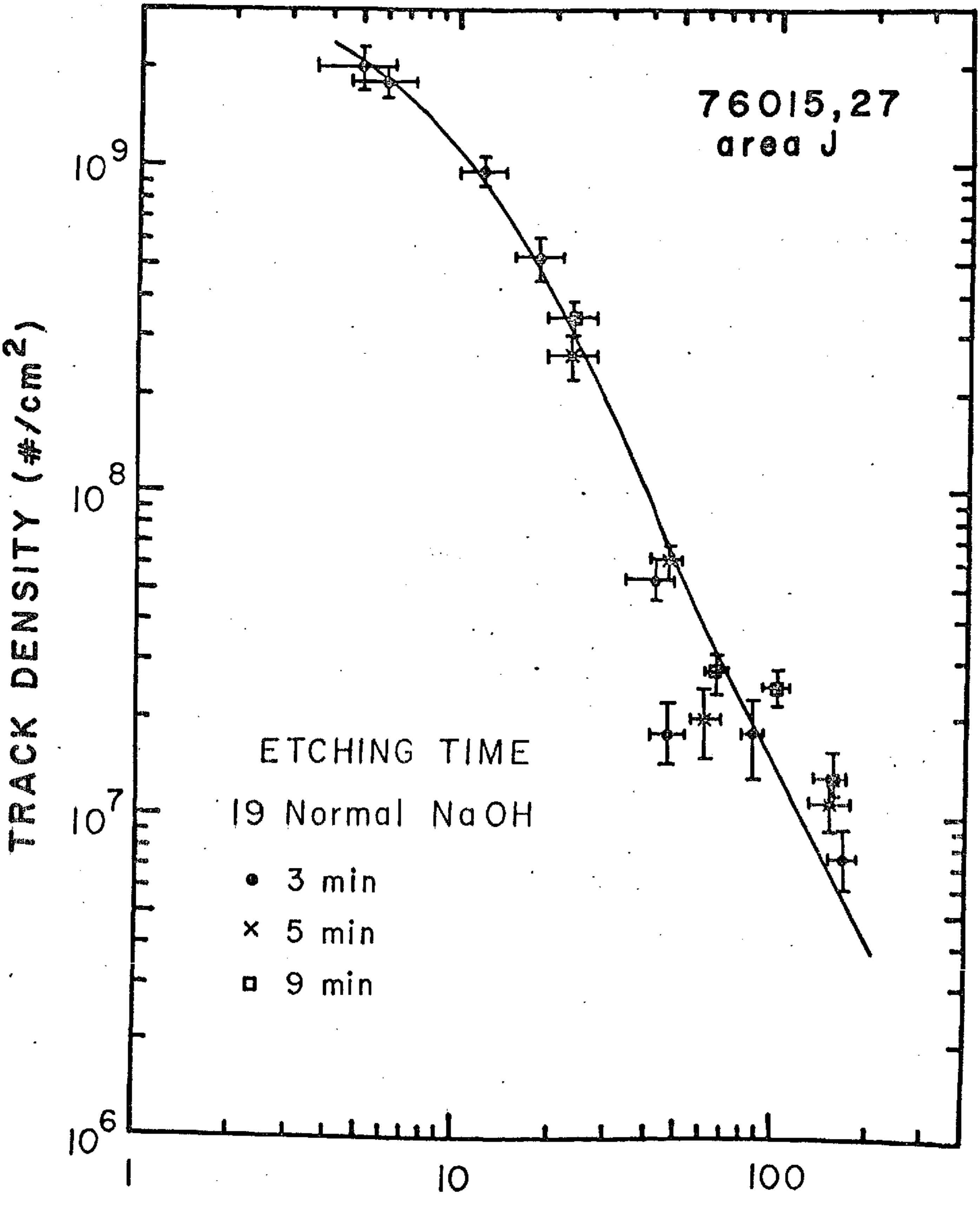


FIG. 3



76015,27
area J
TRACK DENSITY (#/cm²)
10⁹
10⁸
10⁷
10⁶
1
10
100
DEPTH (microns)
ETCHING TIME
19 Normal NaOH
● 3 min
× 5 min
□ 9 min

FIG. 4

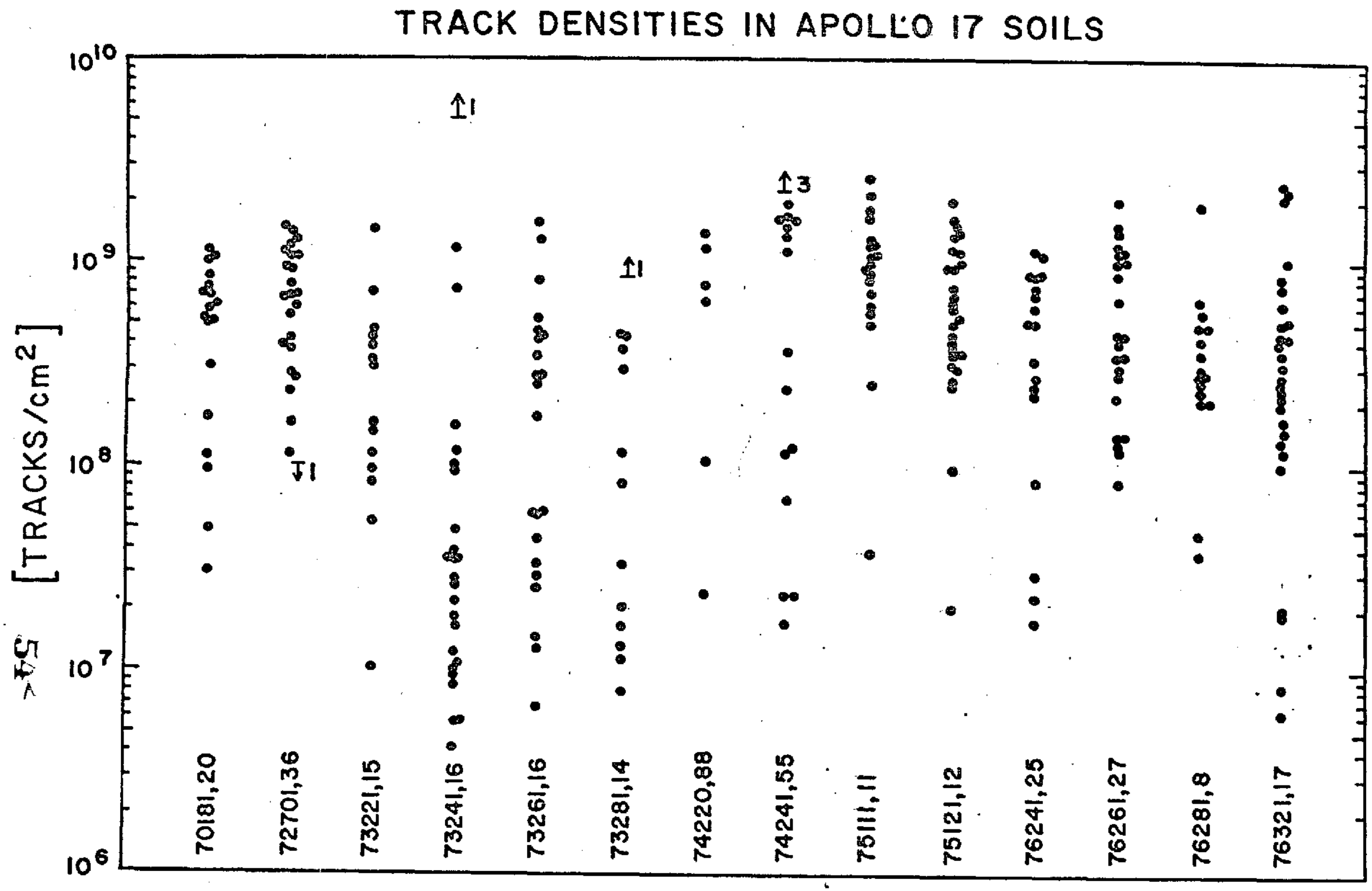

TRACK DENSITIES IN APOLLO 17 SOILS
>5μ [TRACKS/cm²]
10¹⁰
10⁹
10⁸
10⁷
10⁶
↑1
↑1
↑3
↓1
70181,20
72701,36
73221,15
73241,16
73261,16
73281,14
74220,88
74241,55
75111,11
75121,12
76241,25
76261,27
76281,8
76321,17

FIG. 5

EXPOSURE MODEL FOR BALLET CRATER TRENCH SAMPLES

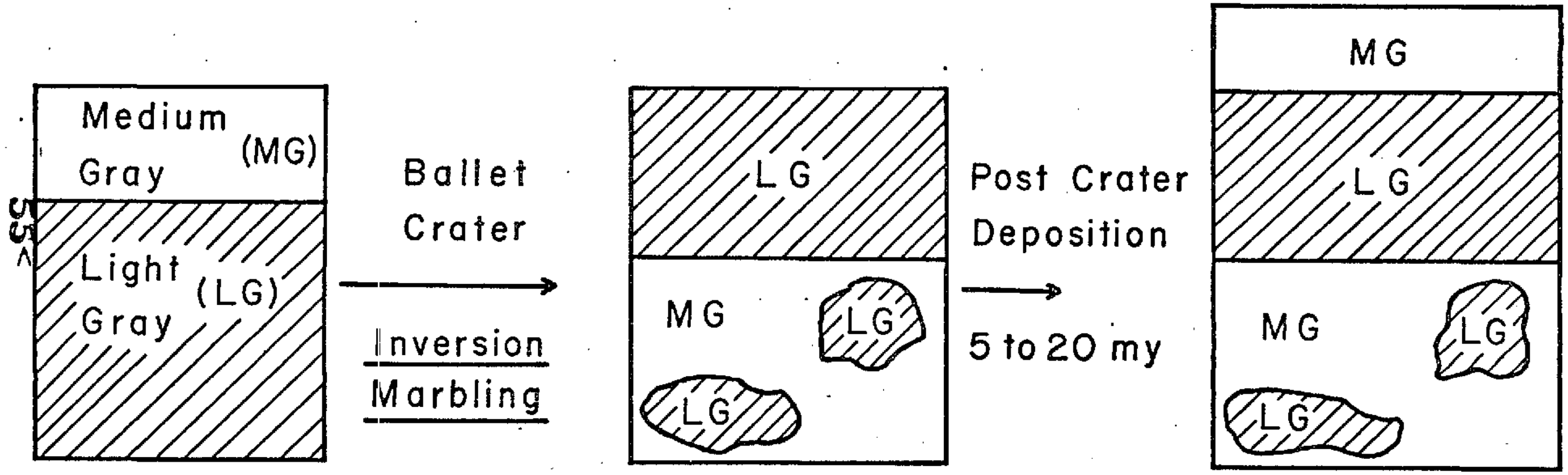


FIG. 6

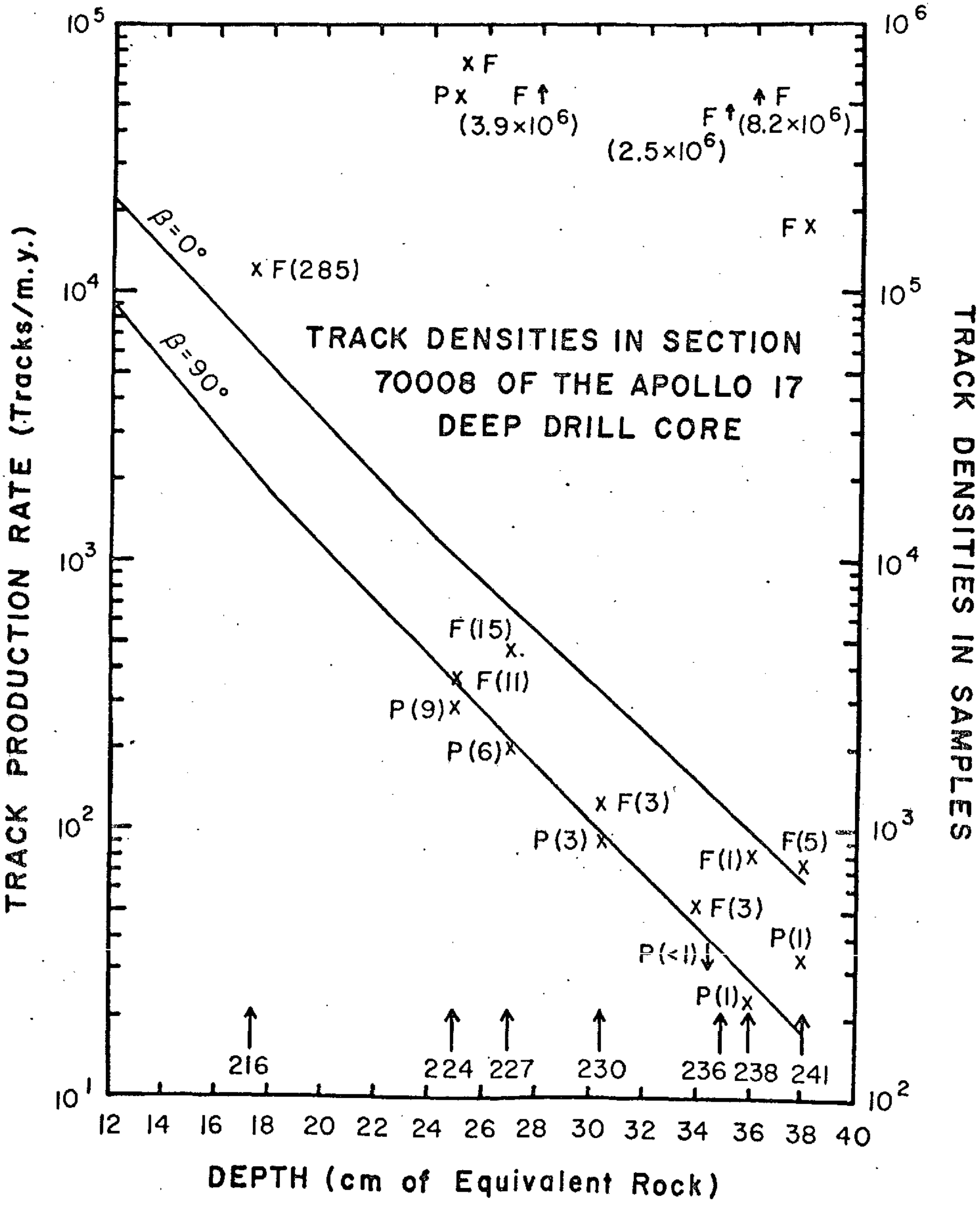

TRACK DENSITIES IN SECTION 70008 OF THE APOLLO 17 DEEP DRILL CORE
TRACK PRODUCTION RATE (Tracks/m.y.)
TRACK DENSITIES IN SAMPLES
DEPTH (cm of Equivalent Rock)
10^5
10^4
10^3
10^2
10^1
10^6
10^5
10^4
10^3
10^2
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
β=0°
β=90°
x F
P x
F ↑ (3.9×10^6)
F ↑ (2.5×10^6)
↑ F (8.2×10^6)
F x
x F(285)
F(15) x
x F(11)
P(9) x
P(6) x
x F(3)
P(3) x
F(1) x
F(5) x
x F(3)
P(1) x
P(<1) ↓
P(1) x
216
224
227
230
236
238
241

FIG. 7