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ESTIMATION OF THE PHYSICAL CONSTANTS OF THE LUNAR SURFACE

by

Radiation Laboratory

M. Brunschwig  
W. E. Fensler  
E. Knott  
A. Olte  
K. M. Siegel

Rensselaer Polytechnic Institute

T. J. Ahrens  
J. R. Dunn  
F. B. Gerhard, Jr.  
S. Katz  
J. L. Rosenholtz

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## ABSTRACT

An estimate is given for the bounds on particle size, thermal conductivity, volumetric specific heat and electromagnetic constants of the lunar surface.

These constants allow us to compare rocks, meteorites, and tektites, which scientists have proposed as possible lunar materials or similar to lunar materials, with our results obtained by electromagnetic diagnostics of the lunar surface. Since the values for many of these constants were unknown, laboratory tests were made to obtain the fundamental constants of these possible lunar materials.

Penetrometer tests in dust - like materials in vacuo took on new meaning. Results of these tests showed that the danger of sinking or partially sinking into the lunar surface upon landing should not be considered lightly.

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## I

### INTRODUCTION

In [1] a lunar scattering theory was presented in considerable detail augmenting, clarifying and correcting our original paper, [2]. The theory showed that when all existing experiments on lunar reflections known to the authors were compared at a common pulse length after applying Trexler's modulation loss [3], these were found to be consistent as far as large dominant returns were concerned.

In [1], values for the ratios of permittivity ( $\epsilon$ ) to permeability ( $\mu$ ) and conductivity ( $s$ ) to permeability for the key scattering centers on the surface of the moon were obtained as

$$\frac{\epsilon}{\mu} = 7.6 \times 10^{-6} \text{ mhos}^2 \qquad \frac{s}{\mu} = 2.7 \times 10^2 \text{ mhos/henry} \qquad (1a)$$

If  $\mu = \mu_0$ , then

$$\frac{\epsilon'}{\epsilon_0} = 1.08 \qquad \frac{\epsilon''}{\epsilon_0} = \frac{3.8 \times 10^7}{\omega} \qquad (1b)$$

Where  $\omega = 2\pi f$ , and  $f$  is the frequency.

Since that time additional experiments have shown that those constants are typical constants not only for the key scattering centers at the surface of the moon but are probably good average values for the whole lunar surface as seen from the earth. This conclusion is reached because Pettengill [4] has

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found that the small background return outside the key scattering-center portion of the moon obeys Lambert's law except for limb brightening; see Figure 1.

The coefficient of the  $\cos \theta$  dependence for the part of the curve obeying Lambert's law is the same order of magnitude as derived in [1] for the reflection coefficient for the key scattering centers after the effect of interference between scattering centers has been removed. But by Lambert's law the coefficient of  $\cos \theta$  should be a constant times the reflection coefficient. This constant is believed to be between one and six. In any case the value of reflection coefficient so obtained will be in agreement to one significant figure with the reflection coefficient found for the key scattering centers [1] and it predicts almost, if not exactly, the same results in the second significant figure for relative permittivity. Thus we now have a measure of the permittivity to permeability ratio for the whole lunar surface as seen from earth and we are happy to find this agreement with our previous results.

Concurrently measurements have been made on tektites [5], meteorites [6] and on those rocks which one theory or another would have predicted came from the moon or could be similar to lunar materials. Our results showed that, in the form which they were found on earth, these could not be the materials of the outer surface of the moon. However, these analyses — petrographic, ultrasonic and electromagnetic — resulted in useful information in their own right as fundamental constants of the materials tested.

Passive radiation data obtained on earth from the visual spectrum through the infrared and microwave frequencies down to 1000 Mc has been analyzed

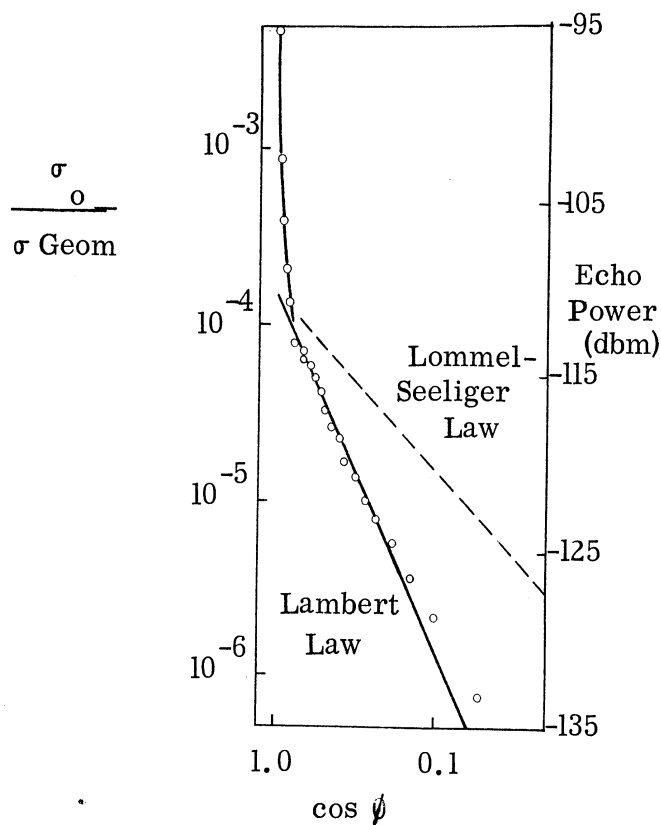


FIG. 1. DISTRIBUTION OF POWER IN MOON ECHOES PLOTTED AS A FUNCTION OF THE COSINE OF THE ANGLE OF INCIDENCE TO THE SURFACE

as to consistency and utility in deriving constants of the lunar surface. It was found that when this data was utilized with the constants obtained from the radar data, the average thermal conductivity and volumetric specific heat of the lunar material could be derived. The expected values on a best fit basis from this combined analysis yield a thermal conductivity of  $3.3 \times 10^{-5}$  calories per centimeter seconds per degree. The volumetric specific heat was 0.036 calories per degree centimeter cubed. An upper bound on particle size lay between 300 and 1000 microns. The above numbers are derived in [7] which was part of this study.

Optical scattering laws show a uniform brightness over most of the lunar disc [8] and when this is analyzed by rough scattering laws, considering

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also the criteria on when rough scattering laws apply, one concludes that the lower bound on the significant particle size is of order one micron. Analysis of infrared data shows that the moon acts as a rough surface at these wavelengths also [9] and thus the lower bound on particle size is probably ten microns. From these considerations the expected range of particle size is probably between 30 and 100 microns or to be on the safe side, possibly 10 to 300 microns.

These analyses quickly made us aware of the importance of obtaining electromagnetic constants as a function of particle size; this data has now been obtained for representative materials. Only the curves for glasses and tektites approach a low relative permittivity fast enough with diminishing particle size to qualify for additional measurements on these materials; their thermal conductivity and volumetric specific heats should also be measured in the particle range of 10 to 300 microns.

Having pulverized the materials and graded them as a function of particle size it was obviously in order to study effect of packing factor as a function of particle size and material as this information would be useful to check certain concepts associated with lunar landing problems. The results of this study is included in Section II. The next logical step was to determine penetration as a function of particle size and vacuum pressures. These penetrometer experiments have also been made and reported in Section III. The results show an increase of penetration with a reduction in pressure for particle sizes measured down to  $40\mu$ .



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In [10] it was stated that a lunar satellite properly instrumented could determine the depth of the outer layer of the surface of the moon and the electromagnetic constants of the inner layers. Thus we would like to reason, based on correlation between electromagnetic constants and other physical properties of materials, how to obtain knowledge of the hardness and density of inner layer materials by correlation with the electromagnetic constants. To assist us in this analysis, we let a subcontract with Professors Rosenholtz, Katz and Dunn of Rensselaer Polytechnic Institute to make petrographic and ultrasonic tests of the rocks of possible interest. We then made electromagnetic analyses of the same rocks. These results are reported in Section IV and will undergo considerable correlation analysis to see what hope exists in this direction.

Theories on the lunar origin of tektites have been made by O'Keefe, Urey, Ninninger, et. al. Urey and others are credited with having related meteorites to the structure of the outer surface layer of the moon. Suggestions have been made also on the possibility of the surface material of the moon being similar to volcanic ash or pumice. By analogy with earth history, some have assumed that igneous activity on the moon would result in acidic and basic rocks such as rhyolite, andesite and basalt as extrusive volcanic or surface rocks and granite, diorite and gabbro as intrusive plutonic or beneath-the-surface rocks. Because of the lack of water on the moon sedimentary rocks have been excluded from most of our studies. Consequently for our tests we have chosen rocks and minerals primarily in the igneous class, with a few sedimentary

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and metamorphic types for comparison. Volcanic rocks were of primary interest; pumice, basic scoria, and basalt were investigated in powdered form as well as were tektites and meteorites. Tektites, meteorites and rocks in the rhyolite, andesite, basalt, granite, diorite and gabbro classes as well as sedimentary and metamorphic types were investigated as solid samples.

In summary, our preliminary investigation reveals that particle sizes of tens of microns with thermal conductivity of  $3.3 \times 10^{-5}$  and volumetric specific heat of 0.036 are in store for the lunar lander who must also be prepared to face the possibility of sinking beneath the surface of the moon.

We thank John O'Keefe, Ralph Hiatt, T. B. A. Senior, H. Urey and John Henderson for their help and assistance in our program.

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## II

### PERMITTIVITY AS A FUNCTION OF PARTICLE SIZE FOR METEORITES, TEKTITES, GLASS AND ROCKS

An investigation was made to determine the manner in which permittivity varies as a solid sample is reduced into finer and finer fragments. For the materials to be reduced we have selected sea sand (which is readily available in various grain sizes), plate glass, tektites from Moldavia, a Plainview, Texas chondrite, basalt (New Jersey), scoria (Oregon) and pumice (Utah).

The ordering of the grain sizes was done by the use of standard sieves. The range of particle sizes in each batch thus obtained are given in Table I. It is clear that such an ideal grading of particles as shown in the table could occur only if they were spherical. The grain shapes varied, some were cubical, some spherical, some spheroidal, and some splinterlike. Thus the boundaries are to be taken in a rough sense only. The batch containing the smallest particles is labeled as dust. No sieves were available to establish the particle size accurately because the particles were exceedingly small. To get a distribution curve a microscope was used to measure particle sizes and to count the particles. Most of the particles were about  $1\mu$  in size for the dust grade.

The particle-size distribution of the four dust grade powders shown in Table II were obtained by the microscopic method of measurement in

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TABLE I  
GRADING OF PARTICLES

Grain Size	Range of Particle Size, microns	
	Maximum	Minimum
7	6000	2000
6	2000	840
5	840	420
4	420	177
3	177	90
2	90	44
1	44	2 (approx.)
Dust*	50	.1

TABLE II  
PARTICLE SIZE DISTRIBUTION FOR THE DUST GRADES

Material	Frequency of Occurrence in Percent						
	0-5 microns	5-10 microns	10-20 microns	20-30 microns	30-40 microns	40-50 microns	50-60 microns
Sea Sand	98.52	1.0	0.4	0.70	-	0.01	-
Plate Glass	76.86	12.7	7.1	1.8	0.77	0.63	0.14
Tektite	87.03	9.8	2.7	0.30	0.05	0.05	0.07
Plainview, Tex. Chondrite	96.23	3	0.6	0.09	0.02	0.03	0.03

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which an attempt was made to classify the individual particles as to nominal size in 5 or 10 micron increments. A small amount of powder was placed in a container of acetone and mixed vigorously. Upon placing a drop of solution on a glass specimen slide, the acetone evaporated leaving the dry particles dispersed over a circular area. Neither the density nor the mixture of the particles was constant as one moved from the outer rim to the center of the circular patch. The finer particles were grouped at the outside strip, and as one moved towards the center, the proportion of the bigger particles increased. Starting approximately from one third of the radius the particle density was practically zero. The particle distribution was approximately symmetrical along the direction of circumference. The particles were counted in two narrow tracks normal to each other, using a microscope.

The method used for grinding each specimen should be pointed out, since the contamination of the sample is an ever present problem in the grinding process.

As obtained, the sea sand was in grade 5 particle size. It was ground in a porcelain ball mill partially filled with pebbles and then graded into batches using the sieves. The dust grade was ground from grade 1 sand; hardened steel balls were used in the ball mill. No iron contamination could be observed using a strong permanent magnet.

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The plate glass was crushed by hand using a pair of pliers. The first four grades were obtained in this manner. They were subsequently ground to finer powders in a ball mill. Flint pebbles were used for the first three sizes and hardened steel balls for the dust grade. A small amount of iron contamination of the glass dust could be observed by employing a strong permanent magnet. The glass particles had a tendency to be splinter-like.

Six small tektites from Moldavia were purchased from Ward's Natural Science Establishment, one was saved, and the rest were first crushed and then ground into dust with a mortar and pestle. Thus the contamination is very small for the tektite dust.

The Plainview, Texas chondrite was ground in a hand mill with cast-iron grinding plates. The meteorite was relatively soft so that it is believed that the contamination problem is not a severe one. However, the magnetic test could not be applied since the meteorite is originally magnetic. The dust grade chondrite was obtained by grinding the total available in all other grades in the porcelain jar mill, using hardened steel balls for grinding action.

The New Jersey basalt also was ground in the hand mill. Unfortunately, the hardness of basalt was such that some of the cast iron was worn away from the plates of the mill and became part of the fragmentized sample.

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The main iron impurities were easily removed magnetically from grades 4, 5, and 6, because iron particles were much more magnetic than the basalt particles. However, practically all particles in grades 3, 2, and 1 seemed magnetic and the effectiveness of the magnetic clean up is not known. With respect to the problem of contamination, an unsuccessful attempt was made to establish the relative amount of magnetic material in the basalt. A small piece of it was ground to fine powder with a mortar and pestle, guaranteeing zero iron contamination. The relative amount of magnetic material was then to be established in the uncontaminated sample. However, all the powder seemed to respond to a permanent magnet, but not quite as energetically as the fine sample from the mill.

The scoria was found to be slightly magnetic and use of the grinding mill was avoided. The sample was fragmentized mainly by crushing in a steel vise, and iron contamination is small. Pumice is quite soft and was reduced to powder by merely rubbing two blocks of the material together.

The sea sand and plate glass could be considered as homogeneous, and thus different grades are of the same material. On the other hand, the chondrite, the basalt, the scoria and the pumice consist of different minerals of various hardness and toughness so that upon crushing one may expect them to fragmentize preferentially. Upon grading the crushed sample by the sieves, we had no guarantee that each grade would contain the grains

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of each mineral in the same proportions as in the solid sample. It is extremely difficult to get rid of this variable. This problem exists in all the grades, except the chondrite dust, which represents the whole meteorite.

A coaxial sample holder, as shown in Figure 2 was fabricated of aluminum. Guard rings were provided to insure that fringe capacitance was not entering into the capacitance measurements. A General Radio Type 650-A impedance bridge was modified to be used in conjunction with the guarded sample holder. The measurements were carried out at 1000 cps. Since it was discovered that in some cases the reduced material was not sufficient to fill the sample holder shown in Figure 2, another one was constructed, the same in every way, but smaller in volume by a factor of four. A sample of carbon tetrachloride was measured in both sample holders as a check and its permittivity found to be within 3% of the accepted value. Thus we feel the measurements reported on the powder are accurate to the same order.

All samples were heated in an oven for at least a half hour at  $105^{\circ}$ - $110^{\circ}$ C prior to measurement. In many instances the samples were stored for greater lengths of time. It was discovered that measurements upon a given sample were repeatable whether it had been stored in the oven for a half hour or for two days. We feel that the half hour period was adequate to guard against moisture condensing on the particle surfaces.



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The sample holder was placed in a vertical position and was loaded with the graded particles through a funnel. Care was taken to let them fall naturally into the cylinder in order to get as low a packing factor as possible. Grade 1 of both sand and glass particles exhibited a tendency for the particles to cling together. It was at first thought that not all the moisture had been driven off the samples. However, after 15 hours of vacuum heating at 183<sup>o</sup> (see Figure 3 ), the clinging nature had been reduced but slightly. The only explanation that we can offer is that the particles acquire charges which give rise to interparticle attraction.

We have defined packing factor as the ratio of the density of the reduced sample to the density of the solid sample. Since pumice and scoria are porous, the "uncrushed" density for these two materials was determined from crushed particles by comparing the weight of a quantity of particles in air to their weight in water. Table III lists the densities of the materials upon which the values of packing factor are based. The density of the sample is evaluated from knowledge of the weight of the sample which filled the known volume of the sample holder.

TABLE III

## DENSITIES OF THE SOLID MATERIALS

<u>Material</u>	<u>Specific Gravity</u>
Cheap Plate Glass	2.49
Sea Sand	2.64
Moldavite	2.37
Plainview, Texas Chondrite	3.61
Basalt (New Jersey)	2.96
Scoria (Oregon)	2.58
Pumice (Utah)	2.13

Bakelite caps on either end confine the sample.

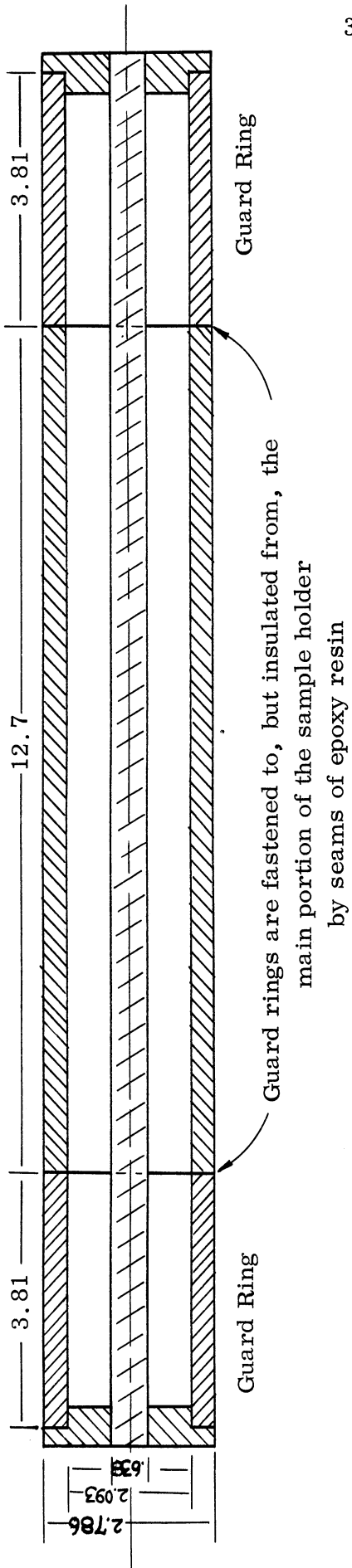


FIG. 2: THE GUARDED COAXIAL SAMPLE HOLDER  
(dimensions in cm.)

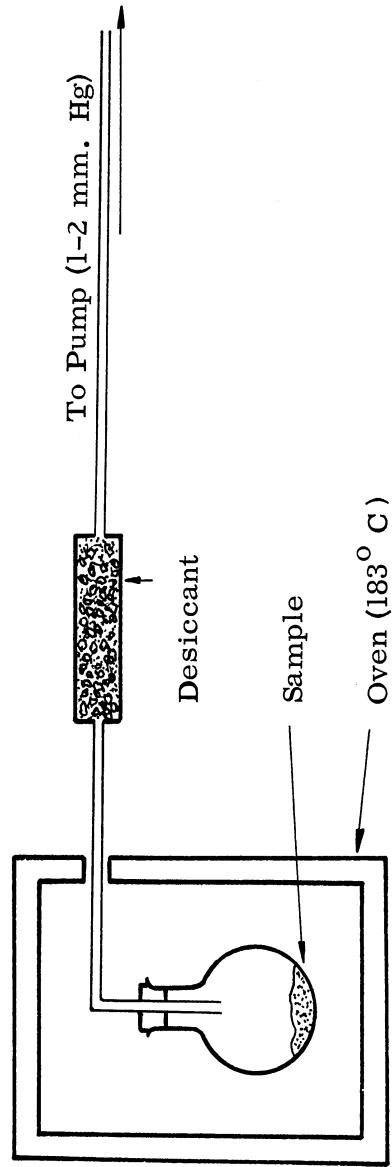


FIG. 3: THE VACUUM HEATING SYSTEM

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Table IV summarizes the relative permittivities and the packing factors obtained from the measurements for the various grain sizes. The result was obtained from three measurements which were averaged. The repeatability was good. In general we observe that the relative permittivity decreased with the particle size. Also the packing factor decreased with the particle size. It was observed that for particles larger than 100 microns the permittivity did not depend on moderate tapping of the sample holder. However, for particles less than 100 microns in size a significant increase in the relative permittivity of all materials could be brought about by tapping the sample holder. For example, by a gentle but prolonged tapping the relative permittivity of Grade 1 sand was increased from 1.94 to 2.58 and the corresponding packing factor from 0.355 to 0.580. Similar results were measured for plate glass. The relative permittivities listed are the minimum values obtainable. The smallest relative permittivities obtained were practically the same for sand, plate glass, Moldavite, and pumice, with the Plainview, Texas chondrite not very far behind.

The relative permittivities presented in Table IV may be plotted either as a function of particle size or as a function of packing factor. First we present the relative permittivities as a function of particle size in Figures 4 and 5. The particle size plotted is the one which was judged to be most preponderant in each grade of particles. The range of permittivities

TABLE IV  
RELATIVE PERMITTIVITY OF FRAGMENTIZED MATERIALS AT 1000 CPS

Material	Grain Size		Solid	6	5	4	3	2	1	Dust
	F	$\epsilon'_r$								
Sea Sand	1.00			-	.657	.600	.497	.440	.355	.363
	3.78*			-	2.92	2.68	2.36	2.19	1.94	1.90
Plate Glass	1.00		.588		.522	.501	.495	.441	.320	.271
	7.30		3.38		3.40	3.35	3.36	3.01	2.27	1.96
Moldavite	1.00		-		-	-	-	-	-	.305
	5.38		-		-	-	-	-	-	1.91
Plainview, Texas Chondrite	1.00		.537		.519	.452	.409	.383	-	.346
	$\ll \frac{\sigma}{\omega}$		6.12		5.21	4.33	3.83	3.32	-	2.66
Basalt (New Jersey)	1.00		.495		.431	.432	.415	.374	-	-
			4.14		3.34	3.43	3.24	3.43	-	-
Scoria (Oregon)	1.00		.414		.419	.470	.485	.436	-	-
			2.80		2.90	3.14	3.19	2.83	-	-
Pumice (Utah)	1.00		-		.310	.373	.336	.296	-	-
			-		2.02	2.23	2.03	1.88	-	-

Explanations: F - Packing Factor,  $\epsilon'_r$  = real part of relative permittivity.  
 $\sigma/\omega$  - ratio of conductivity to angular frequency.

\* - Taken for fused quartz from A. Von Hippel, Dielectric Materials and Applications, John Wiley and Sons, 1954, pg. 311.

- Scoria (Oregon) Particles
- ⊙ Plainview, Texas Chondrite

□ Plate Glass Particles

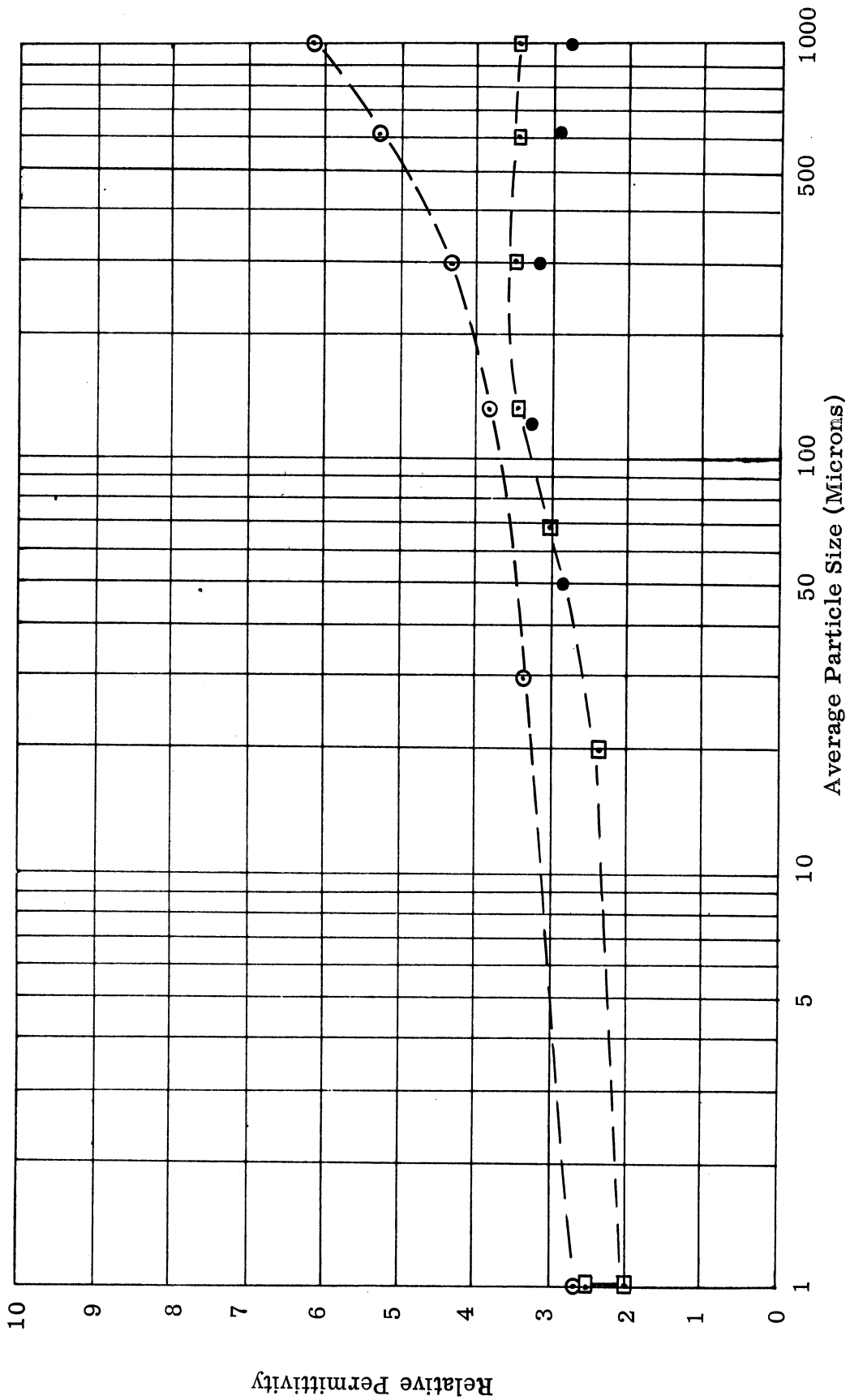


FIG. 4: RELATIVE PERMITTIVITY VS PARTICLE SIZE

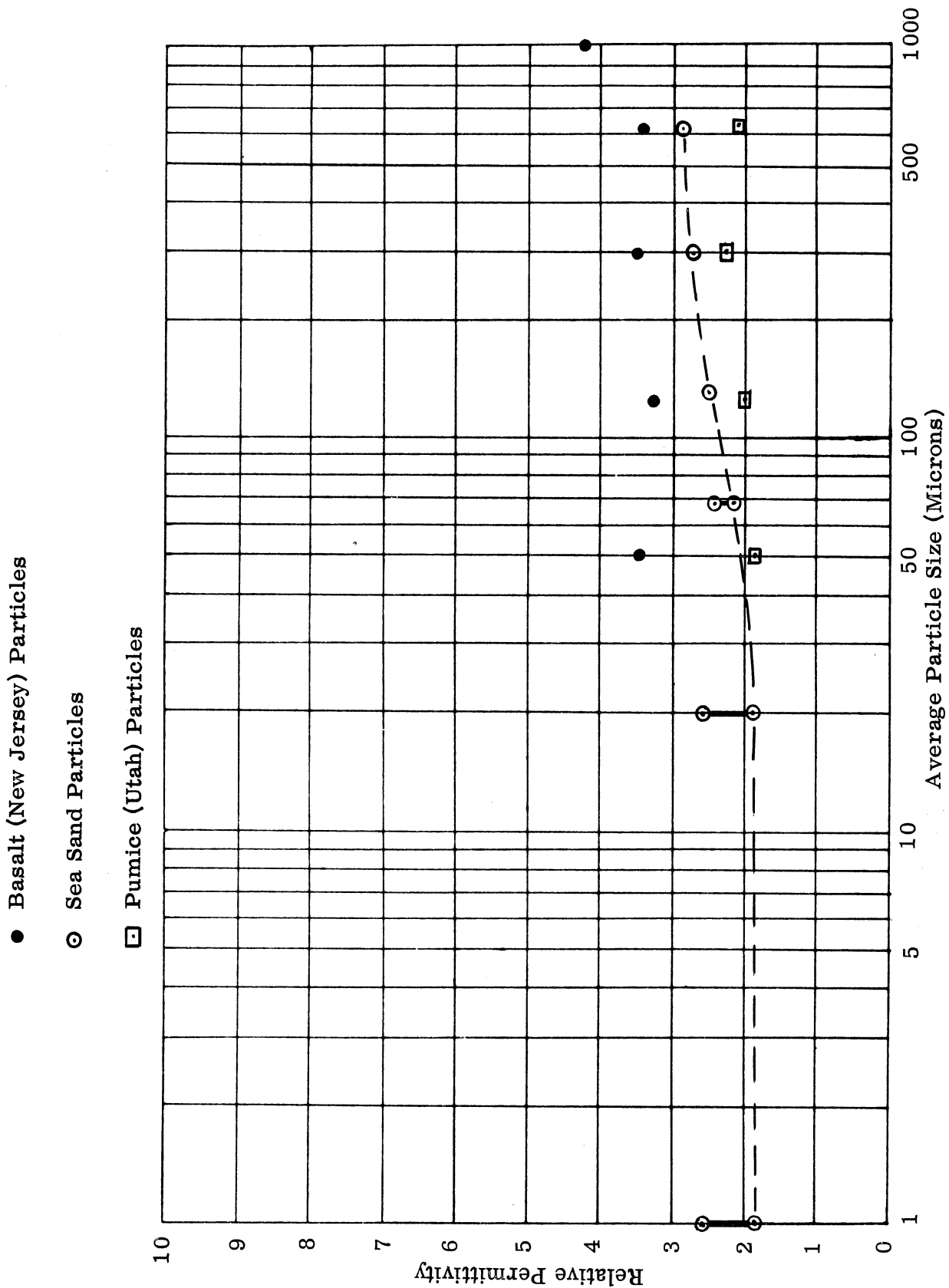


FIG. 5: RELATIVE PERMITTIVITY VS PARTICLE SIZE

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obtainable for the finer powders are shown as solid segments for sand and glass particles. This property of the particles is not indicated for the other materials, but it is to be understood. For sand, plate glass, and chondrite the measured points are joined by a dashed curve to indicate the expected behavior of the relative permittivity as a function of particle size. For basalt, scoria, and pumice the relative permittivity does not decrease uniformly with the particle size. This may indicate preferential fragmentation upon reducing the sample so that the particles in each grade do not represent correctly the proper proportions of the minerals in the solid specimen. In addition, for these materials it was very difficult to estimate the preponderant particle size for the finer powders shown. To emphasize these observations the measured points have not been connected by dotted curve.

If the relative permittivity is plotted as a function of the packing factor, we observe that for the reduced materials the relative permittivity is to first order a linear function of the packing factor. As an illustration the sand results are shown in Figure 6. We know the end-points of the curve and the expected curve joining the end points with the measured points is shown dashed. The curve for the sand is somewhat more linear than for the other materials. From this curve we conclude that if by one means or another we can reduce the packing factor then the relative permittivity will also be reduced.

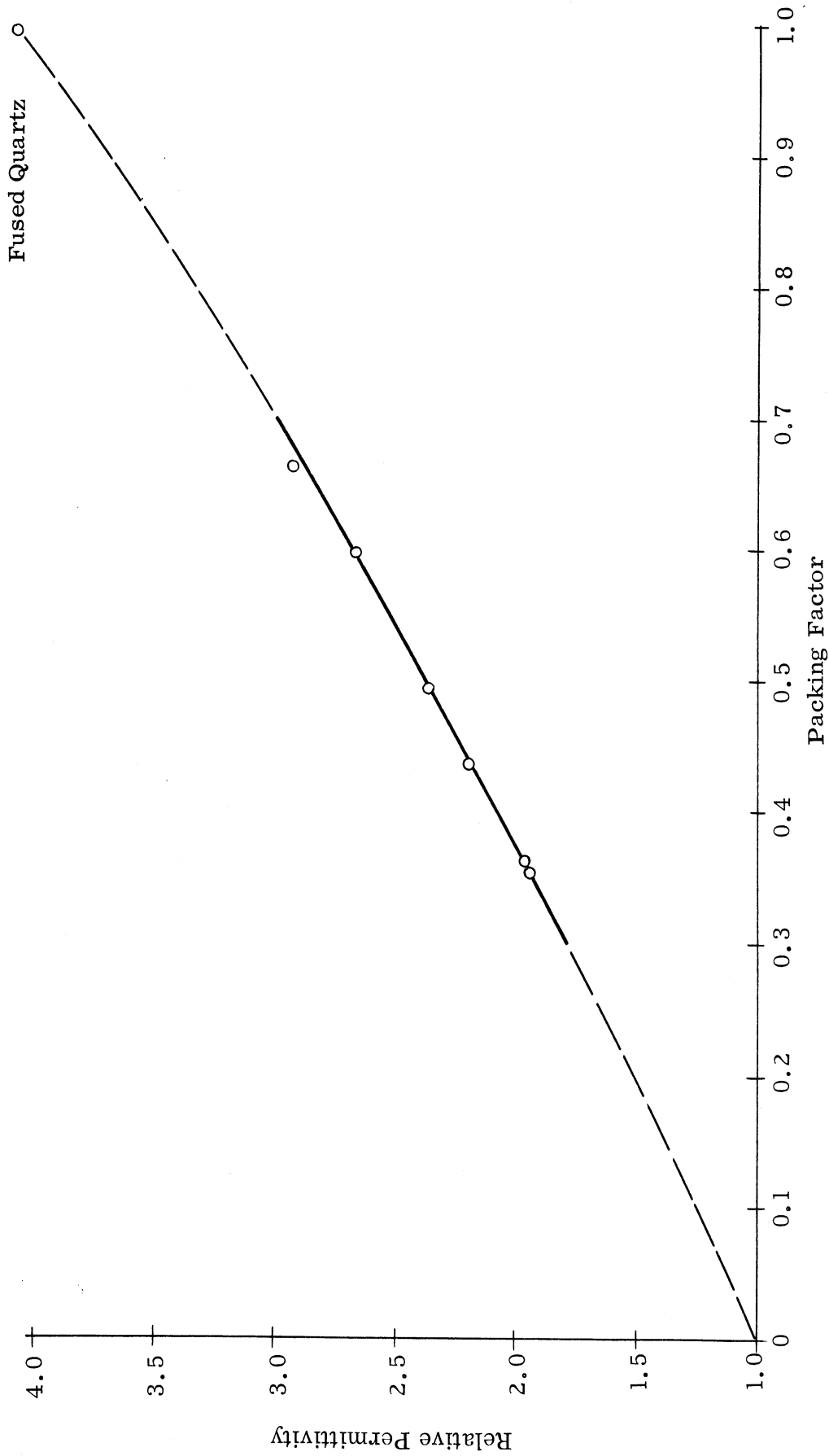


FIG. 6: RELATIVE PERMITTIVITY VS PACKING FACTOR FOR SAND

(at 1000 cps)



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We have measured packing factors for congregations of particles which are not spherical and which are not of the same size. It is interesting to note that for solid spherical particles of identical size we may easily compute the packing factor. We distinguish two limiting cases. If the spheres are stacked in a cubical lattice, then we find a spherical particle in each cube whose edge is the diameter of the sphere. The volume of the sphere to that of the enclosing cube gives us the packing factor which comes to  $\frac{\pi}{6}$ , or 0.524. This is the lowest packing factor obtainable with all spheres in contact with each other at four points. It is independent of the diameter of the sphere. The highest packing factor is obtained for the tetrahedral lattice which follows from the cubical lattice if we shift alternate layers of spheres in the diagonal direction a distance  $\sqrt{2} a$ , where  $a$  is the radius of the sphere. Each layer then would rest in the holes of the lower layer, and the packing factor for this configuration is  $\sqrt{2} \frac{\pi}{6}$ , or 0.740, again independent of sphere size. It seems intuitively obvious that if identical spheres are dumped in a container that they will approach a packing factor of 0.740. Our measurements show that when the particles are not spherical, considerably lower packing factors are obtainable than for the spheres, and that the packing factor depends rather significantly also on the particle size.

The lowest packing factors are reached for the dust grade powders, for which the particle size is of the order of the wavelength of light. For the reduced materials, as already observed, the dielectric constant is to first order a linear function of the packing factor. As the packing factor

becomes zero the dielectric constant would become unity, and one would be tempted to deduce that by making the particle size sufficiently small one could produce the packing factor vanishingly small. However, this does not seem to be the case. Upon closer examination of Table IV we see that for sea sand the packing factor has changed but little from grade 1 to dust grade, but the particle sizes differ between the two grades at least by a factor of ten. The packing factors also become very sensitive to tapping the sample holder, as already mentioned, as the grain size becomes less than  $100\mu$ . It was also observed that the low packing factor of No. 1 and dust grade appeared to be partially caused by the air trapped between the grains. For grade No. 1 sand this was confirmed in a separate experiment which showed that the minimum packing factor at an air pressure equal to 1 mm of Hg was higher by 35% than the minimum packing factor at normal air pressure. However, it is to be expected that by making the grain size considerably less than  $1\mu$  we would have a dust which could be kept in agitation by the air molecules and thus we really would have a gas of a sort. In this case the packing factor would be very close to zero.

The loss tangents of the reduced materials also were measured. These were independent of particle size for all except basalt. Table V lists the loss tangents of those materials for which loss tangents were constant. In the case of basalt, Table VI, the loss tangents decreased with grain size. This may show that there was some preferential fragmentation of the basalt upon reducing.

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TABLE V

THE LOSS TANGENT OF FRAGMENTIZED MATERIALS.

Material	Loss Tangent
Sea Sand	.04
Plate Glass	.05
Moldavite	.02
Chondrite, Plainview, Texas	.05
Scoria (Oregon)	.04
Pumice (Utah)	.04

TABLE VI

THE LOSS TANGENT OF FRAGMENTIZED NEW JERSEY BASALT.

Grain Size	Loss Tangent
Solid	Larger than 50
6	.114
5	.101
4	.105
3	.094
2	.068

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## III

### PENETRATION IN DUSTS AS A FUNCTION OF PARTICLE SIZE AND PRESSURE

A preliminary investigation has been made to determine if a falling object penetrates deeper into dust under atmospheric pressure or in a vacuum. The results of this investigation tend to show that, within the limits of particle sizes investigated, objects penetrate deeper under vacuum conditions than under atmospheric pressure.

The material chosen for investigation was sea sand due to its availability, cheapness and the fact that its bulk dielectric properties are of the same order of magnitude as materials used in other phases of this project. Three grades of sand were used, the sizes of which are listed in Table VII. A sketch of the apparatus appears in Figure 7.

TABLE VII  
Grading of Particles

Grade No.	Range of Size in Microns	
	Minimum	Maximum
1	44	90
2	90	177
3	177	420

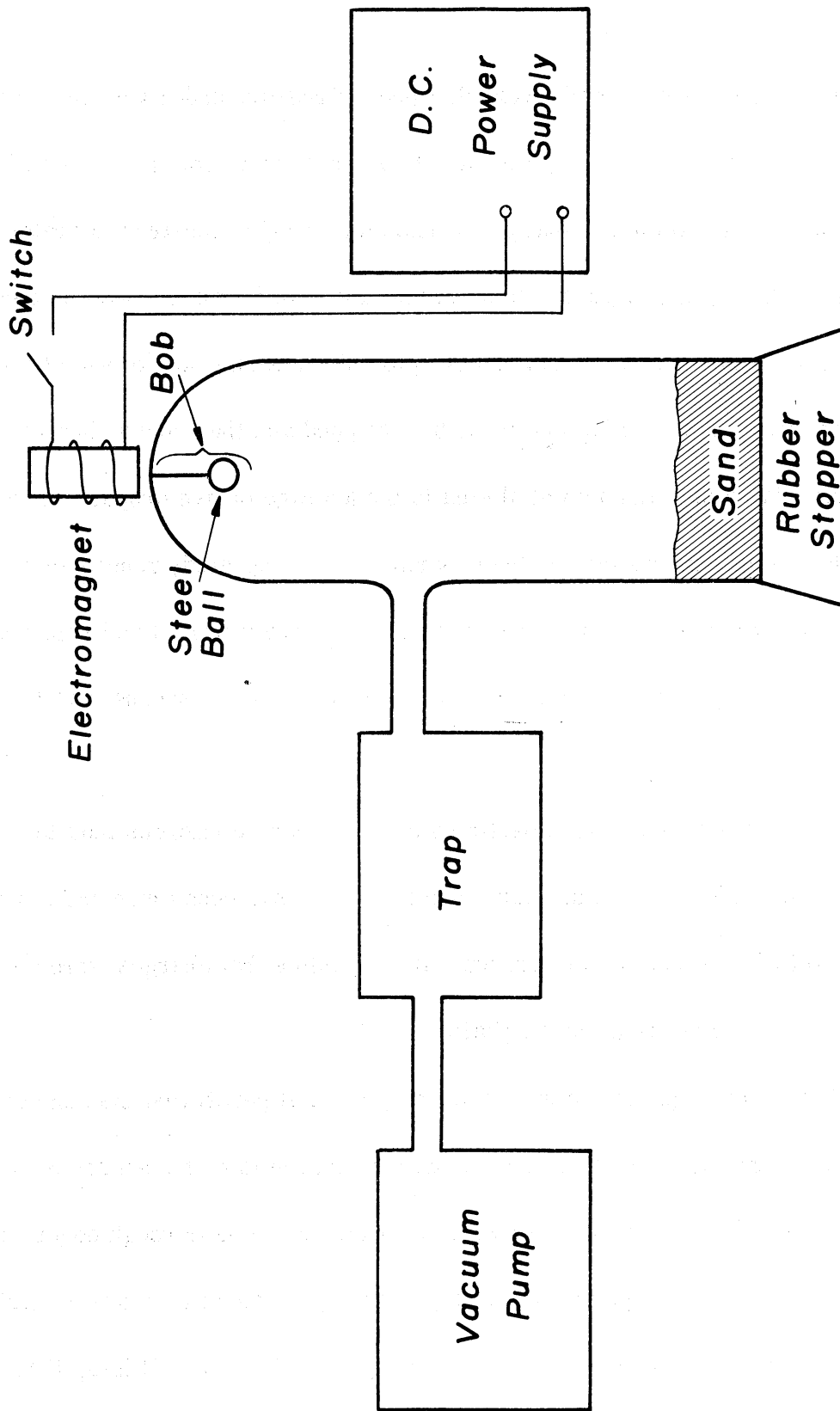


FIG. 7: TEST SET-UP

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Four sizes of steel balls were dropped. Pressure under vacuum conditions was estimated at less than 1 mm of Hg. It was observed, for the grades of sand and size of balls used, that penetration was roughly linear with crater diameter. The graph of penetration versus crater width for one grade of sand is given in Figure 8 . Two curves were plotted for each grade of sand (Figures 9-14), the first shows the weight of the bob dropped and the second shows the steel ball diameter. Each point plotted is the average of five drops. Six weeks after the original investigation, the experiment was repeated; results of the second series are identified on the curves. A slightly different and somewhat more accurate system of measurement was used during the second set of measurements.

Under vacuum conditions particles smaller than 90 microns tend to adhere to the sides of the glass jar. Since the sand had been dried and did not adhere to the jar when air was present, it is possible that charges were acquired by the particles when they were agitated.

For the three grades of sand reported, the ball penetrated the sand deeper in a vacuum than it did in air. A possible explanation is that when air is removed, the particles of sand form a wider spaced lattice due to their rough edges touching. In other words, the rough edges may support the particles in a more unstable array than when an air layer smoothes the edges. When the ball hits, it breaks down this loose lattice. Another possible, and perhaps more intuitive, explanation is that compression of air within the layer of sand or dust retards penetration.

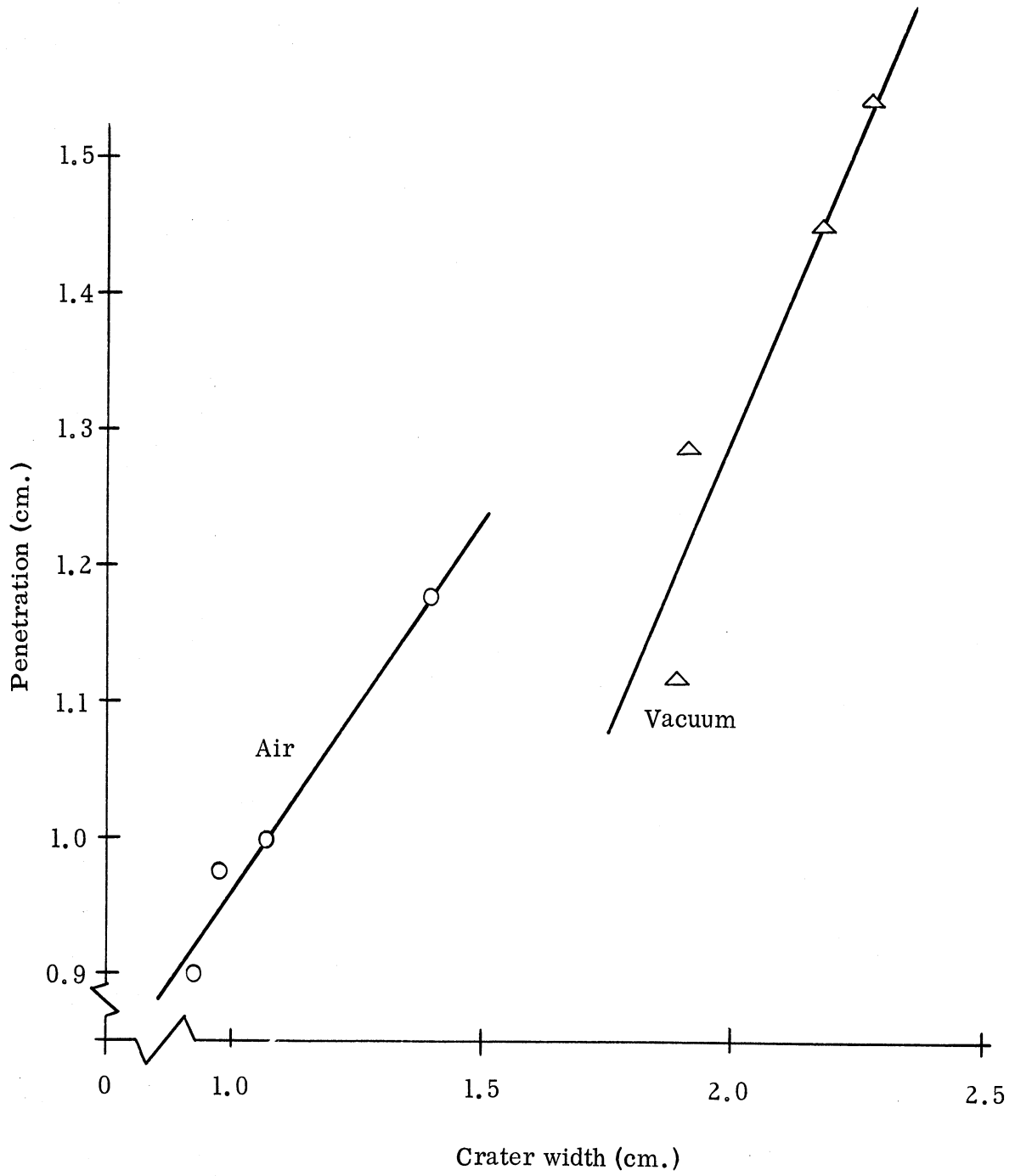


FIG. 8: PENETRATION VS. CRATER WIDTH. GRADE 1 SAND

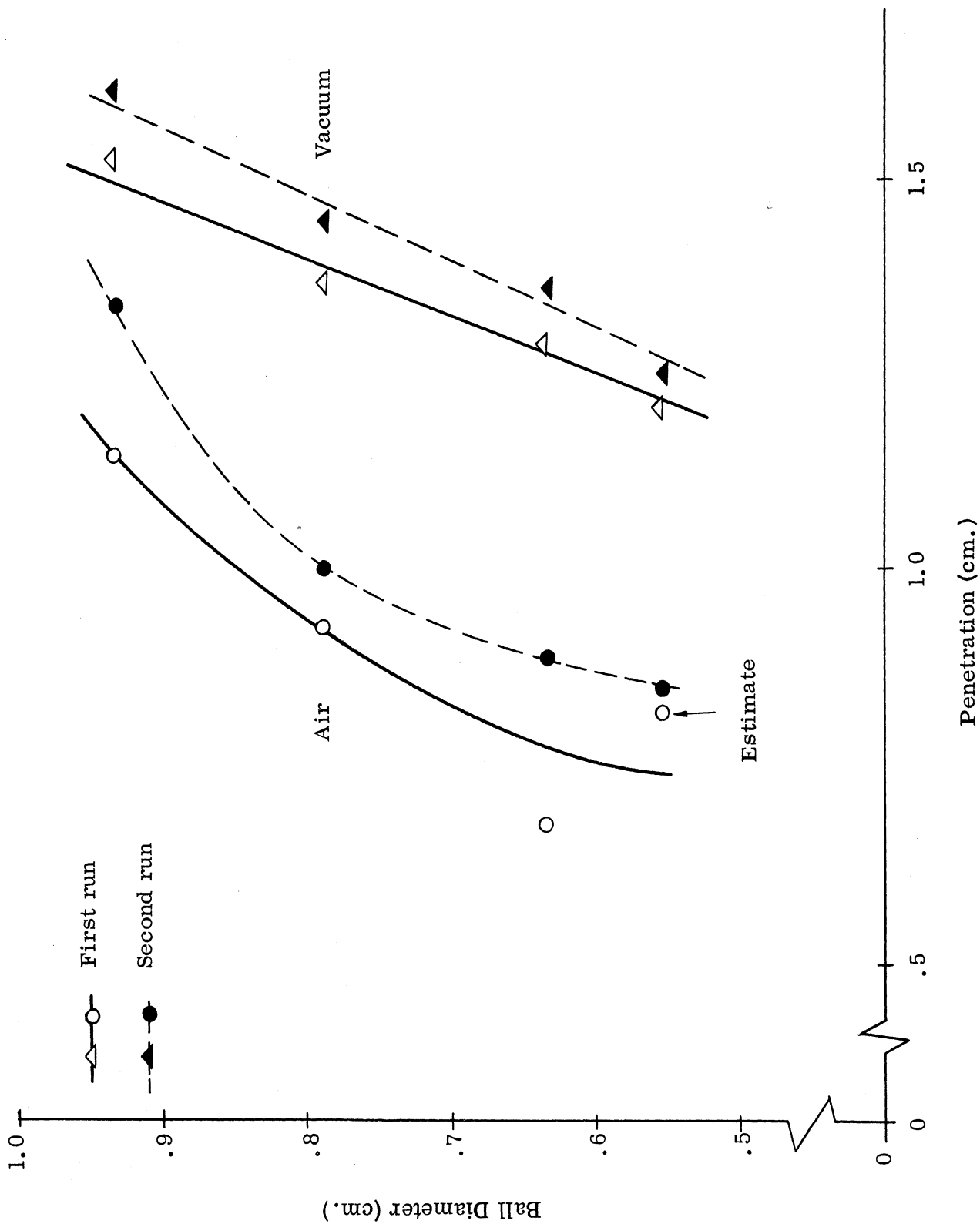


FIG 9: STEEL BALL DIAMETER VS. PENETRATION. GRADE 1 SAND



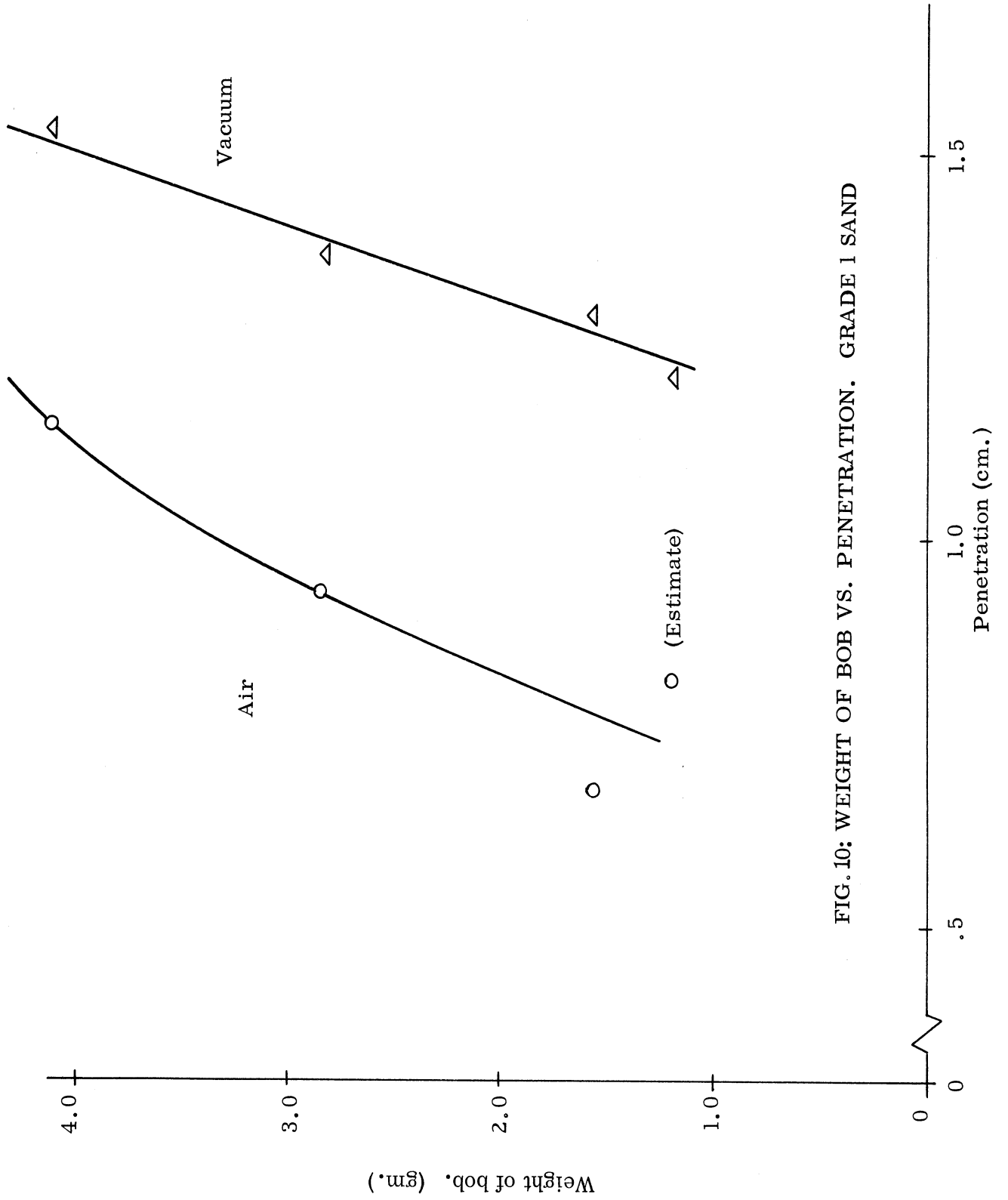


FIG. 10: WEIGHT OF BOB VS. PENETRATION. GRADE 1 SAND

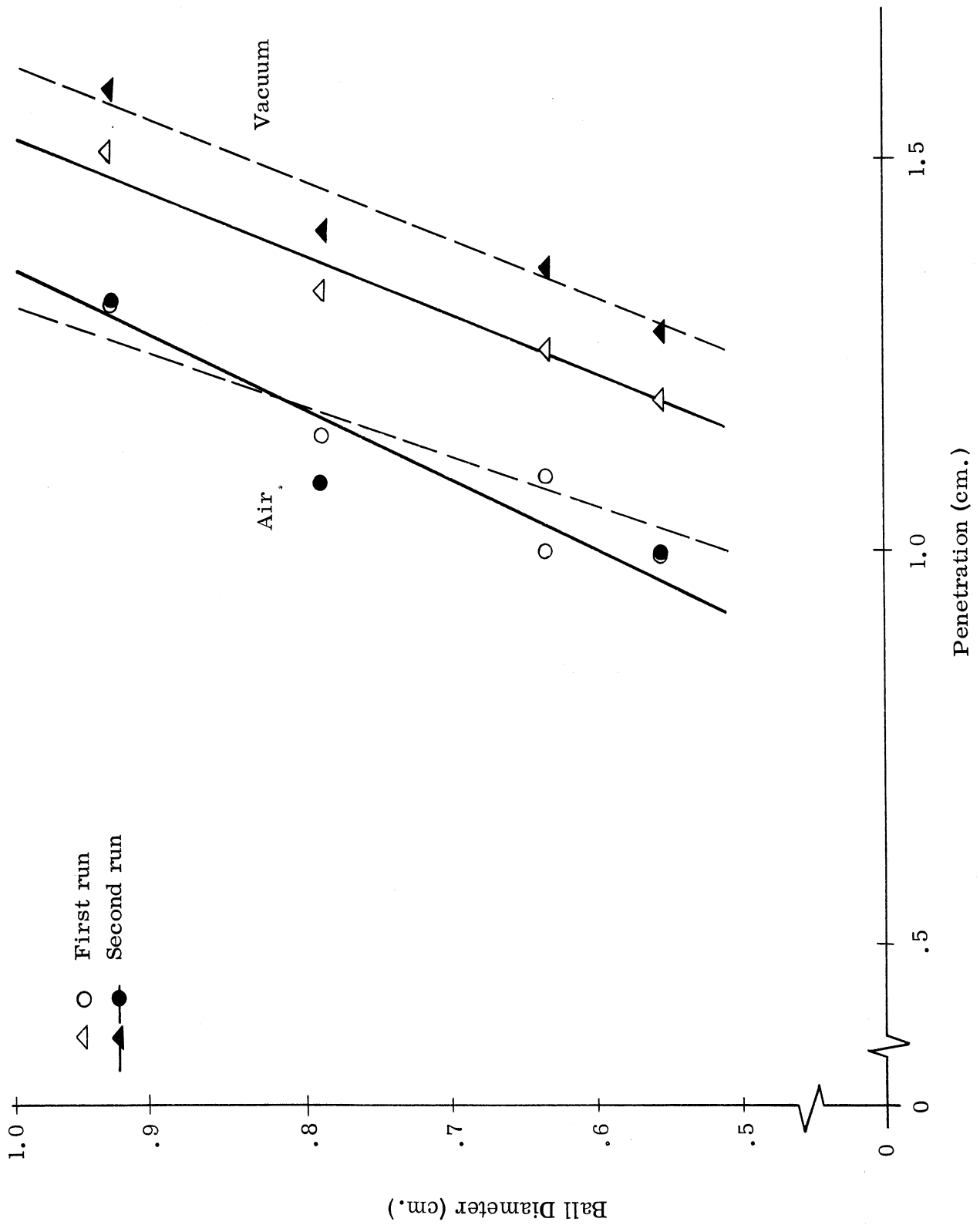


FIG. 11: STEEL BALL DIAMETER VS. PENETRATION. GRADE 2 SAND

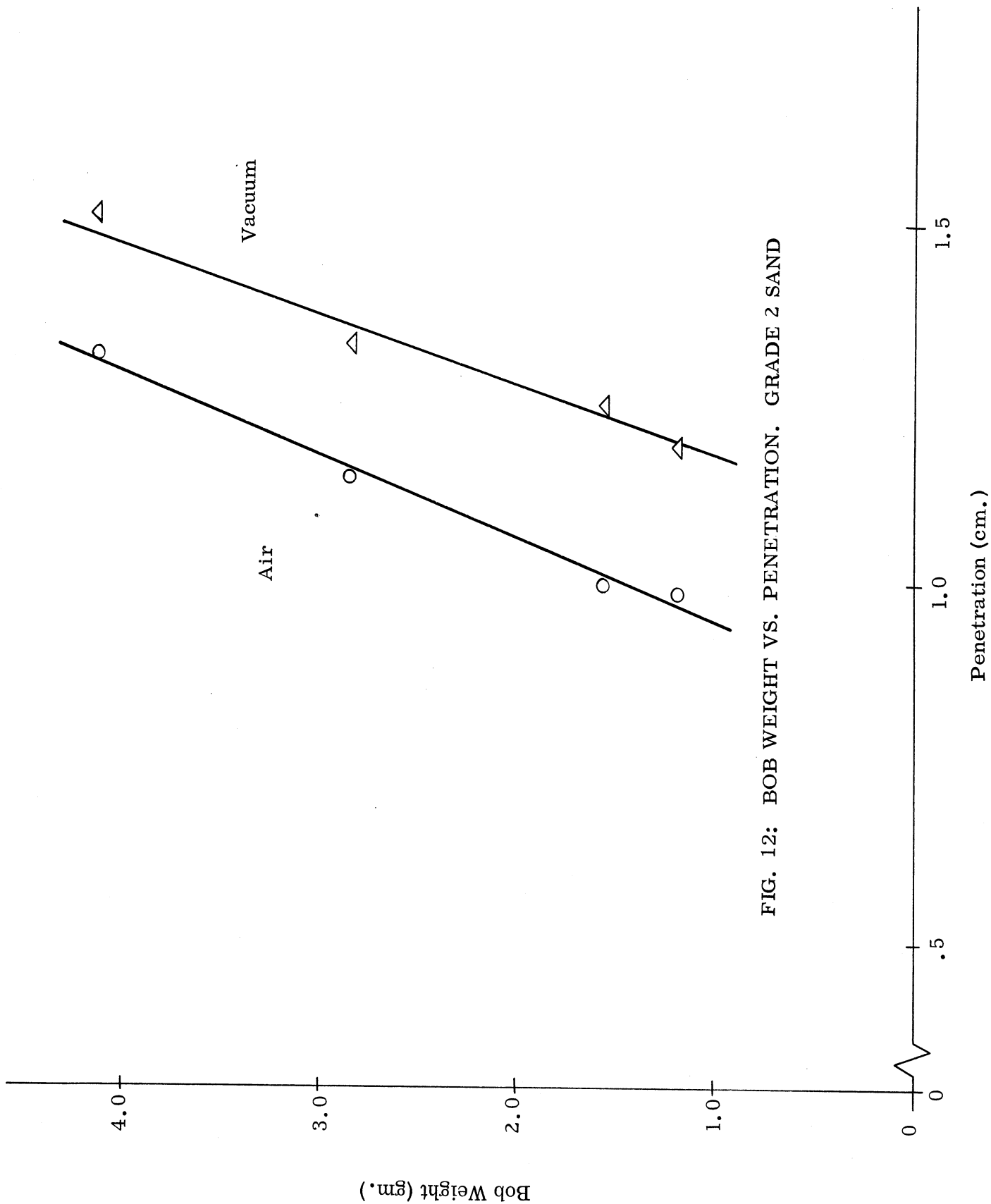


FIG. 12: BOB WEIGHT VS. PENETRATION. GRADE 2 SAND

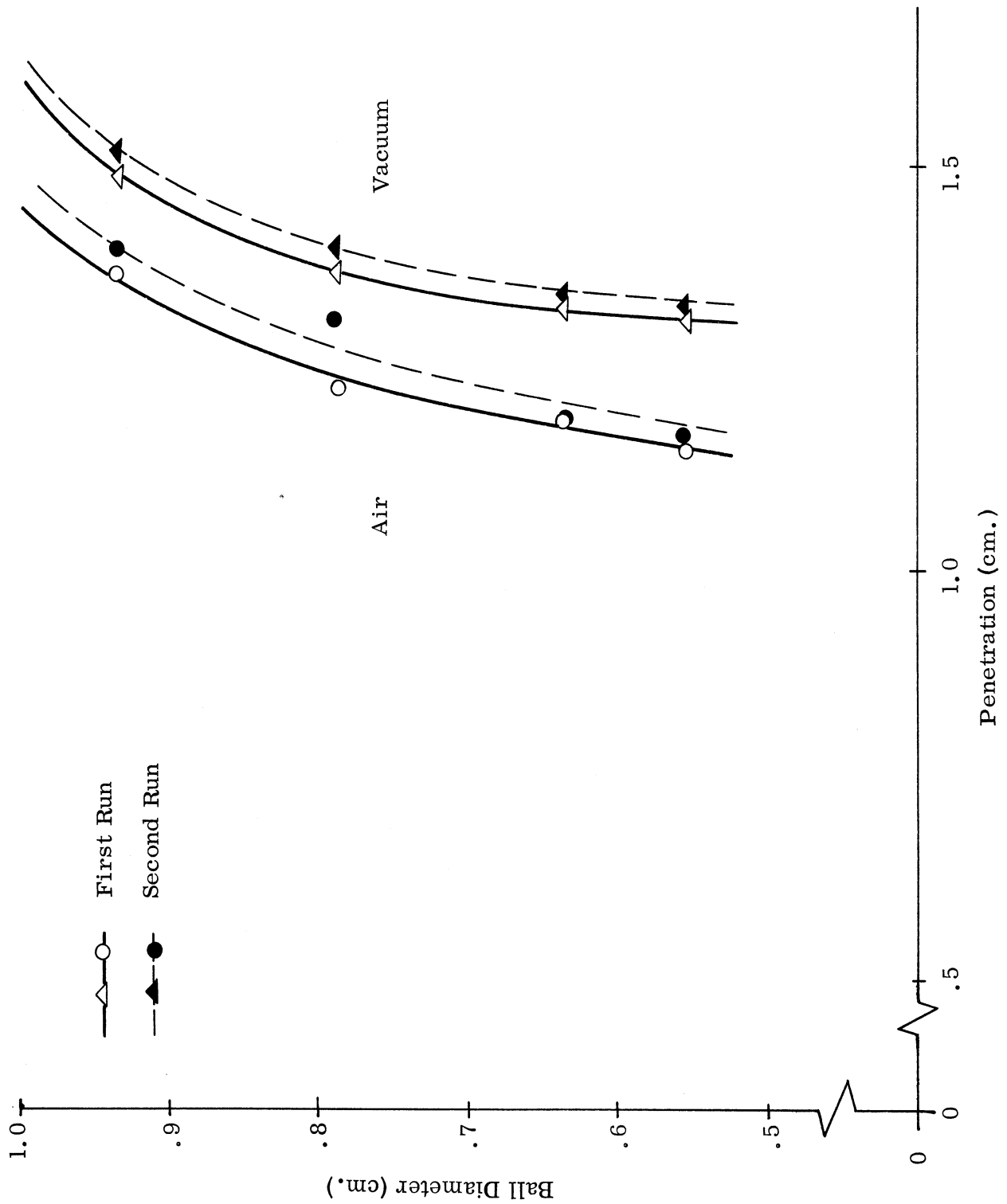


FIG. 13: STEEL BALL DIAMETER VS. PENETRATION. GRADE 3 SAND

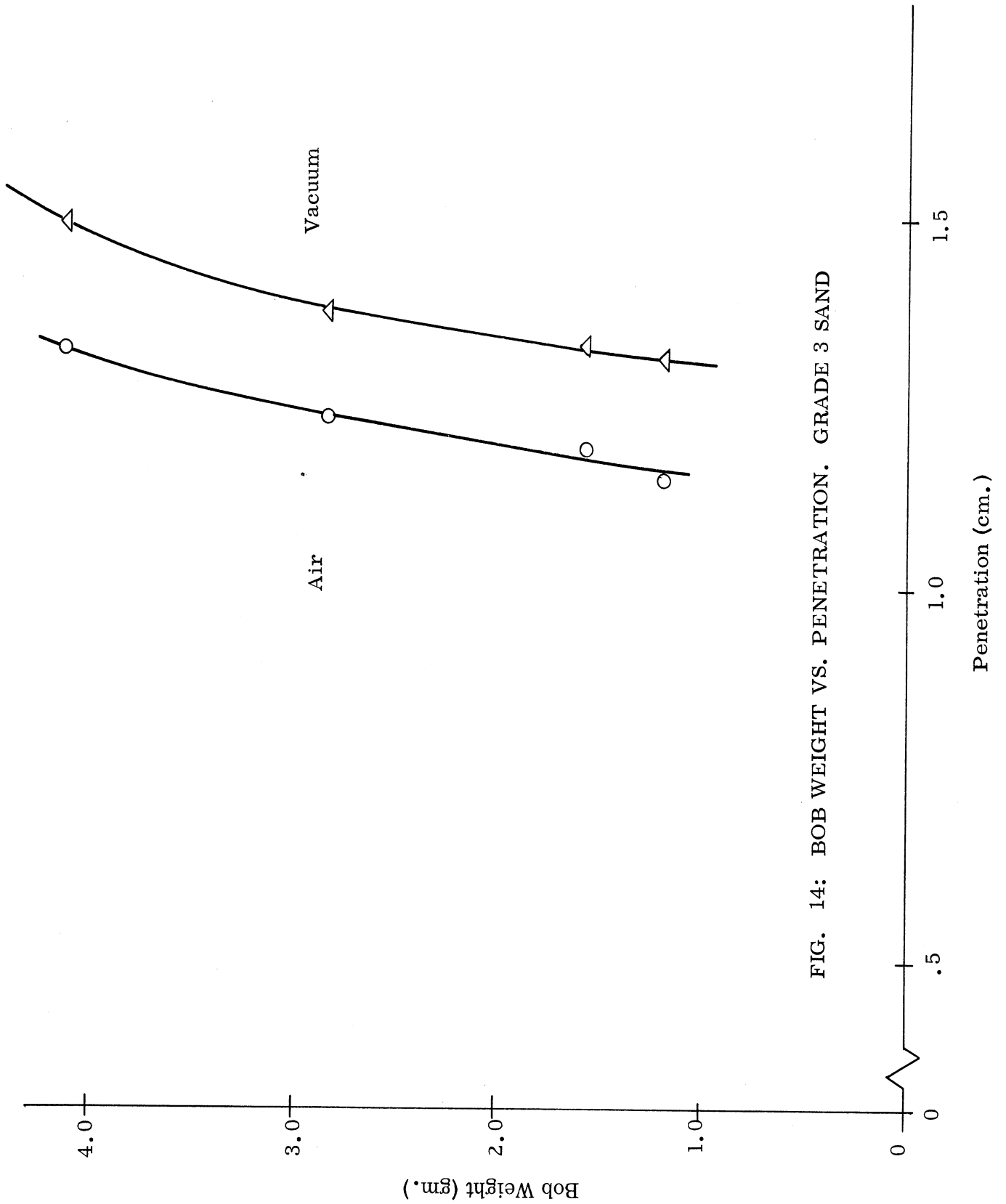


FIG. 14: BOB WEIGHT VS. PENETRATION. GRADE 3 SAND

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## IV

### ELECTROMAGNETIC, GEOLOGIC AND ULTRASONIC PROPERTIES OF SELECTED ROCKS AND MINERALS

As a result of conclusions by Senior and Siegel [1] as to permittivity and (electrical) conductivity of the surface of the moon, it was decided to determine relative permittivity and conductivity of earth rocks and minerals believed to be similar to those of the moon.

In order to increase the value of the data so collected, a contract was entered into with Rensselaer Polytechnic Institute for geologic investigation, specifically a petrographic and an ultrasonic study, of these rocks and minerals. Thus, geologic and electromagnetic properties are available for correlation studies. Such studies - if the correlation is good - may increase greatly the value of data collected by radar, by permitting the determination of geologic properties from distances limited only by the ability of radars to collect suitable data.

Professor J. L. Rosenholtz, head of the Geology Department, R. P. I. planned and supervised the geologic study.

The rocks and minerals (34 rocks and 13 minerals) chosen by Professor Rosenholtz were obtained from Ward's Natural Science Establishment, Rochester, New York, and the rock designations are Ward's.

With a few monominerallic exceptions, the rocks selected for study under this contract were expected to include some materials likely to be found on the lunar surface. The selection was necessarily limited to the substantial, representative supply available at Ward's.

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The petrographic studies were made under the direction of Dr. James R. Dunn, with the assistance of F. Bruce Gerhard, Jr., and the ultrasonic studies were made under the direction of Dr. Samuel Katz, with the assistance of Thomas J. Ahrens, all of R. P. I.

Every rock was examined in hand specimens and all, except Kaolin, were studied in thin section. In rocks containing two feldspars, the thin sections were stained to reveal potash feldspar.

Most thin sections were counted with a point counter to determine the percentage of the various minerals. The error was computed with a standard deviation formula. Mineral counting was done only when it appeared that the results would have significance. Plagioclase, pyroxenes, amphiboles, etc. were determined in thin section using standard procedures. The universal stage could not be used because of the time limitations so that all angular measurements are estimates. Plagioclase compositions are indicated as minimum anorthite (An) content.

The velocities of compressional waves of all but one of the rocks and all minerals selected for this program was measured by an ultrasonic method first developed by Arenberg [11] and Huntington [12]. Specimens in the shape of cuboids, approximating 1 in., with opposite sides parallel to within 0.0002 in., were prepared from each rock sample, the orientation being random. The sides were lapped with No. 600 silicon carbide grit. Barium titanate transducers, resonant at 2 mc/sec, were attached to opposite sides of each specimen, using salol. Pulses of 0.5

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microsecond duration were applied to one transducer, while the output of the transducer on the opposite side was amplified with a broadband Hewlett-Packard amplifier and displayed on a sweep-delay oscilloscope.

The velocities were determined by measuring the dimensions of the specimen and the time interval between the applied and transmitted pulses. Velocities were measured along the three mutually perpendicular directions of each specimen, the mean of the three velocities for each specimen being given in the Tables. These velocities are reproducible to within better than  $\pm 1\%$ .

The densities, were measured with a Jolly balance using the cuboids prepared for the ultrasonic measurements.

All specimens are available for further study. If further work should be authorized at a later time, the velocities of shear waves, measured by the use of quartz shear-transducers, should be included in the program.

The data on the velocities of compressional waves includes some results which have not been available before now. They should certainly be supplemented by the corresponding velocities of shear waves.

## Electromagnetic Measurements

Permittivity\* and conductivity were determined for forty four rocks and minerals.

Twenty one of the samples were cut into 3" x 1 1/2" x 1/4" slabs, while the

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\* Or Dielectric Constant



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remaining 25 were cut into  $1\frac{1}{2}'' \times 1\frac{1}{2}'' \times \frac{1}{8}''$  slabs: variation of thickness in all slabs was less than  $10^{-3}$  inches.

The two faces of each slab were coated with silver paint, such as is used for printed circuits, in order to provide equipotential faces during the tests. Porous samples and those which were highly conductive, were not so coated. See Figure 15 for a flow diagram of the experiment.

Before testing, the samples were heated (in an oven) at  $110^{\circ}$  C for twenty hours. After this heating, samples were stored in capped jars containing a desiccant until tested. Thus, it is believed that any effects of moisture on results of these tests have been minimized. In some earlier measurements, the dielectric properties and conductivity of several unbaked samples were measured. It was found that the results were highly dependent upon moisture content. In general, the permittivity and conductivity of the unbaked samples were about double that reported here.

It was found that the dissipation factor of heated - stored samples is approximately half that of samples stored openly in the ambient atmosphere.

A General Radio Type 544-B megohm bridge was used to measure the D. C. conductivity of those samples having low and medium - high conductivities. A resistance value of  $10^{12}$  ohms can be determined with the bridge, and can be distinguished from infinite resistance.

A General Radio Type 650-A impedance bridge was used in the measurement of capacitance and dissipation factor of the samples at 1000 cycles per second and D. C.

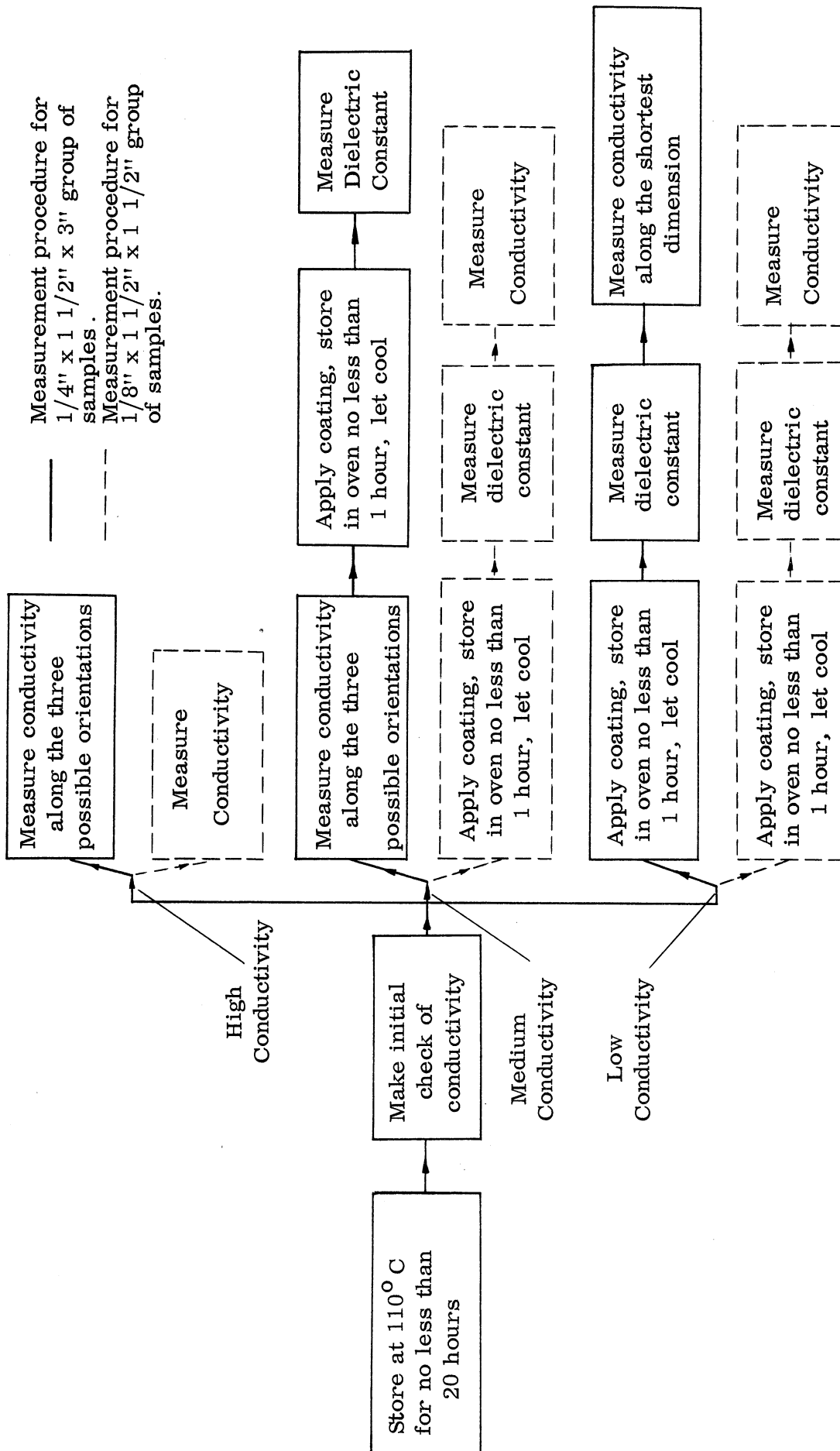


FIG. 15: FLOW DIAGRAM OF ELECTROMAGNETIC MEASUREMENTS

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conductivity of high-conductivity samples. The specimens were measured in a sample holder which held the samples between two parallel metal plates. The plate-to-plate D.C. resistance of the sample holder was in excess of  $10^{12}$  ohms. The A.C. resistance, due to the bakelite structure which held the plates was on the order of 660 megohms. A straight forward measurement technique was used. Corrections were made for errors due to the finite A.C. resistance of the sample holder when measuring the dissipation factor of low loss samples.

Loss tangents were computed from dissipation factors read from the impedance bridge.

Since, as has been noted before although the reasons are obscure, (see for example [13]) conductivities of materials of these types change with time, resistance was measured at 10 seconds, and 1, 2, and 3 minutes after application of the electric field. Ten-second and 3-minute readings are recorded in the tables as Initial and Final Conductivity respectively.

Ten seconds is the minimum practicable, since this time is required to manipulate the controls of the bridge.

Samples having conductivities on the order of  $10^{-12}$  mhos/meter may be in error by as much as 30%, while those samples having conductivities on the order of  $10^{-9}$  are believed accurate to within 5%; loss tangents near  $10^{-2}$  are accurate to about 10% while those near  $10^{-1}$  are accurate to within 5%.

In certain of the samples (30, 36, 37, 38, 42, 44, and 45 in the tables) conductivity was measured along the long (3-inch) axis. It was impossible to

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measure the dielectric constant of samples 35, 37, 38, 42, and 44 due to the high conductivity of these samples.

TABLE VIII

PETROGRAPHIC, ULTRASONIC AND ELECTROMAGNETIC

PARAMETERS OF ROCKS AND MINERALS

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSONAL WAVES		ELECTROMAGNETIC MEASUREMENT			
	Per Cent	Error	Grain Size Groundmass Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon' / \epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m)	DC Conductivity Final (mho/m)
1 ANDESITE San Juan County Colorado				5.50	2.700	19.3	.213	$1.3 \times 10^{-8}$	$1.7 \times 10^{-8}$
<u>Minerals</u> Quartz Calcite Magnetite Plagioclase Clay Former Plagi- glass Groundmass	6.7	$\pm 3.2$	1 mm						
	41.6	$\pm 6.2$							
	51.7	$\pm 6.3$							
	Petrographic Detail Fabric - Porphyritic with plagioclase phenocrysts set in a microcrystalline groundmass. Alteration - Rock largely altered to calcite and clay.								

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT			
	Per Cent	Error	Grain Size Groundmass Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m)	DC Conductivity Final (mho/m)
2 HORNBLENDE ANDESITE Hornblende Andesite; Mount Shasta, California				2.58	2.32	4.87	.024		$9.6 \times 10^{-12}$
Minerals Plagioclase	53.3	$\pm 3.16^*$	0.25-1.5 mm Most are 1.0 mm						
Opaque Minerals (Magnetite?) Hornblende	2.7 1.2	$\pm 1.0$ $\pm 0.7$	0.01-0.05 mm 0.25-1.5 mm Most are 0.75 mm						
Hornblende, alteration Apatite Glass	0.4 1.7 27.9	$\pm 0.4$ $\pm 0.6^*$ $\pm 2.8^*$							

\*Note: These errors are possibly considerably higher because percentage of glass and apatite were estimated.

Additional data on critical minerals:  
Plagioclase phenocrysts- rims An 45<sup>+</sup>  
cores An 70<sup>+</sup>  
Hornblende - 2V about 70<sup>o</sup>, (-),  
extinction angles 20<sup>o</sup> (+); x = tan;  
y = red-brown; z = dark red-brown.

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT		
	Per Cent	Error	Grain Size Groundmass Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon' / \epsilon_0$ )	Loss Tangent	DC Conductivity Initial Final (mho/m)
HORNBLENDE ANDESITE (cont.)			Petrographic Detail Fabric - Porphyritic, megapheno- crystals of plagioclase and hornblende with microphenocrysts of plagioclase and apatite in a glassy groundmass. Micro- phenocrysts have a subparallel orientation. Alteration - Plagioclase is zoned, partly resorbed and slightly altered. Hornblende is rimmed by opaque mineral, probably magnetite.					



MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT				
	Per Cent	Error	Grain Size Groundmass	Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m)	Final (mho/m)
3 ANDESITE Andesite Porphyry; Boulder County, Colorado					5.25	2.68	7.65	.032		$4.9 \times 10^{-11}$
<u>Minerals</u>										
Plagioclase	66.1	±2.8		3-5 mm						
Hornblende	2.0	±0.8		0.75x1.5 mm						
Magnetite	1.5	±0.7		0.10 mm						
Calcite	21.2	±2.4								
Epidote minerals	21.2	±2.4								
Chlorite	8.6	±1.7		av. 0.5 - 0.75 mm max. 0.5 x 1.75 mm						
Tremolite	0.2	±0.2								
Zircon	0.4	±0.3								
Apatite	Trace									
Garnet	Trace									
	Additional data on critical minerals: Plagioclase: About An 50-55+; zoning oscillatory. Hornblende: High 2V, (-); x = yellow-green; y = dark green; z = dark green. Petrographic Detail Fabric - Porphyritic with plagioclase phenocrysts and minor hornblende. Groundmass appears to be devitrified glass. Alteration - Rock appears to be partially altered hydrothermally to chlorite, calcite, epidote and possibly some clay. The groundmass is probably largely devitrified glass.									

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT		
	Per Cent	Error	Grain Size Groundmass Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m) Final (mho/m)
4 OLIVINE BASALT Basalt; Lintz, Rhenish-Prussia				5.79	3.00	17.4	.42	$3.1 \times 10^{-8}$ $2.8 \times 10^{-8}$
Minerals Olivine	12.0	±1.8	av. 0.3 x 0.4 mm					
Augite	31.3	±2.6	av. 0.2 x 0.6 mm					
Plagioclase	11.4	±1.7	0.01 x 0.05 mm					
Magnetite	9.3	±1.6						
Groundmass	35.9	±2.6						
Additional data on critical minerals: Augite: moderate to high 2V, (+), strong dispersion, maximum extinction angle is 40-45°. Olivine: 2V = 80-85°, (-). Plagioclase: probably labradorite. Petrographic Detail Fabric - Porphyritic with phenocrysts of olivine, magnetite, and pyroxene in a cryptocrystalline groundmass. Plagioclase is present as microlites. Alteration - None.								

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT			
	Per Cent	Error	Grain Size Groundmass Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m) Final (mho/m)	
5 BASALT Hornblende Basalt; Chaffee County, Colorado				5.23	2.69	9.94	.103	$1.6 \times 10^{-11}$ $1.1 \times 10^{-11}$	
Minerals Plagioclase	62.4	$\pm 2.7$	av. 0.12 x 0.5 mm max. 0.75 x 1.5 mm						
Augite	2.8	$\pm 0.9$	0.01 mm 0.25 x 0.25 mm						
Magnetite	11.9	$\pm 1.8$	0.15 mm						
Calcite	10.4	$\pm 1.8$							
Chlorite	2.5	$\pm 0.9$							
Indeterminate alteration products and groundmass	10.0	$\pm 1.8$							
Additional data on critical minerals: Plagioclase: An 60-70 Augite: High 2V, (+), extinction angle 40°									
Petrographic Detail Fabric - Porphyritic, cryptocrystal-line groundmass, possible devitrified glass Minerals have a slight parallel orientation. Alteration - Alteration of some groundmass to calcite and chlorite.									

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT				
	Per Cent	Error	Grain Size Groundmass Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m)	DC Conductivity Final (mho/m)	
6 BASALT Olivine Basalt; Jefferson County, Colorado				5.40	2.73	8.89	.057	$1.1 \times 10^{-10}$	$2.2 \times 10^{-10}$	
<u>Minerals</u>										
Pyroxene	12.5	±2.0	av. 0.75 x 2.0 mm							
Plagioclase	64.7	±2.8	av. 0.5 x 0.8 mm							
Apatite	0.4	±0.4								
Calcite	0.1	±0.1								
Chlorite	10.5	±1.8								
Biotite	0.4	±0.4	av. 0.10 x 0.25 mm							
Magnetite	6.2	±1.4								
Undetermined alteration product	4.3	±1.2								
Pore Space	0.8	±0.5								
	Additional data on critical minerals: Pyroxene: High 2V, (+), maximum extinction angle 44° Plagioclase: An 56+ in cores. Labradorite  Petrographic Detail Fabric - Porphyritic with pyroxene and plagioclase phenocrysts set in a micro- crystalline groundmass. Rough parallel orientation of the phenocrysts. Alteration - Cloudy zonal alteration of plagioclase to indeterminate substances. Dark green chloritic material altered from ferromagnesian mineral, possibly biotite.									

MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT		
	Per Cent	Error	Grain Size Groundmass Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m) Final (mho/m)
7 OLIVINE BASALT CELLULAR Olivine Basalt, Cellular; Washington				2.78	2.44	5.50	.033	$1.1 \times 10^{-11}$
<u>Minerals</u>								
Plagioclase	49.5	±2.9	av. 0.05 x 0.35 mm					
Augite	15.6	±2.1						
Olivine and Iddingsite	5.8	±1.4	1.0x1.25mm					
Magnetite	5.8	±1.4						
Miscellaneous alteration products and groundmass	5.7	±1.3						
Vesicles	17.7	±2.2	av. 0.75 x 1.5 mm					
	Additional data on critical minerals: Plagioclase: An 55-70 Olivine: High 2V, (-) Pyroxene: 2V about 50°, (+), maximum extinction angle 45°.							
	Petrographic Detail Fabric - Porphyritic, vesicular, aphanitic groundmass, microphenocrysts of plagioclase, macrophenocrysts of olivine and augite. Crystals have a sub-parallel orientation. Alteration - Incipient alteration of olivine to iddingsite.							

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT		
	Per Cent	Error	Grain Size Groundmass Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m) Final (mho/m)
8 ANDESITE Vesicular Basalt; Chaffee County, Colorado				5.27	2.57	6.51	.088	$1.2 \times 10^{-11}$ $5.0 \times 10^{-12}$
Minerals Plagioclase	47.1	$\pm 2.8$	av. 0.5 x 0.15 mm 0.5 x 2.0 mm					
Augite	4.4	$\pm 1.1$	av. 1 x 2 mm					
Groundmass	39.3	$\pm 2.7$						
Opal and	3.7	$\pm 1.0$						
Chalcedony								
Magnetite	5.0	$\pm 1.2$	0.25 mm					
Additional data on critical minerals: Plagioclase: An 46-55 <sup>+</sup> Pyroxene; Augite: High 2V, (+), <sub>0</sub> Maximum extinction angle 44 <sub>0</sub> .								
Petrographic Detail Fabric - Porphyritic, microcrystal- line groundmass. Pyroxene phenocrysts partially resorbed. Some vesicles are filled with tan opal. Alteration - Argillaceous and calcitic alteration from plagioclase.								

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT			
	Per Cent	Error	Grain Size	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon' / \epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m)	DC Conductivity Final (mho/m)
9 OLIVINE BASALT Olivine Basalt Porphyry; Boulder County Colorado				5.59	2.83	22.9	.412	$6.2 \times 10^{-8}$	$5.3 \times 10^{-8}$
Minerals Plagioclase Olivine Pyroxene Apatite Magnetite Garnet Groundmass and alteration products including serpentine	45.4 1.5 25.9 Trace 6.1 Trace 19.5	$\pm 2.9$ $\pm 0.7$ $\pm 2.6$  $\pm 1.4$  $\pm 2.3$	0.3 x 1.0 mm 0.5 x 0.8 mm 1.4 x 2 mm						
	Additional data on critical minerals: Plagioclase: An 72+ Olivine: 2V over 80°, (-). Pyroxene: Pale green, 2V 50-60°, (+), maximum extinction angle 45°  Petrographic Detail Fabric - Porphyritic, dense groundmass. Alteration - Cloudy (argillaceous?) alteration of plagioclase.								

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT		
	Per Cent	Error	Grain Size Groundmass      Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m)      Final (mho/m)
10 ANDESITE (?) BRECCIA Andesite Breccia Ouray, Colorado				4.52	2.73	7.56	.026	$6.6 \times 10^{-11}$ $5.2 \times 10^{-11}$
<u>Minerals</u>								
Plagioclase	11.3	±1.7	0.4 x 1.2 mm					
Epidote	13.5	±1.8						
Chlorite	16.1	±2.0						
Groundmass	43.4	±2.7						
Plagioclase alteration products (largely calcite)	12.7	±1.8						
Muscovite (?)	1.5	±0.6						
Biotite (?)	0.4	±0.4	0.25 x 1.5 mm					
Opaque	0.9	±0.5						
	Additional data on critical minerals: Plagioclase: An 15 <sup>+</sup> , in some cases x y = balsam, but altered. Epidote: colorless, strong dispersion 2V about 70°, (-), maximum extinction angle about 25°.							
	Petrographic Detail Fabric - Breccia consisting of frag- ments of andesitic material with phenocrysts of the above minerals in a microcrystalline groundmass. Alteration - Altered largely to epi- dote, chlorite, muscovite and alkaline plagioclase.							



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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT		
	Per Cent	Error	Grain Size Groundmass Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m) Final (mho/m)
11 DACITE Mica Dacite Porphyry; Ward Boulder County, Colorado				6.12	2.67	8.84	.080	$3.5 \times 10^{-11}$ $2.4 \times 10^{-11}$
Minerals Plagioclase	9.5	±1.6	av. 1.5 x 2.5 mm					
Quartz	12.0	±1.8						
Epidote	1.0	±0.6						
Chlorite	5.4	±1.3						
Apatite	Trace							
Calcite	14.8	±2.0						
Biotite	Trace		0.6 x 1.25mm					
Magnetite	1.8	±0.7						
Zeolite (chabazite)	0.2	±0.2						
Microclites	55.5	±2.8						
Additional data on critical minerals Plagioclase: An 33+ Epidote: variable optics; x = yellow; y = yellowish tan; z = yellowish tan; 2V about 80-85°, (-), maxi- mum extinction angle is 16°, zones Chlorite: variable optics, 2V = 30-40° (-), parallel extinction, x = yellow- ish tan, y and z = dark green.  Petrographic Detail Fabric - Phenocrysts of the primary minerals, including epidote, in a micro- crystalline groundmass. Alteration - Biotite largely altered to chlorite.								

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT		
	Per Cent	Error	Grain Size	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial Final (mho/m)
12 DIABASE Diabase; Mount Tom, Massachusetts				5.41	2.97	10.8	.113	$8.6 \times 10^{-10}$ $8.0 \times 10^{-10}$
<u>Minerals</u>								
Plagioclase	44.0	±2.6	0.4 x 0.75 mm					
Augite	40.4	±2.6	0.2 x 0.5 mm					
Quartz	0.4	±0.3	0.2 mm					
Apatite	Trace							
Magnetite	5.0	±1.1						
Calcite	4.8	±1.1						
Uralite and other altera- tion products	5.4	±1.2						
	Additional data on critical minerals: Plagioclase: An 65 <sup>+</sup> Augite: 2V high (+), maximum extinction angle 45°.							
	Petrographic Detail Fabric - Diabasic texture, fine grained. Alteration - Altered locally to chloritic and/or uraltic material.							

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT			
	Per Cent	Error	Grain Size	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m)	DC Conductivity Final (mho/m)
13 PERIDOTITE; SERPENTINIZED Mica-Augite Peridotite; Murfreesboro, Arkansas <u>Minerals</u> Serpentine Olivine Biotite (?) Magnetite Pyroxine (?)			Grain Size Phenocrysts	3.98	2.67	10.0	.114	$3.1 \times 10^{-10}$	$5.4 \times 10^{-10}$
<p>Serpentine pseudomorphs av. 1.0 mm</p> <p>Additional data on critical minerals:                      Biotite: Pleochroic red-brown to tan.                      Small 2V, (-).</p> <p>Petrographic Detail                      Fabric - Rock consists of colorless to green serpentinous material largely pseudomorphous after olivine phenocrysts, all set in a microcrystalline groundmass consisting of pyroxine (?) microlites, magnetite and indeterminate material.                      Alteration - Serpentine is largely an alteration product from olivine.</p>									

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT					
	Per Cent	Error	Groundmass	Grain Size	Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m)	Final (mho/m)
14 RHYOLITIC PUMICE Pumice; Millard County, Utah <u>Minerals</u> Quartz Anorthoclase Calcite Vesicles						Not Measured		2.29	.103		$5.3 \times 10^{-12}$
	Trace										
	Trace										
	Trace										
	Additional data on critical minerals: Anorthoclase: moderate 2V, (-).										
	Petrographic Detail Fabric - Glassy, pumiceous, crystallites in glass. Alteration - Local devitrification.										

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT			
	Per Cent	Error	Grain Size Groundmass Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m) Final (mho/m)	
15 RHYOLITE (?) Rhyolite; Chaffee County, Colorado				4.03	2.39	4.85	.018	$9.4 \times 10^{-11}$ $1.9 \times 10^{-10}$	
<u>Minerals</u> Groundmass Quartz Plagioclase	87.9 6.7 Trace	$\pm 1.9$ $\pm 1.5$	av. 0.3 x 0.5 mm max. 0.6 x 0.8 mm						
Opaque Pore Space	1.2 4.2	$\pm 0.6$ $\pm 1.2$							
	Petrographic Detail Fabric - Rock shows pronounced banding and was quite possibly originally glassy. Quartz and plagioclase are phenocrysts in a cryptocrystalline groundmass. Alteration - Groundmass is probably devitrified glass.								

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT		
	Per Cent	Error	Grain Size Groundmass Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon' / \epsilon_0$ )	Loss Tangent	DC Conductivity Initial Final (mho/m)
16 RHYOLITE Rhyolite; Castle Rock, Colorado				3.22	2.05	4.00	.054	$1.8 \times 10^{-10}$ $7.9 \times 10^{-10}$
<u>Minerals</u>								
Microcline Sanidine	2.1	±0.8	0.01 mm    av. 0.5 x 0.9 mm					
Groundmass Plagioclase	93.9 00.7	±1.3 ±0.5	0.5 x 1.75mm min. 0.30 x 0.80mm 0.20 x 0.7mm					
Biotite Chalcedony Quartz Magnetite Zircon	0.3 0.2 0.9 1.9 Trace	±0.3 ±0.2 ±0.5 ±0.8						
	Petrographic Detail Fabric - Porphyritic, Cryptocrystal- line groundmass. Alteration - Groundmass possibly devitrified glass.							

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS				VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT			
	Per Cent	Error	Grain Size		Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity	
			Groundmass	Phenocrysts					Initial (mho/m)	Final (mho/m)
17 PORPHYRITIC HORNBLLENDE BIOTITE DIORITE Diorite Porphyry; Jackson, Wyo.					5.21	2.91	12.3	.25	$4.5 \times 10^{-9}$	$4.1 \times 10^{-9}$
<u>Minerals</u> Plagioclase	42.9	$\pm 3.0$	av. 2.0 x 2.5 mm max. 2.5 x 6.0 mm							
Hornblende	14.2	$\pm 2.1$								
Quartz	0.2	$\pm 0.2$								
Microcline	0.8	$\pm 0.5$	av. 0.5 x 1.5 mm							
Pyroxene	0.9	$\pm 0.7$								
Biotite	7.7	$\pm 1.6$								
Apatite	1.1	$\pm 0.6$								
Chlorite	16.5	$\pm 2.2$								
Magnetite	4.2	$\pm 1.2$								
Garnet	Trace									
Calcite	11.5	$\pm 1.9$								
Additional data on critical minerals: Biotite: pleochroic tan to brown Plagioclase: at least as calcic as andesine. Hornblende: High 2V, (-); x=yellowish y = dark green; z = dark green Petrographic Detail Fabric - Porphyritic with plagioclase phenocrysts in a fine-grained groundmass. Alteration - Minor calcite and chlorite alteration from calcic plagioclase and mafics, respectively.										

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT			
	Per Cent	Error	Grain Size Groundmass Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m)	DC Conductivity Final (mho/m)
18 QUARTZ LATITE OR RHYOLITE Rhyolite Porphyry; Chaffee County, Colorado <u>Minerals</u> Plagioclase Sanidine Quartz Chalcedony Groundmass	2.7 5.5 7.9 Trace 83.2	$\pm 0.8$ $\pm 1.1$ $\pm 1.3$ $\pm 1.9$	0.01 x 0.10mm av. 0.4 x 0.8 mm 0.01 x 0.10mm av. 1.5 x 2.0 mm av. 0.25 mm	2.85	2.91	5.40	.027	$1.4 \times 10^{-11}$	$4.5 \times 10^{-11}$
	Additional data on critical minerals Sanidine: small 2V, (-). Plagioclase: An 2 to 4+.								
	Petrographic Detail Fabric - Porphyritic with phenocrysts of salic minerals in a cryptocrystalline groundmass. Minor chalcedonic veins. Alteration - Groundmass may be largely devitrified glass.								



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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT				
	Per Cent	Error	Grain Size		Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity	
			Groundmass	Phenocrysts					Initial (mho/m)	Final (mho/m)
19 BASALTIC SCORIA Scoria; Near Klamath Falls, Oregon					4.25	2.23	6.08	.041		$1.6 \times 10^{-11}$
Minerals Plagioclase	18.6	±2.3	max. 0.25 x 0.75 mm min. 0.1 x 0.4 mm av. 0.15 x 0.15 mm							
Olivine	0.6	±0.5								
Augite	2.9	±1.0								
Vesicles	32.1	±2.8	Vesicles av. 1.25 mm							
Cryptocrystal- line alteration products	23.9	±2.5								
Opaque	21.9	±2.4								
	Additional data on critical minerals: Olivine: 2V about 90. 10-15% Fe <sub>2</sub> SiO <sub>4</sub> Plagioclase: An 64 <sup>+</sup> .									
	Petrographic Detail Fabric - Scoriaceous, porphyritic with phenocrysts of plagioclase, olivine and augite in a dark, probably magnetic-rich, cryptocrystalline groundmass. Alteration - Incipient alteration of olivine to red brown substance (iddingsite?).									

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT				
	Per Cent	Error	Grain Size Groundmass	Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m)	DC Conductivity Final (mho/m)
20 TRACHYTE(?) Trachyte Porphyry; Bannockburn Twp., Ontario Minerals Plagioclase  Quartz (?) Sphene Epidote Chlorite Potash feldspar Calcite				av. 0.3 x 1.5 mm min. 0.3 x 0.5 mm max. 3.25 x 5.75 mm  0.75 mm	5.82	2.62	8.19	.040	$1.8 \times 10^{-11}$	$1.4 \times 10^{-11}$
				Petrographic Detail Fabric - Porphyritic, phenocrysts of above minerals in microcrystalline ground- mass. Alteration - Phenocrysts strongly altered, partly resorbed. Plagioclase largely argillaceous (?).						

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT		
	Per Cent	Error	Grain Size Groundmass Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m) Final (mho/m)
21 LATITE Sanidine- Trachyte; Chaffee County, Colorado				3.19	2.45	7.39	.057	$1.9 \times 10^{-11}$ $8.2 \times 10^{-11}$
<u>Minerals</u> Plagioclase	26.2	±2.8	av. 1.25 x 2.5 mm					
Biotite	3.5	±1.2	av. 0.35 x 0.75 mm					
Magnetite and Zircon	13.4	±2.2						
Augite Horn- blende	3.4	±1.1	0.1 x 0.4 mm					
Groundmass (potash rich)	53.5	±3.2						
<p>Additional data on critical minerals:                      Hornblende: Pleochroic; x = yellow-brown; y = brown; z = red-brown.                      High 2V, (-).                      Augite: Moderate 2V, (+).                      Plagioclase: Oligoclase to albite.</p> <p>Petrographic Detail                      Fabric - Phenocrysts of plagioclase, biotite, augite, hornblende and magnetite are set in a felted cryptocrystalline to microcrystalline mass of sanidine (?).                      Alteration - The biotite and hornblende are altered somewhat to opaque minerals, probably largely magnetite.</p>								

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT			
	Per Cent	Error	Grain Size Groundmass Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial Final (mho/m) (mho/m)	
22 TRACHYTIC TUFF (?) Tuff; Near Cripple Creek, Colorado <u>Minerals</u> Plagioclase Magnetite Sanidine (?)				4.32	2.42	5.32	.028	$8.1 \times 10^{-12}$	$5.3 \times 10^{-12}$

Petrographic Detail  
 Fabric - Altered, tuffaceous,  
 devitrified glass (?) with phenocrysts.  
 Alteration - Calcite, devitrification  
 of glass (?).

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT			
	Per Cent	Error	Grain Size Groundmass Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m)	DC Conductivity Final (mho/m)
23 VOLCANIC BRECCIA (largely of rhyolitic glass) Volcanic Breccia Park County Colorado Minerals Quartz Microcline Plagioclase				4.14	2.19	4.88	.017	$3.2 \times 10^{-11}$	$9.3 \times 10^{-11}$
Petrographic Detail Fabric - Breccia largely of fragments of glassy rhyolitic material with angular pits between. Alteration - Glass is mostly devitrified.									

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT			
	Per Cent	Error	Grain Size Groundmass Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial Final (mho/m)	
24 DUNITE Dunite; Jackson County North Carolina <u>Minerals</u> Olivine Talc Serpentinous materials			av. 1.3 mm   Additional data on critical materials: Olivine: $2V = 90^\circ$ . Talc: $2V = 10^\circ$ .  Petrographic Detail Fabric - Allotrimorphic granular with interstitial and irregular serpentine zones. Alteration - Talc and serpentine alteration from talc.	6.15	3.25			Properties were not measured.	

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT			
	Per Cent	Error	Grain Size Groundmass Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m)	DC Conductivity Final (mho/m)
25 ANORTHOSITE OR GABBROIC ANORTHOSITE Bytownite Gabbro; Duluth, Minn.				6.51	2.75				
Minerals Plagioclase	79.9	±2.5	av. 1.75 x 2.5 mm						
Calcite and Zeolite	12.3	±2.0							
Pyroxene	0.4	±0.4							
Hornblende	5.9	±1.5							
Opaque (Magnetite)	1.4	±0.7							
Vein Quartz	Trace								
Chlorite	Trace								
	Additional data on critical minerals: Plagioclase: An 63 to over An 75.								
	Petrographic Detail Fabric - Hypidiomorphic granular. Alteration - Minor veinlets of calcite through plagioclase crystals. Pyroxene locally unalitized to hornblende.								
	Properties were not measured.								

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT			
	Per Cent	Error	Grain Size	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon' / \epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m)	Final (mho/m)
26 TUFF (partially welded) Volcanic Ash; San Luis Obispo County, Calif.				1.24	1.38				
Minerals Plagioclase Quartz Biotite Sanidine Magnetite			0.02 x 0.2mm 0.3 mm (few)  av. 0.1 x 0.1						
	Additional data on critical minerals: Sanidine: small 2V, (-).								
	Petrographic Detail Fabric - Partially welded ash consisting of glassy fragments containing phenocrysts of above minerals. Alteration - Minor devitrification.								
	Properties were not measured.								



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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSONAL WAVES		ELECTROMAGNETIC MEASUREMENT			
	Per Cent	Error	Grain Size Groundmass Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m)	DC Conductivity Final (mho/m)
27 QUARTZ GABBRO Diorite, Salem, Mass.				6.29	2.99	21.3	.186	$5.8 \times 10^{-9}$	$5.3 \times 10^{-9}$
Minerals									
Plagioclase	38.0	±2.8	0.2-1.5 mm						
Quartz	3.6	±1.1	0.2-0.3 mm						
Augite	16.8	±2.2	0.5-0.8 mm						
Hornblende	9.5	±1.7	0.5-0.8 mm						
Biotite	7.8	±1.6	0.5-0.8 mm						
Magnetite	10.2	±1.8	0.2-0.3 mm						
Orthoclase	Trace								
Apatite	1.4	±0.7	Max. length 1.6 mm						
Zircon	Trace								
Sphene	0.1	±0.1							
Calcite	12.6	±1.9	0.01 mm						
Iron Sulfide	Trace								
	Additional data on critical minerals: Plagioclase: An 52+ Hornblende: High 2V, (-); x = tan; y = olive drab; z = dark green; Augite: Moderately high 2V, (+), maximum extinction angle 45°. Biotite: Pleochroic brown to tan.								
	Petrographic Detail Fabric - Hypidiomorphic, fine to medium grained. Alteration - Augite partially altered to hornblende.								

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT		
	Per Cent	Error	Grain Size Groundmass Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial Final (mho/m)
28 BIOTITE MUSCOVITE ALKALI GRANITE (strained) Biotite Granite; Woodbury Vermont				4.90	2.66	6.82	.067	$7.3 \times 10^{-12}$ $2.2 \times 10^{-12}$
<u>Minerals</u>								
Plagioclase	29.3	±2.2	0.1 x 2.0 mm					
Microcline	22.1	±2.5	2.0 mm					
Quartz	32.1	±2.5	1.5 mm					
Biotite	8.0	±1.5	0.4 x 1.0 mm					
Muscovite	6.1	±1.3						
Calcite	1.7	±0.7						
Apatite)								
Sphene)								
Chlorite)								
Zircon)								
Epidote)								
Opaque)								
			Additional data on critical minerals: Plagioclase: Albite. Biotite: Pleochroic brown to tan.					
			Petrographic Detail Fabric - Hypidiomorphic, medium grained. Alteration - Minor clay in microcline and minor chlorite from biotite.					

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS				VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT				
	Per Cent	Error	Groundmass	Grain Size	Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m)	DC Conductivity Final (mho/m)
29 OBSIDIAN Obsidian; Lake County, Oregon <u>Minerals</u> Volcanic Glass						5.67	2.35	7.76	.027	$7.2 \times 10^{-9}$	$1.1 \times 10^{-8}$
	Petrographic Detail Fabric - Glassy. Alteration - Partially devitrified.										

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS				VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT			
	Per Cent	Error	Grain Size Groundmass	Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m)	Final (mho/m)
30 BASALT Basalt; Somerset County, New Jersey					6.31	2.97	26.7	.444	$7.0 \times 10^{-9}$	$6.7 \times 10^{-9}$
<u>Minerals</u> Augite Plagioclase Serpentine Plagioclase alteration product Opaque Groundmass	35.3 6.4 4.7 8.6	$\pm 3.6^*$ $\pm 1.8$ $\pm 1.6$ $\pm 2.1$		2-3 mm 0.5 mm						
	4.4 40.6	$\pm 1.5$ $\pm 3.7$		0.1 mm						
	<p>*Error may be greater because of the clotting of pyroxene phenocrysts.</p> <p>Additional data on critical minerals:                      Augite: Moderate to high 2V, (+) maximum extinction angle <math>45^\circ</math>.                      Plagioclase: Probably labradorite but too altered to be certain.</p> <p>Petrographic Detail                      Fabric - Porphyritic with megaphenocrysts of augite and microphenocrysts of the other minerals set in a microcrystalline groundmass.                      Alteration - Serpentine probably altered from olivine.</p>									

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT		
	Per Cent	Error	Grain Size Groundmass Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m) Final (mho/m)
31 BIOTITE MUSCOVITE QUARTZ MONZONITE Quartz Monzonite Westerly, Rhode Island				5.67	2.65	6.23	.028	<2.2 x 10 <sup>-12</sup>
<u>Minerals</u> Quartz Microcline Plagioclase Biotite Muscovite Chlorite Calcite Magnetite	32.0 30.5 24.4 2.5 4.4 0.5 5.3 0.4	±1.9 ±1.8 ±1.7 ±0.6 ±0.8 ±0.3 ±0.9 ±0.3	av. 0.5 mm av. 0.8 x 1.2 mm 0.75 x 1.25 mm					
	Additional data on critical minerals: Plagioclase: Oligoclase to albite (about An 5-15).  Petrographic Detail Fabric - Hypidiomorphic, locally poikilitic with quartz blebs in microcline. Alteration - Moderate calcitic and argillaceous alteration of plagioclase and chloritic alteration of biotite.							

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT			
	Per Cent	Error	Grain Size Groundmass Phenocrysts	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m)	DC Conductivity Final (mho/m)
<sup>32</sup> QUARTZ SANDSTONE Sandstone; Columbia County Pennsylvania Minerals Quartz			average diameter of grains 0.6 mm  Petrographic Detail Fabric - Interlocking grains with somewhat sutured boundaries. Alteration - None.	1.96	2.61	4.84	.008		$<2.2 \times 10^{-12}$

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT			
	Per Cent	Error	Grain Size	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m)	DC Conductivity Final (mho/m)
33 KAOLIN (Ward's Name) Kaolin; Drybranch, Georgia Mineralogy Not Verified				1.21	1.58	7.29	.179	$3.8 \times 10^{-11}$	Not measured.
Petrographic Detail Fabric - Earthy, porous. Alteration - Probably none.									

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS			VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT			
	Per Cent	Error	Grain Size	Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity Initial (mho/m)	DC Conductivity Final (mho/m)
34 MARBLE (strained) White Marble; Tate, Georgia <u>Minerals</u> Calcite Quartz Cloudy material not determinable			Phenocrysts           av. 4 mm 0.3 mm	5.22	2.71	9.84	.012		$< 2.2 \times 10^{-12}$
			Petrographic Detail Fabric - Granoblastic, some twin lamellae curved indicating strain. Alteration - None.						



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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS				VELOCITY OF COMPRESSONAL WAVES		ELECTROMAGNETIC MEASUREMENT			
	Per Cent	Error	Grain Size		Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity	
			Groundmass	Phenocrysts					Initial (mho/m)	Final (mho/m)
35 GRAPHITE Ceylon					2.93	2.16	Not measurable.			$4.0 \times 10^3$
36 LIMONITE Alabama					5.24	3.55	18.9	.145		$3.7 \times 10^{-9}$
37 PYRRHOTITE Ontario					4.60	4.55	Not measurable.			$4.3 \times 10^3$
38 PYRITE Colorado					7.46	4.81	Not measurable.			2.14
39 MICROCLINE Ontario					6.52	2.57	6.52	.027	$5.5 \times 10^{-12}$	$2.2 \times 10^{-12}$
40 ALBITE Ontario					6.28	2.63	11.7	.195	$3.5 \times 10^{-11}$	$5.1 \times 10^{-12}$
41 PYROXENE (DIOPSIDE) Quebec					6.72	3.08	8.30	.013		$< 2.2 \times 10^{-12}$
42 HEMATITE Michigan					6.65	4.93	Not measurable.			$8.1 \times 10^{-3}$

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MINERAL SAMPLE	PETROGRAPHIC ANALYSIS				VELOCITY OF COMPRESSIONAL WAVES		ELECTROMAGNETIC MEASUREMENT				
	Per Cent	Error	Grain Size		Mean Velocity (km/sec)	Density (gm/cc)	Relative Permittivity ( $\epsilon'/\epsilon_0$ )	Loss Tangent	DC Conductivity		
			Groundmass	Phenocrysts					Initial (mho/m)	Final (mho/m)	
43 BYTOWNITE Minnesota					6.78	2.71	7.61	.048			$3.3 \times 10^{-10}$
44 MAGNETITE New York					5.02	4.81	Not measurable.				$2.9 \times 10^{-11}$
45 HORNBLLENDE Ontario					6.14	3.32	14.0	.64			$3.5 \times 10^{-8}$
46 AUGITE New York					3.67	3.26	9.22	.042	$7.0 \times 10^{-11}$	$1.8 \times 10^{-11}$	
47 TREMOLITE New York					4.77	2.86	6.30	.013			$< 2.2 \times 10^{-12}$

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These constants allow us to compare rocks, meteorites, and tektites, which scientists have proposed as possible lunar materials or similar to lunar materials, with our results obtained by electromagnetic diagnostics of the lunar surface. Since the values for many of these constants were unknown, laboratory tests were made to obtain the fundamental constants of these possible lunar materials.

Penetrometer tests in dustlike materials in vacuo took on new meaning. Results of these tests showed that the danger of sinking or partially sinking into the lunar surface upon landing should not be considered lightly.

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