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# PHYSICAL PROPERTIES OF THE APOLLO 12 LUNAR FINES

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ABSTRACT--The size distribution of the lunar fines is measured, and small but significant differences are found between the Apollo 11 and 12 samples as well as among the Apollo 12 core samples. The optical and the radio frequency electrical properties are measured and are also found to differ only slightly from Apollo 11 results.

## APOLLO 12 GRAIN SIZE ANALYSIS

The Apollo 12 lunar fines were subjected to similar grain size analysis to that carried out for the Apollo 11 sample (Gold et al.,1970). The general appearance and the appearance under the microscope of all samples of fines are rather similar, and the measured optical properties also show only small but significant differences. Although this type of uniformity was expected as a consequence of ground-based optical observations of the moon, it nevertheless has to be emphasized as a remarkable conclusion.

The particle size distribution has been determined by two methods: electron microscopy and sedimentation rate in a column of water. The first was described in the Apollo 11 report and is of greatest value for particle sizes ranging down from 10 microns to less than 0.1 micron; it utilizes scanning electron micrographs of small "sections" of powder. The second method utilizes a sedimentation column which has been improved and perfected more recently.

The water sedimentation column consists of a vertical pipe 70.9 cm long, terminating below in a cubical box of optical glass plate. A photographic flash gun is imaged through a large aperture lens with focus just below the point of entry of the tube. Flash synchronized photographs are taken in a viewing direction perpen-

dicular to the direction of the light. Stray and multiply scattered light is carefully excluded, and as a result the light scattered by a particle as small as 1 micron gives a perfectly recordable image. The water column is heated at the top and the temperature distribution along it is carefully controlled so that no thermal convection can set in. The particle sizes are deduced by Stokes' Law assuming them to be spherical. While this is of course not accurate, the optical and electron microscope examination showed the particles to be on the whole rather compact shapes, making this error rather small. Freedom from disturbing convection in the column is demonstrated by taking the photographs in pairs with a short duration in between, showing that each group of particles has settled a distance in that short time appropriate to its settling time from the top.

For an absolute measurement this method would perhaps not be sufficiently accurate, both for reasons of the particle shapes and perhaps also their unknown densities. For a comparison the method is very good, and it is much easier to accumulate good statistics than by the method of counting particles under the microscope.

Fig. 1 compares the small-size particle size distribution of the Apollo 11 bulk box with that of the Apollo 12 contingency sample; the data, obtained by electron microscopy, are plotted as the cumulative number, per cubic centimeter, of particles larger in size than the abscissa value. A porosity of 0.5 is assumed and the number of particles counted is about 2000 in each case. The two curves are very similar, showing greatest divergence at particle

sizes of a few microns; the difference, which amounts to less than a factor 2.5, is probably real. Its significance is shown a little more clearly in Fig. 2 in which the differential rather than cumulated particle density is plotted.

The Apollo 12 contingency sample and three core samples (from cores 12025 and 12028) have been analyzed by the sedimentation column method, and the comparisons are shown on Figs. 3 and 4. From these curves it would appear that the surface sample from Apollo 12 is slightly coarser grained than that from Apollo 11. Among the core samples there is also a variation in the grain size distribution, with the deeper samples being somewhat richer in small particles than the surface and close subsurface ones. In particular the sample taken from a trench 15 cm deep (sample 12033) is significantly different in appearance from most others, and the size distribution analysis shows this one to possess a much larger proportion of small particles.

The fact that the grain size distribution in the core sample shows significant differences within tens of centimeters variation of depth requires comment. Differences over intervals of some centimeters in the core sample are also seen in the albedo,and very striking chemical differences have been reported (E. Anders, 1971). One has to discuss how sharply defined layers or other local configurations could be preserved despite the fact that some plowing of the ground by meteoritic impact must be taking place.

A material of different grain size, albedo or chemical composition could be derived either from a sufficiently distant

or deep crater for this material not to have been previously well mixed by meteorite impact, or it could be material that is different as a result of contamination with some direct meteoritic infall. But it is not enough to account for possible sources of such different material. One must also understand firstly how it can have been deposited without excessive mixing, and secondly how it can have avoided being mixed by the plowing over which meteorites must be causing on the lunar surface.

The deposition of the material must be gentle and it cannot have reached its present position by being flung there on ballistic trajectories from a distant and deep crater. A layer some centimeters thick could not be deposited from such ballistic trajectories without mixing with a layer very many times its own thickness. The material seen in the core must thus have reached its position by a surface transportation process resulting in a sufficiently gentle sedimentation to avoid mixing. Secondly, in order to preserve such layers, one has to suppose that further sedimentation has taken place so that the overburden can protect the layer from meteorite plowing. If the rate of the meteorite plowing process were known, one could conclude what the rate of deposition has to be to have a significant probability that a layer at a given depth would be seen preserved. It is quite clear that even a single example of a very inhomogeneous core demonstrates that the ground has not been turned over hundreds of times to these depths, as had been calculated from estimates of the meteoritic infall rate. The mare ground seems to be subject to a sedimentation process much more than to a "gardening" process.

## DIELECTRIC CONSTANT MEASUREMENT

The measurements of the high frequency electrical properties at 450 MHz do not disclose any marked difference in the dielectric constant of powder material from site to site. In Fig. 7 the dielectric constant measurements, as a function of bulk powder density, are shown for two Apollo 12 sites--one at a depth of 15 cm below the surface--as well as for the Apollo 11 bulk sample. The two Apollo 12 samples were chosen for their contrasting physical appearances, sample 12033 being much lighter in color and finer in texture than sample 12070. The variation of dielectric constant with density follows the Rayleigh formula (Campbell and Ulrichs, 1969) in all cases and, indeed, a single such curve fits all the data within ±1 percent excepting only the highest density point of sample 12070. The ground-based radar determinations of the dielectric constant are in complete accord with these measurements if one assumes a density of about 1.7 g $cm^{-3}$ for the soil at a depth of 20 cm, an assumption which does no violence to the known properties of the soil.

Also shown on Fig. 7 are dielectric constant--density points for four solid lunar rocks, two each from Apollos 11 and 12. The latter pair, 12063 and 12065, are very similar petrologically and lie closely adjacent in the figure. Some allowance should be made for the porosity (~15%) of sample 10022 but this cannot greatly change the scatter of the points corresponding to this small but not atypical selection of rocks. None of the four solid rocks, nor any mixture of them, could be ground to a powder with the electrical properties of the dust samples, a conclusion in which

we concur with the mineralogists.

Fig. 8 shows in a similar way the variations with density of the absorption length in the powder samples, with points for the four solid rocks in addition. Again, assuming plausible densities for the powder at depths of a few centimeters, the data agree with prior ground-based radiothermal observations by Krotikov and Troitsky (1963) and others.

## OPTICAL PROPERTIES

The optical reflectivity and polarization of the Apollo 12 soil sample were measured as a function of phase angle with the same instrument and in the same manner as done previously for the Apollo 11 samples (O'Leary and Briggs, 1970). Both Apollo 11 and 12 samples were prepared by gradually dropping the fine-grained soil from a height of about 2 cm onto a sample tray.

Figs. 9 and 10 indicate the dependence of reflectivity and polarization on phase angle for two viewing angles, $\epsilon$, of $0^\circ$ and $60^\circ$, as measured from the normal to the surface of the sample. While the Apollo 11 and 12 samples have similar photometric curves, the Apollo 12 sample is noticeably brighter than Apollo 11 (Fig. 9). The curves labeled "Moon" are taken from Hapke (1968) and normalized to the normal albedo of the Apollo 11 sample. The Apollo 12 soil has a normal albedo at .56 μm wavelength of .125±.003 as compared with.102±.003 for the Apollo 11 sample. Moreover, the Apollo 12 soil is redder than both the Apollo soil and the mean value for the moon (Gehrels et al., 1964). Finally, the Apollo 12 soil shows greater reddening with phase angle than the Apollo 11

soil. At $\epsilon=60^{\circ}$, the photometric functions of both the Apollo 11 and 12 soils indicate a flattening toward larger phase angles compared with the lunar curve. The difference can probably be attributed to large scale roughness of the lunar surface as observed from the earth.

In Fig. 10 the polarization of the Apollo 12 soil is very similar to that of the moon as a whole (Hapke, 1968). However, for $\epsilon=60^{\circ}$, both samples show peaks in polarization at greater phase angles than for the moon (Pellicori, 1969). The maximum polarization from the Apollo 12 sample is in good agreement with earth-based observations, while that of Apollo 11 is anomalously high. The interpretation of these data is somewhat uncertain, however, because of such factors as compaction, interaction with moisture and relative quantities of surface and subsurface soil contained in a given sample.

A study of the dependence of polarization and reflectivity on the degree of compaction, along with spectrophotometry of Apollo 12 soil and rocks, will be reported elsewhere (Briggs and O'Leary, in preparation).

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Gehrels, T., Coffeen, T., and Owings, D. (1964) Wavelength Dependence of Polarization.III. The Lunar Surface, Astron. J. 69, 826-852.

Pellicori, S. F. (1969) Wavelength Dependence of Polarization. XIX. Comparison of the Lunar Surface with Laboratory Samples, Astron. J. 74, 1066-1072.

Briggs, F and O'Leary, B. in preparation

Fig. 1. The cumulative particle size distribution for the Apollo 11 and 12 bulk fines, determined from electron microscope data.

Fig. 2. The differential particle volume distribution for the Apollo 11 and 12 bulk fines, determined from electron microscope data.

Fig. 3. The differential particle size distribution for the Apollo 11 and 12 bulk fines, determined by the sedimentation column method.

Fig. 4. The differential particle size distribution for the Apollo 12 bulk and core samples, determined by the sedimentation column method.

Fig. 5. Differential particle volume distribution for the Apollo 11 bulk fines. Curve fits the electron microscope data, sedimentation data are also shown.

Fig. 6. Differential particle volume distribution for the Apollo 12 bulk fines. Curve fits the electron microscope data, sedimentation data are also shown.

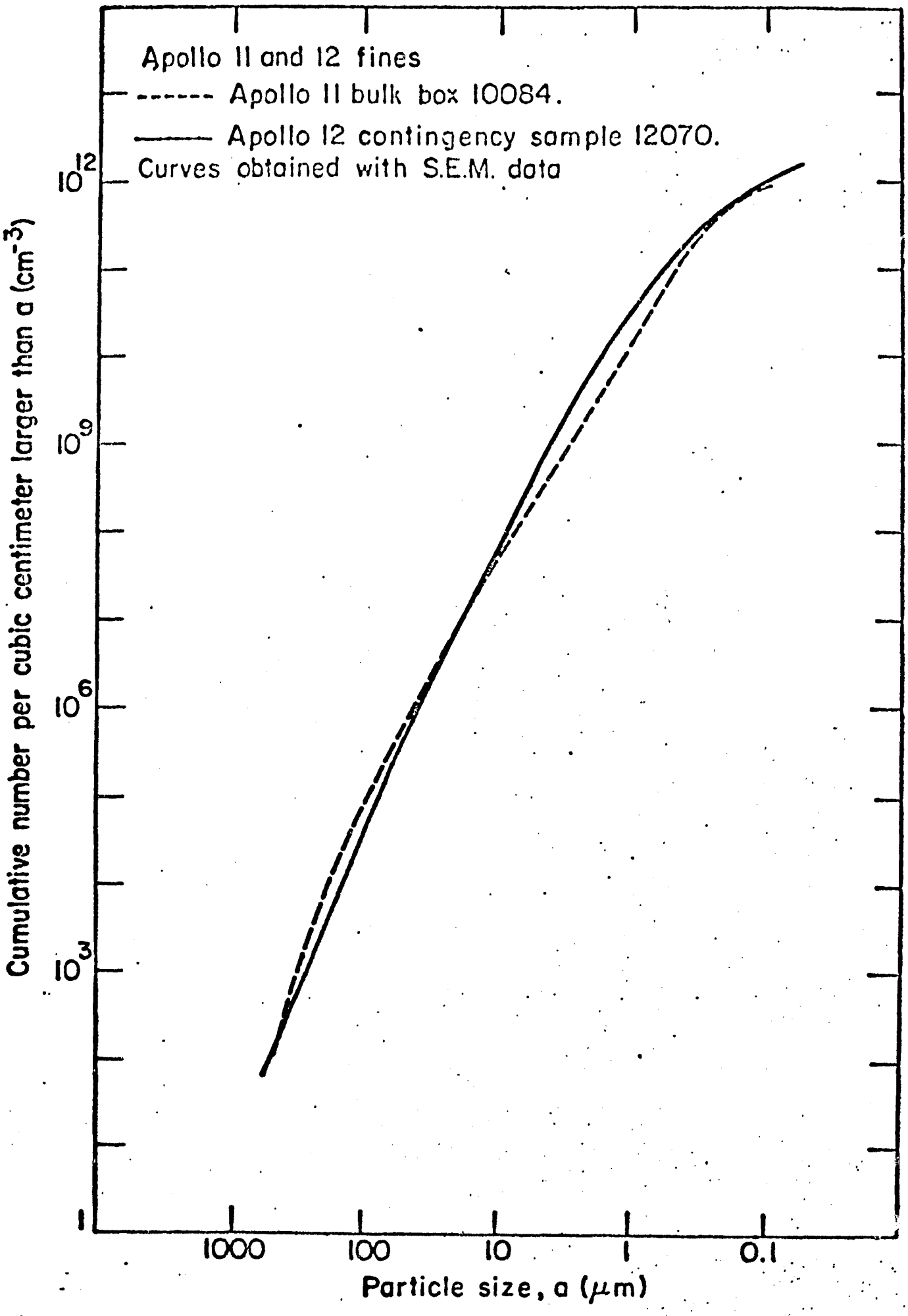
Fig. 7. Dielectric constant measurements for two Apollo 12 powder samples and the Apollo 11 bulk sample, as a function of bulk powder density. Dielectric constant vs. density points for four solid lunar rocks are also shown.

Fig. 8. The variation with density of the absorption length in two Apollo 12 powder samples and the Apollo 11 bulk sample. Points for four solid rocks are also shown.

Fig. 9. (a) Reflectivity of the Apollo 11 and 12 soil vs. phase angle at .56μm wavelength for viewing angles $\varepsilon=0^\circ$ and $60^\circ$. (b) Color index B-V of the powder samples vs. phase angle for $\varepsilon=0^\circ$. Also plotted are (c) the reddening junction of the entire moon, as determined by Gehrels et al. (4), and (d) B-V values for a region of Mare Tranquillitatis.

Fig. 10. The polarization of the Apollo 11 and 12 powders vs. phase angle at .56μm wavelength for viewing angles $\varepsilon=0^\circ$ and $60^\circ$.

Fig. 1


Apollo 11 and 12 fines
------ Apollo 11 bulk box 10084.
—— Apollo 12 contingency sample 12070.
Curves obtained with S.E.M. data
Cumulative number per cubic centimeter larger than a (cm⁻³)
10¹²
10⁹
10⁶
10³
1
1000
100
10
1
0.1
Particle size, a (μm)

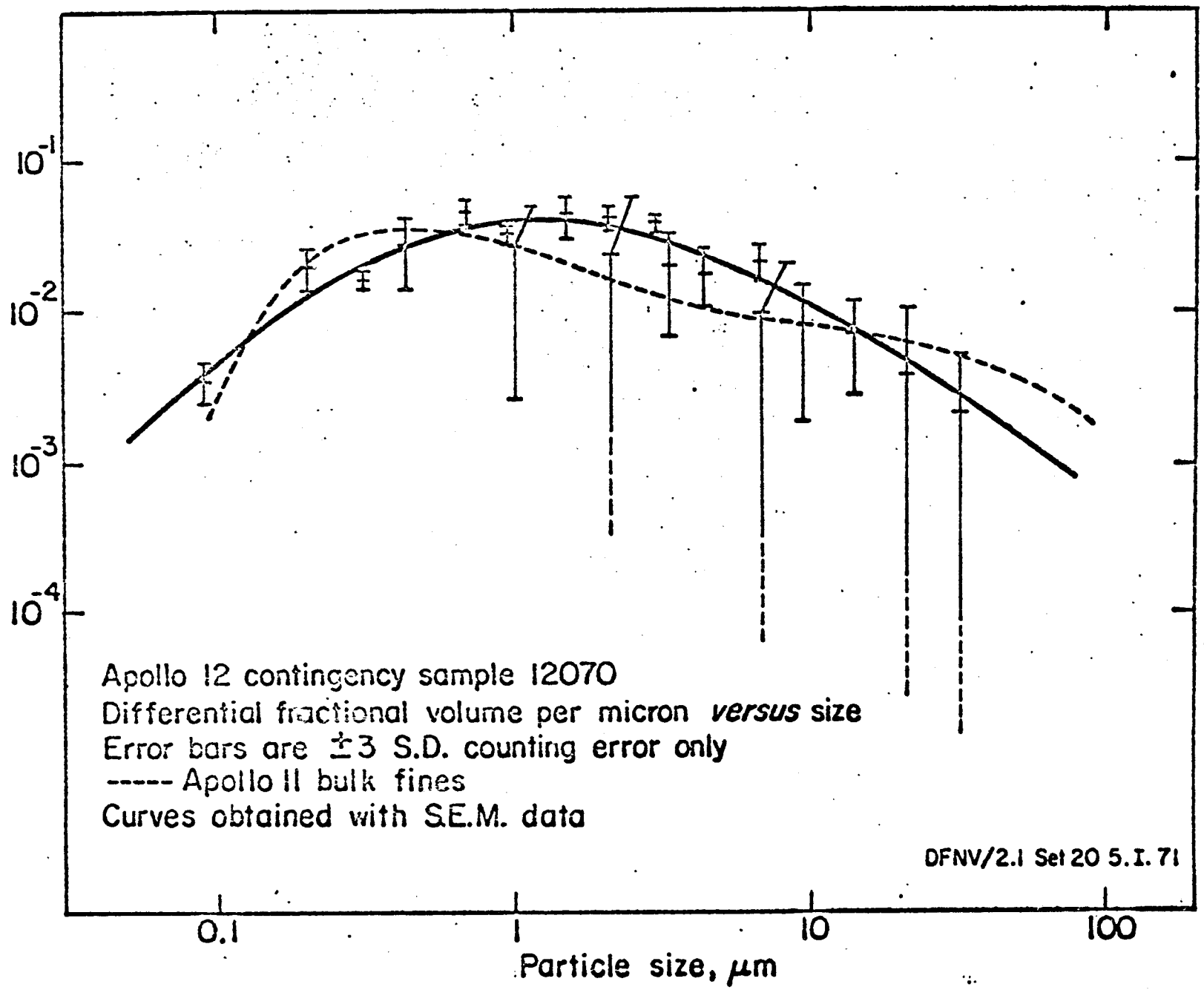
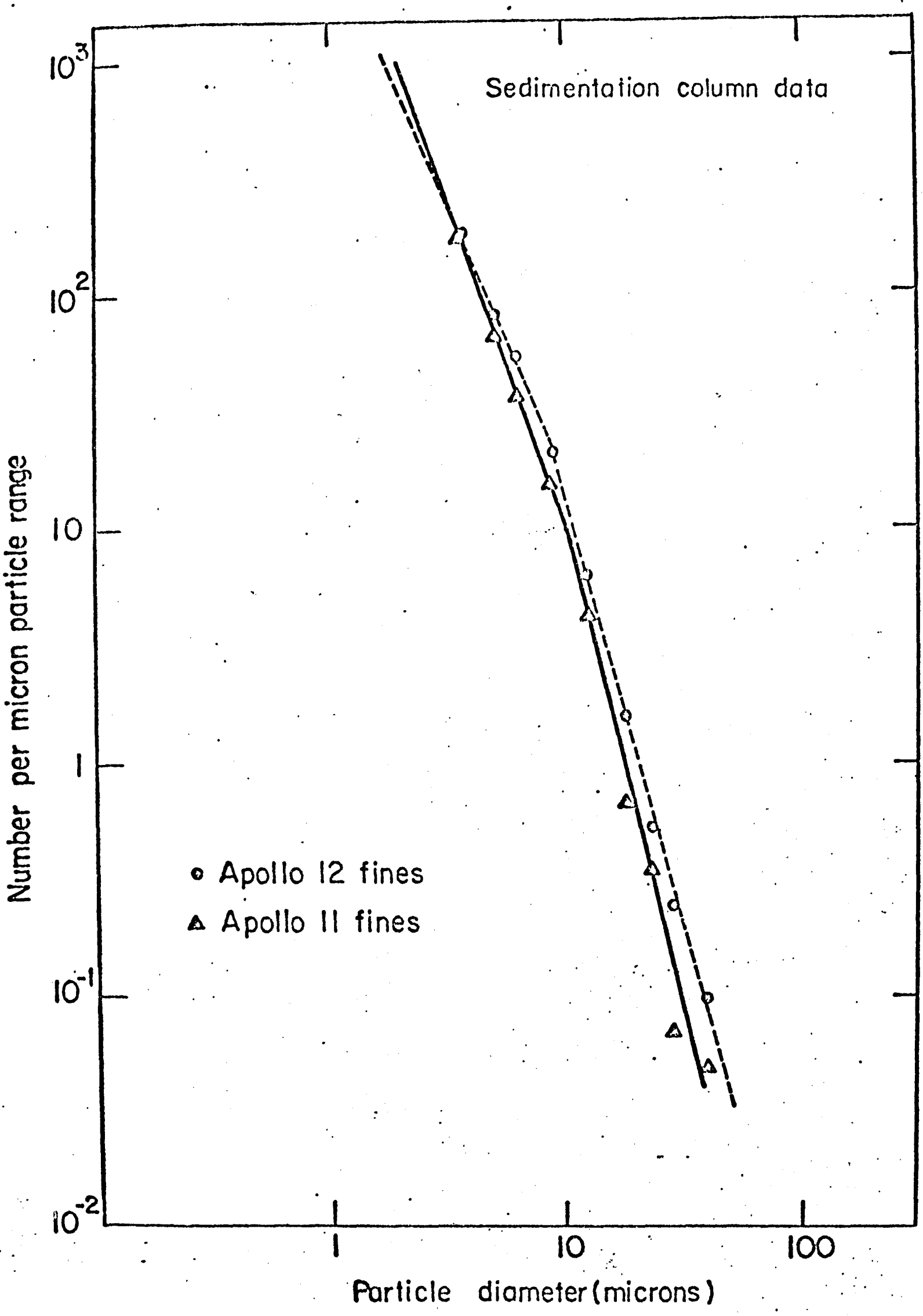
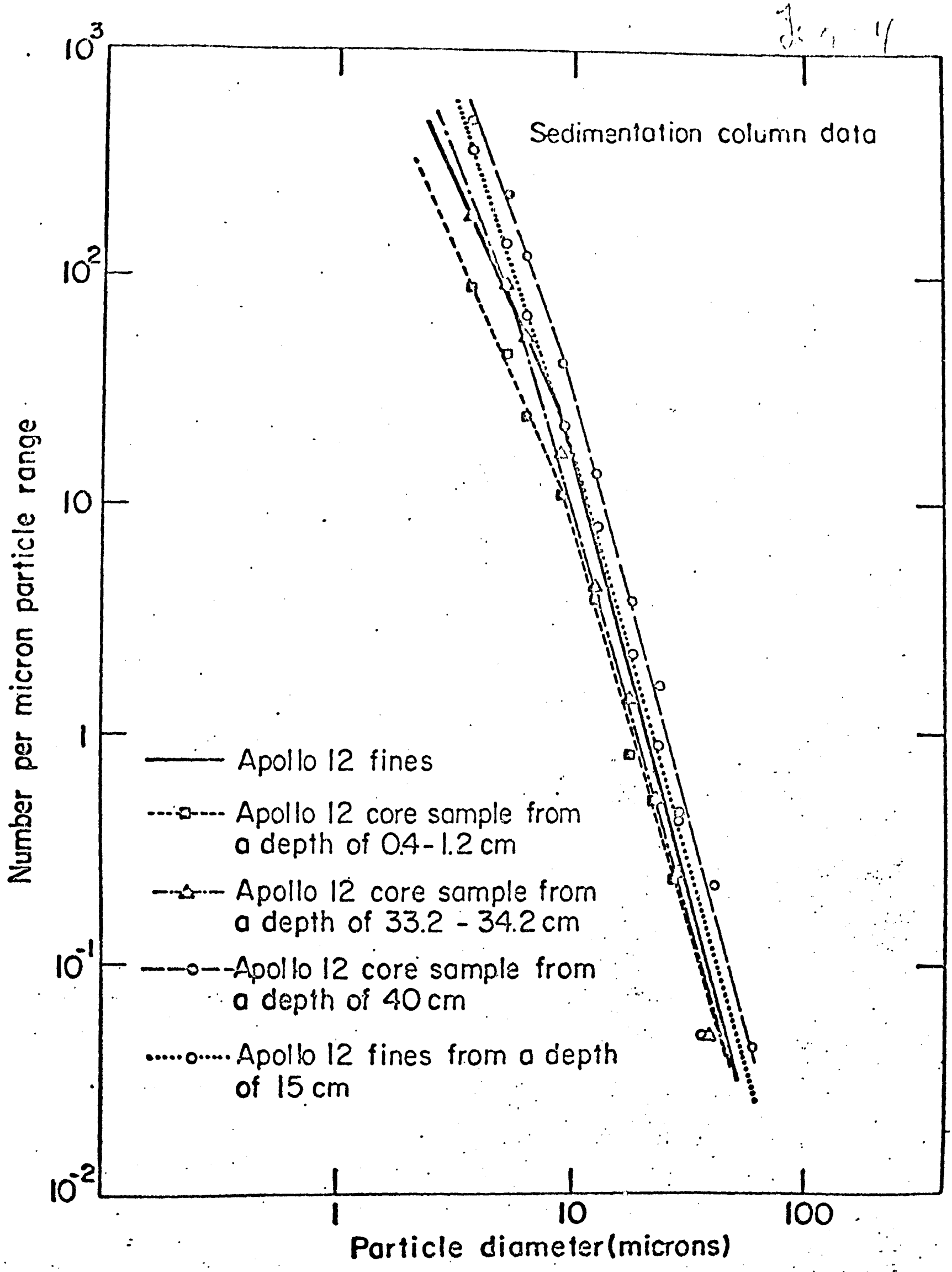
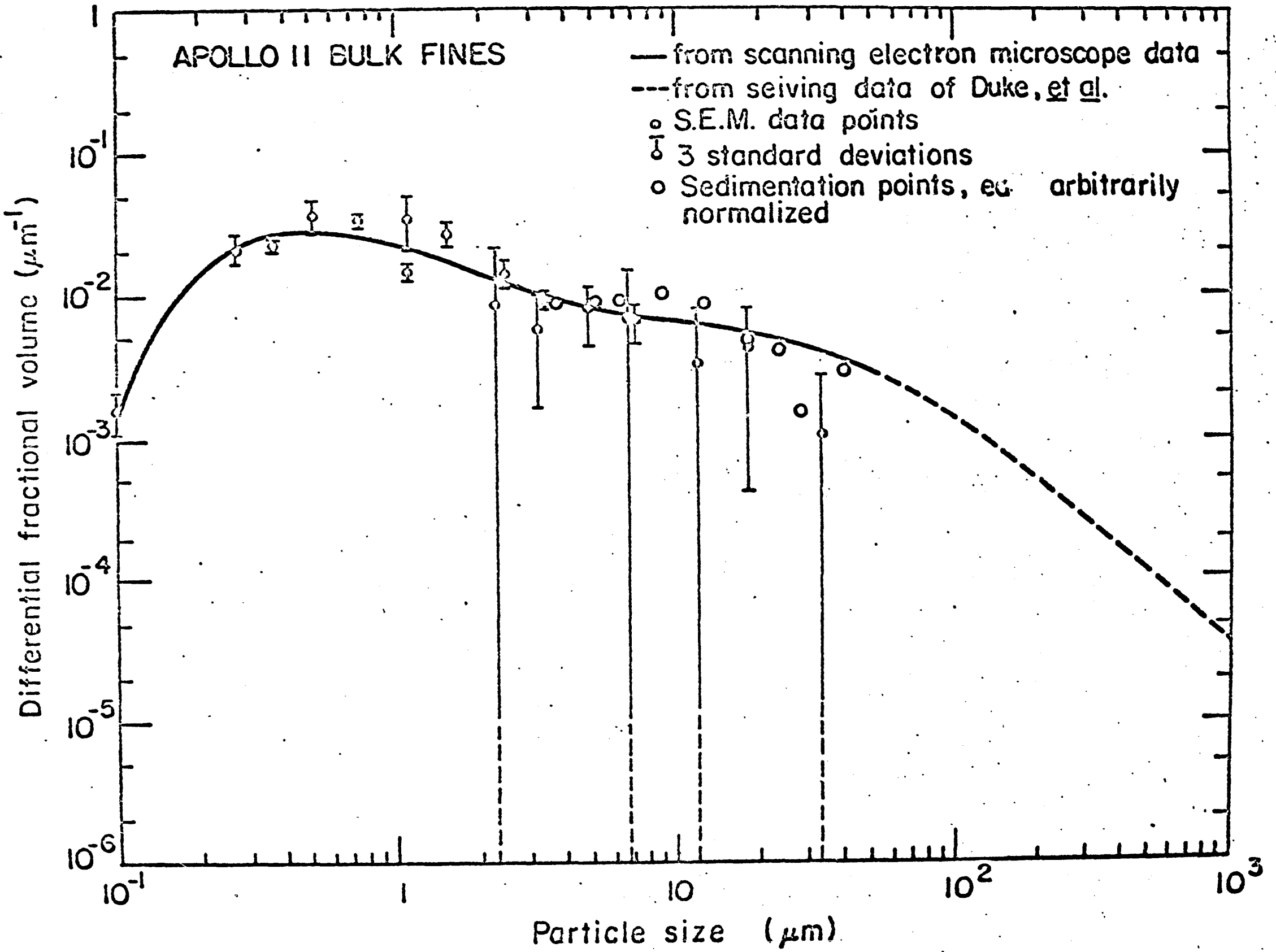
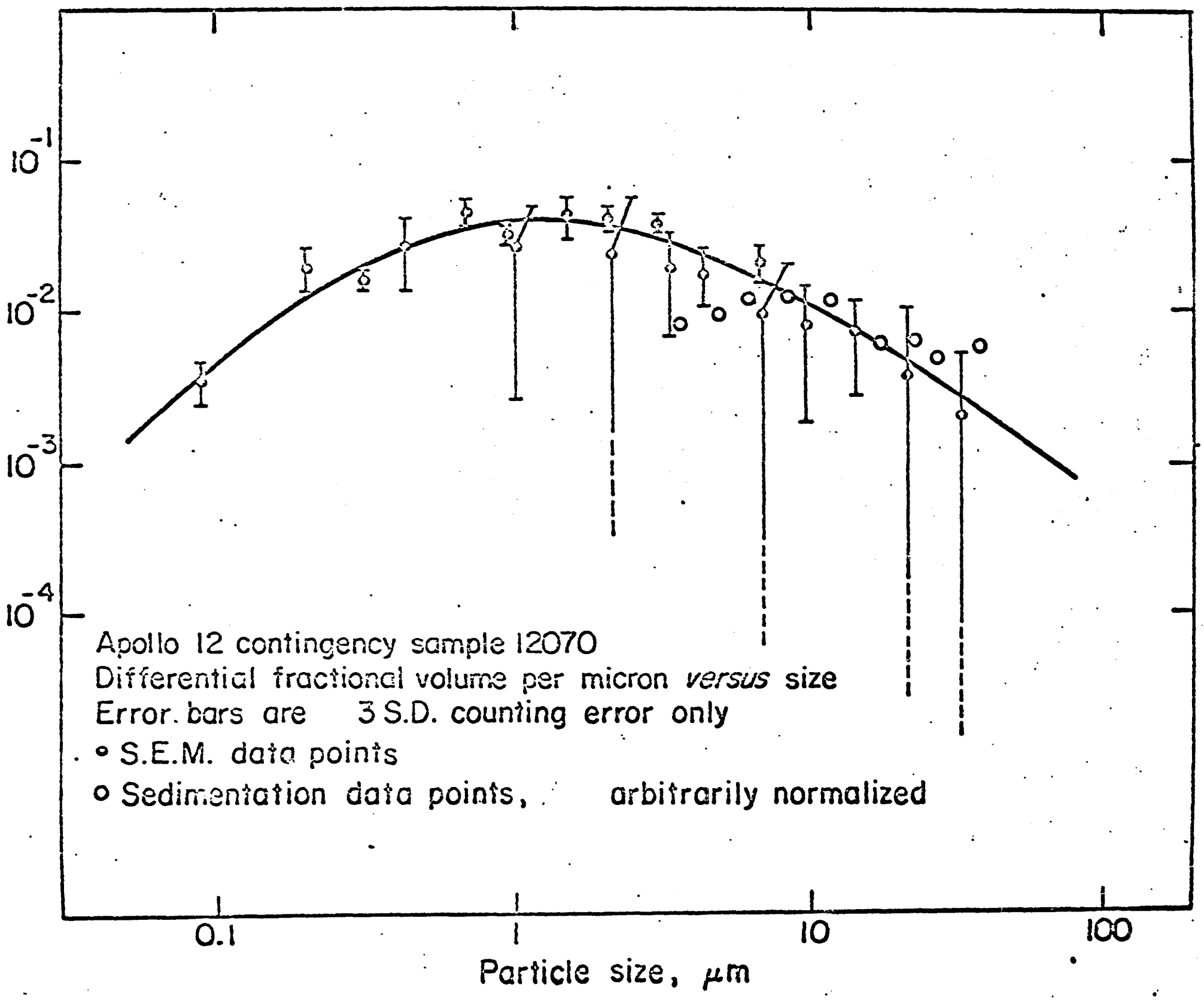

$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-4}$
Apollo 12 contingency sample 12070
Differential fractional volume per micron *versus* size
Error bars are ±3 S.D. counting error only
----- Apollo 11 bulk fines
Curves obtained with S.E.M. data
DFNV/2.1 Set 20 5.I.71
0.1
1
10
100
Particle size, μm

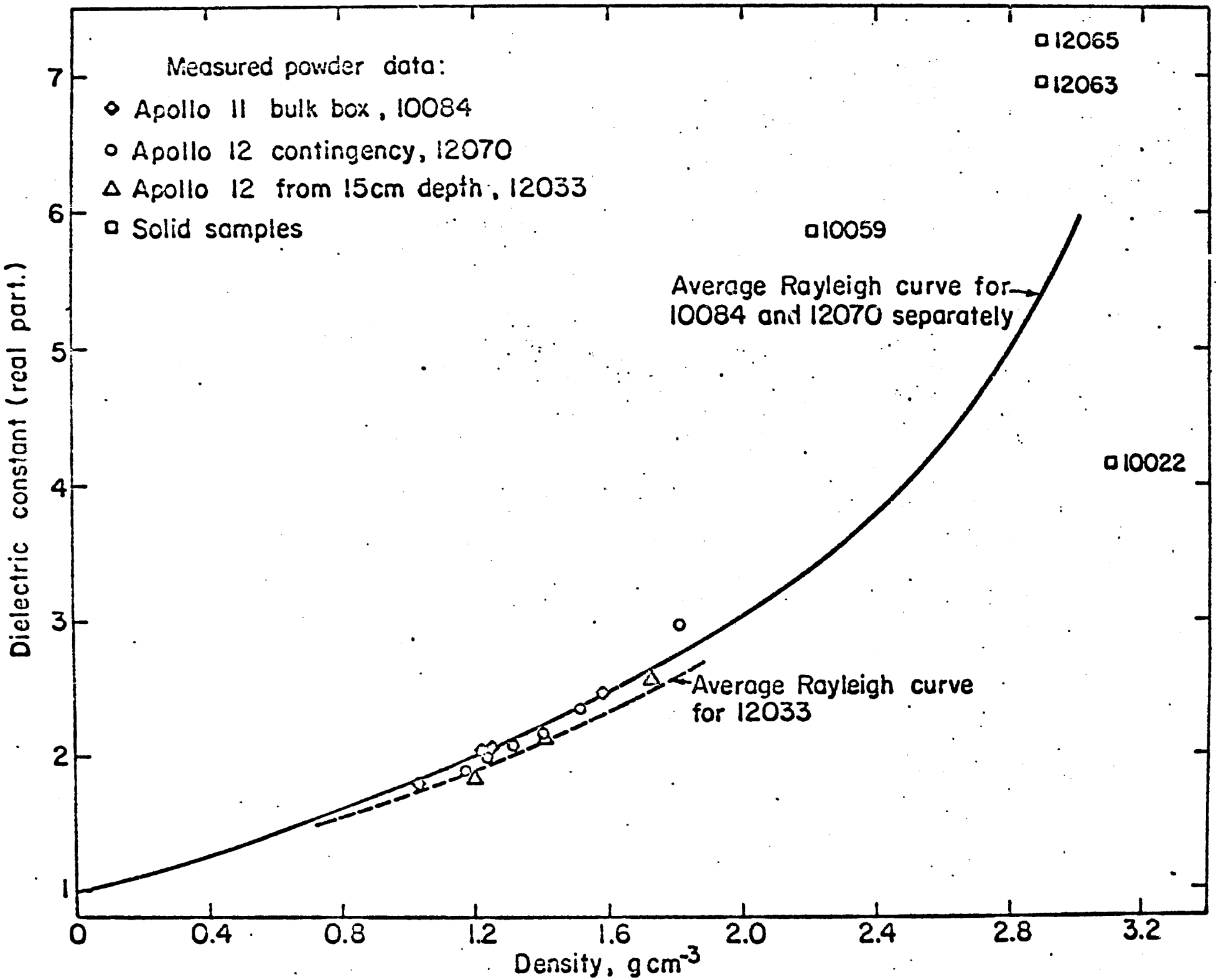
Fig. 3

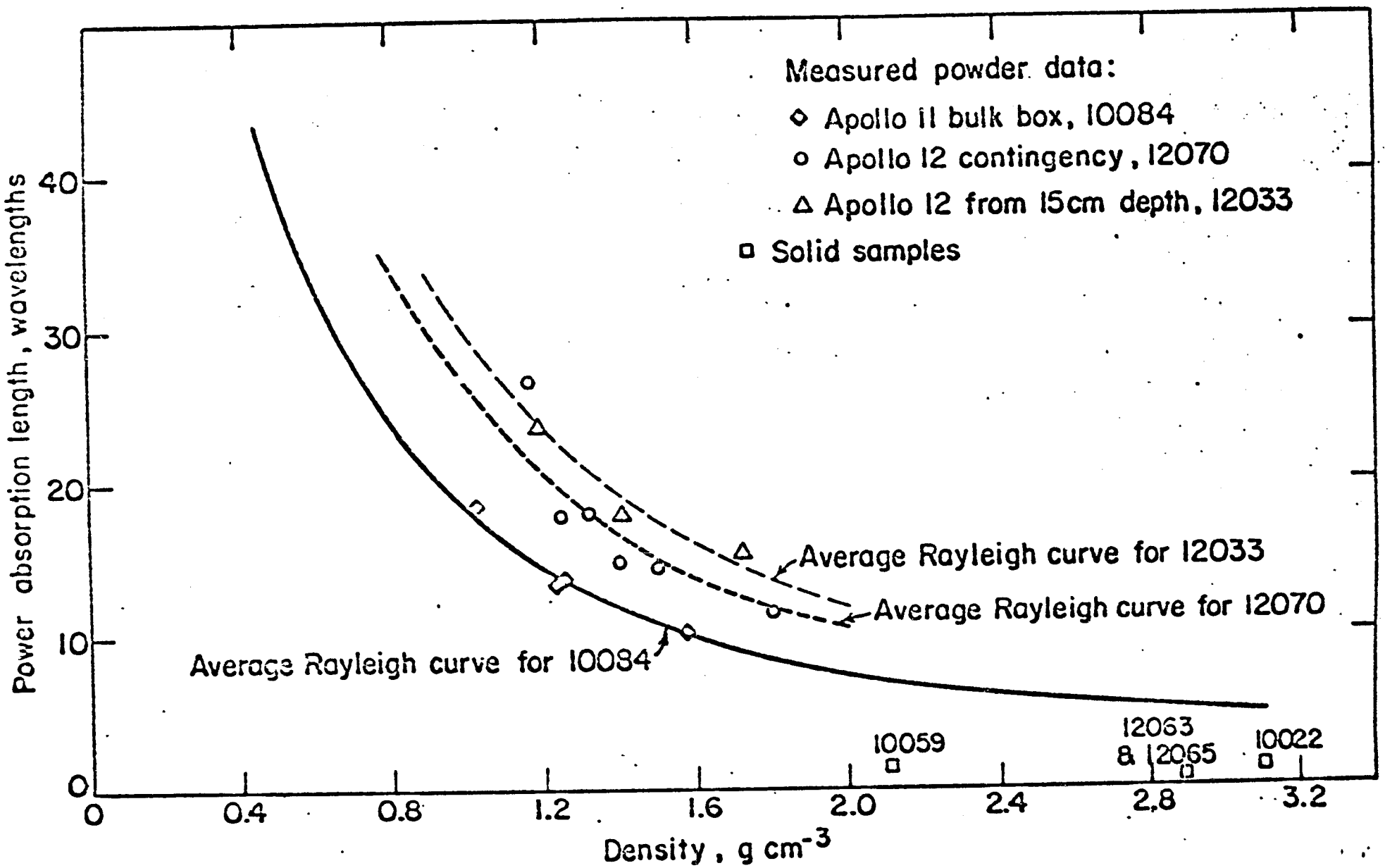

Sedimentation column data
Number per micron particle range
$10^3$
$10^2$
10
1
$10^{-1}$
$10^{-2}$
Apollo 12 fines
Apollo 11 fines
1
10
100
Particle diameter (microns)

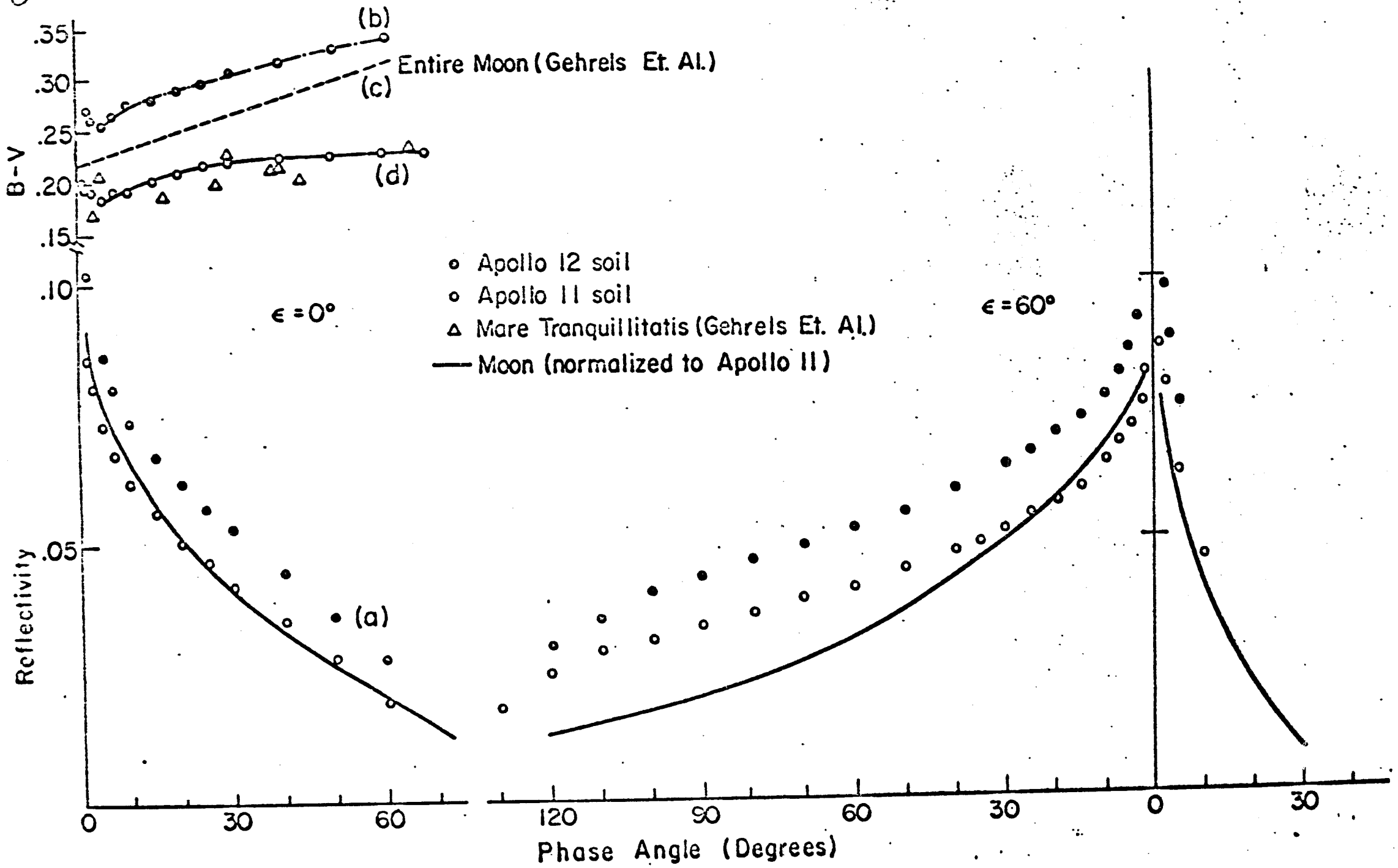

Sedimentation column data
Apollo 12 fines
Apollo 12 core sample from a depth of 0.4 - 1.2 cm
Apollo 12 core sample from a depth of 33.2 - 34.2 cm
Apollo 12 core sample from a depth of 40 cm
Apollo 12 fines from a depth of 15 cm
Number per micron particle range
Particle diameter (microns)
$10^3$
$10^2$
10
1
$10^{-1}$
$10^{-2}$
1
10
100

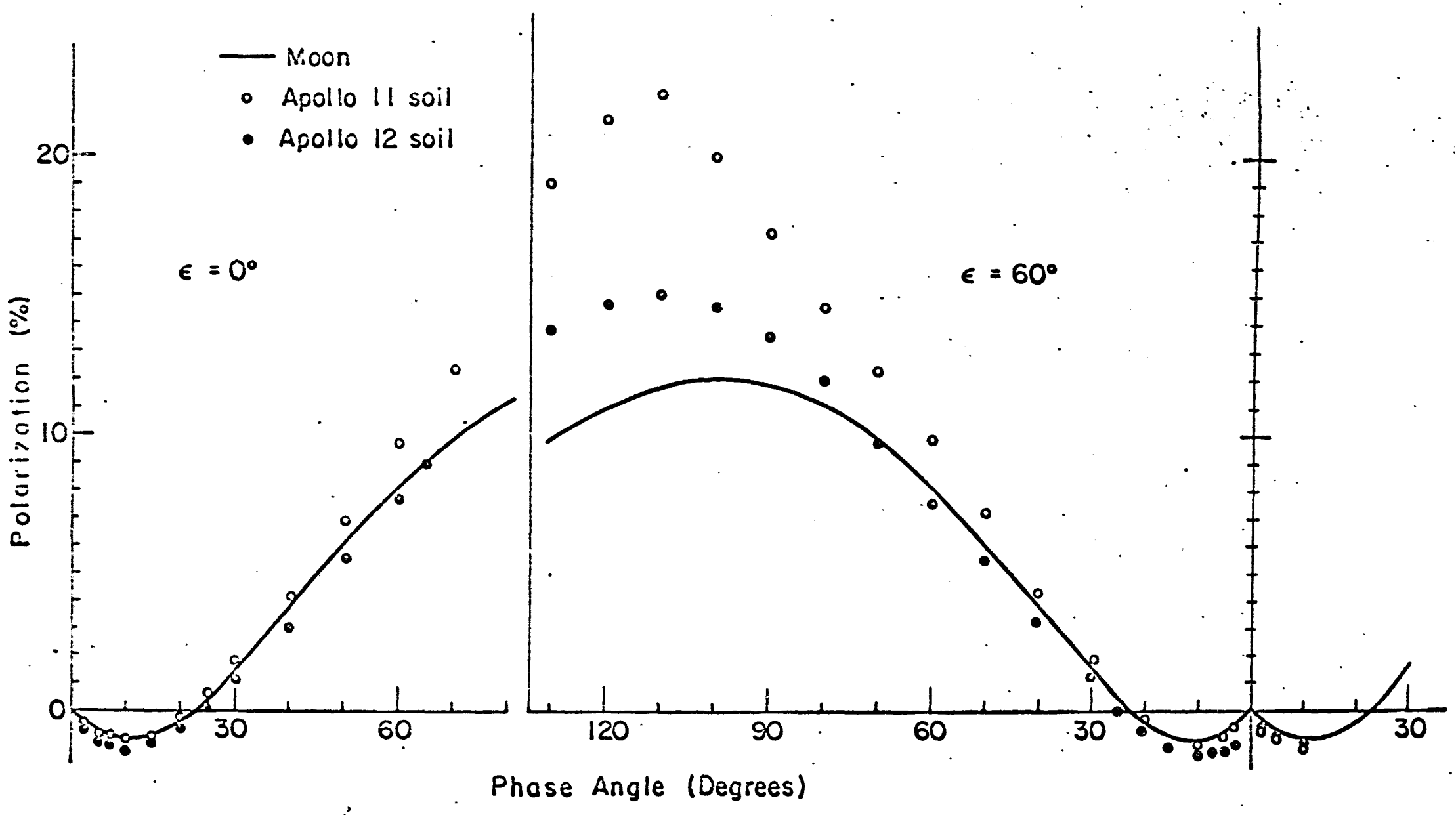

APOLLO II BULK FINES
—from scanning electron microscope data
---from seiving data of Duke, et al.
S.E.M. data points
3 standard deviations
Sedimentation points, eq. arbitrarily normalized
Differential fractional volume ($\mu m^{-1}$)
Particle size ($\mu m$)
1
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-4}$
$10^{-5}$
$10^{-6}$
$10^{-1}$
1
10
$10^{2}$
$10^{3}$


$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-4}$
Apollo 12 contingency sample 12070
Differential fractional volume per micron *versus* size
Error bars are 3 S.D. counting error only
• S.E.M. data points
o Sedimentation data points, arbitrarily normalized
0.1
1
10
100
Particle size, μm


Measured powder data:
◆ Apollo 11 bulk box, 10084
○ Apollo 12 contingency, 12070
△ Apollo 12 from 15cm depth, 12033
□ Solid samples
□12065
□12063
□10059
Average Rayleigh curve for 10084 and 12070 separately
□10022
Average Rayleigh curve for 12033
Dielectric constant (real part.)
Density, g cm⁻³
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
1
2
3
4
5
6
7


Measured powder data:
◇ Apollo 11 bulk box, 10084
o Apollo 12 contingency, 12070
△ Apollo 12 from 15cm depth, 12033
□ Solid samples
Average Rayleigh curve for 12033
Average Rayleigh curve for 12070
Average Rayleigh curve for 10084
10059
12063
& 12065
10022
Power absorption length, wavelengths
Density, g cm⁻³
0
10
20
30
40
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2


(b)
Entire Moon (Gehrels Et. Al.)
(c)
(d)
B-V
.35
.30
.25
.20
.15
.10
.05
Reflectivity
ϵ = 0°
ϵ = 60°
(a)
Apollo 12 soil
Apollo 11 soil
Mare Tranquillitatis (Gehrels Et. Al.)
Moon (normalized to Apollo 11)
0
30
60
120
90
60
30
0
30
Phase Angle (Degrees)


Moon
Apollo 11 soil
Apollo 12 soil
ϵ = 0°
ϵ = 60°
Polarization (%)
20
10
0
30
60
120
90
60
30
30
Phase Angle (Degrees)