A SIMPLE TECHNIQUE TO DETERMINE THE SIZE DISTRIBUTION OF NUCLEAR CRATER FALLBACK AND EJECTA

CPT Brooks D. Anderson, II
U. S. Army Engineer Nuclear Cratering Group
Lawrence Radiation Laboratory
Livermore, California

INTRODUCTION

This report describes the results of an investigation to find an economic method for determining the block size distribution of nuclear crater fallback and ejecta.

It is shown that the modal analysis method of determining relative proportions can be applied with the use of a special sampling technique, to provide a size distribution curve for clastic materials similar to one obtainable by sieving and weighing the same materials.

BACKGROUND

The size distribution of nuclear crater fallback and ejecta is a necessary parameter for input into the analysis of crater slope stability, fallback and rupture zone permeability and the production of aggregate and riprap by nuclear means. Methods presently in use by the Corps of Engineers to determine size distributions of fallback and ejecta have the drawbacks of being either very expensive, in the case of sieving and weighing, or not accurate enough, as in the case of a newly developed grid photography technique. The reason for the lack of reliability in data obtained by grid photography was shown by Anderson (1969) to be due to the low scale level of information obtained by measuring particle size in two dimensions on a photograph and the failure to differentiate between particle size distributions by number and by weight. Because of the expense of sieving and weighing and the lack of accuracy of grid photography, it became imperative to find an alternative to these techniques. This report presents the results of an investigation to find such an alternative.

THEORY

The theoretical concepts which form the basis of a new technique for the modal analysis of fragmental material are developed in this section. A brief review of common geologic sampling techniques is first presented to emphasize the difference between size distribution by number and by weight. Because the measure of "size" obtained by the new modal analysis technique is somewhat different than that obtained by sieving, and the size distribution obtained by application of the two techniques to the same material are to be compared, a justification for using that measure is presented. Sampling requirements of the new technique are stated and the effects of porosity, density, and layering on the sampling technique are discussed.

COMMON GEOLOGIC SAMPLING TECHNIQUES

SIEVING

The size measurement obtained in sieving is very dependent upon the shape of the particle. It is primarily a function of the least cross-sectional area of the particle which is most influenced by the particle's intermediate and short axis. There are other factors which affect the passage of a particle of a given "size" through a sieve. They are; (1) the sphericity and roundness of the particle, (2) the length of time of sieving, which affects the probability of a particle achieving the proper orientation for passage, (3) the type of motion the sieves are subjected to and (4) variation in the individual sieve openings. In summary, any measure of size is merely a function of sample-technique. Different techniques give different measures of size.

MODAL ANALYSIS

Modal analysis is the term given to a method of determining the volume percentage of the mineral constituents of a rock by means of point counts on its surface. It is based upon the discovery by Delesse in 1848 of the equivalence of areal and volumetric proportions. However, it was not until 1956 that Chayes was able to give a mathematical proof to the relationship. Until this time, its application to the study of the mineral content of rocks was seriously hindered. Because Chayes' (1956) mathematical proof of the Delesse relation is germane to the argument for the application of areal modal analysis to clastic rocks it is presented here.

POINT SUMS AS ESTIMATORS OF AREAL PROPORTIONS

To paraphrase Chayes: a small irregular area (B) is enclosed in a large irregular area (B+W). The probability that a point located simply at random in (B+W)[1] will also lie in B is, by definition, the ratio of the areas,

$$p = \left(\frac{A_B}{A_{(B + W)}}\right)$$

Where A_B = area designated B

$A_{(B + W)}$ = area designated (B + W)

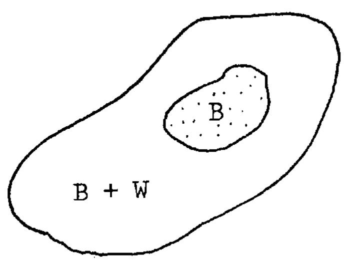


Figure 1: Small area (B) enclosed in large area (B + W), the ratio of the areas to be estimated by the sums of points chosen simply at random in the region (B + W).

The expected number of points E which fall in B in a particular sample containing n points is

$$E = np = n\left(\frac{A_B}{A_{(B + W)}}\right)$$

the fraction μ of the total number of points in the sample that fall in the area

[1]The total area.

B is

$$\mu = \frac{E}{n} = p = \frac{A_B}{A_{(B+W)}}$$

Therefore, the fraction of the total number of points that fall in the smaller area is an unbiased estimate of the ratio of the smaller to larger area.[2]

DELESSE RELATION

The area-volume relation,[3] which determines whether estimates of relative area may also be regarded as consistent estimates of relative volume is both simpler and more widely misunderstood than any other part of the theory of modal analysis.

If the area of a section of a solid parallel to the xy plane is a function of z, $A = f(z)$, and sections through the solid can be chosen simply at random normal to OZ in the region $c \leq z \leq d$, the element of frequency is dz, and the total frequency is (Figure 2)

$$F = \frac{1}{d - c} \int_c^d dz = 1$$

and the expected value E(A) of the area A is

$$E(A) = \frac{1}{d - c} \int_c^d A dz = \frac{V}{d - c}$$

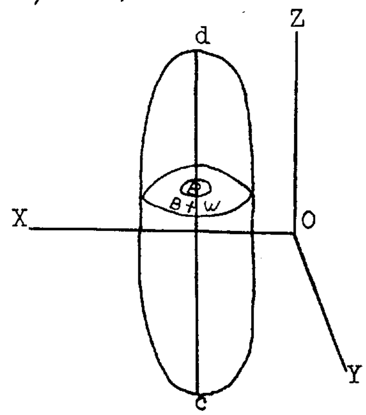


Figure 2: Solid in XYZ Space, c - d Perpendicular to Area B + W.

where A and V represent area and volume respectively. We have at once that

$$\frac{E\,(A_B)}{E\left(A_{(B + W)}\right)} = \frac{V_B}{V_{(B + W)}}$$

where the ratio of an unbiased estimate of the area A_B to an unbiased estimate of the total area $A_{(B + W)}$, obtained by point counting, is also the ratio of the volume V_B to the total volume $V_{(B + W)}$. It is apparent then that as long as we have an unbiased estimate of the relative areal proporations, taken from a surface of a representative sample of rock, then we also have an unbiased estimate of the volumetric proportions of the constituents of that rock.

The preceding proof says nothing about how the estimates of the relative areas are to be obtained. But if we can accept this proof then the determination of relative proportions of minerals in a rock becomes relatively simple.

GRAIN COUNTS

A number of techniques have been developed for grain size analysis of

---

[2]i.e., in such fashion that each point in the area (B + W) has the same probability of being selected as any other point.

[3]Delesse relation.

loose grains, mainly dependent upon the average size of the material. Sands are generally analyzed by making grain counts using sized material obtained by sieving. A precise subdivision of the sample is required so that the several hundred grains in the count are representative of the sample. The grains are counted either by using a grid micrometer or with a mechanical stage and a mechanical counting device. The number of grains in a given grid square, or successively encountered along a line, is counted.

For analysis of gravel deposits, Griffiths and Kahn (1967) have recommended that, depending upon the detail of information required, pebbles can be selected along a line or a number of lines placed at random on the deposit surface. The data obtained by this technique are analyzed in a manner similar to that obtained by grain counting under a microscope. Some work has concentrated on the conversion of number frequency data to size or weight frequency. However, most geologists do not consider the results of these conversions to be sufficiently reliable to permit their general adoption, hence the basic discrimination between number frequency and weight frequency has been maintained.

In summary, the development of techniques designed to acquire data from mixtures of geologic materials has taken two parallel but distinct paths of development. One path has been toward continuing refinement of estimates of the volumes or weights of rocks or minerals in a sample and the other directed toward determining the size distribution by number. There is one exception to this trend: a paper published by M. Gordon Wolman titled, "A Method of Sampling Coarse River-Bed Material."

WOLMAN TECHNIQUE

According to Wolman (1954) it is possible to determine a size-frequency distribution of the clastic material on the bed of a stream based upon an analysis of the area covered by particles of given sizes. Wolman collected his sample of 100 pebbles from the bottom of the stream from the points of intersection of a grid system. He applied the technique to a number of river bottoms, and reproduced his work several times by having his students collect on different days and by having different students make the collection. The results of his studies are plotted in Figure 3.

Wolman found that when he compared samples determined from pebble counts with samples of the same material analyzed by sieving and weighing that the median diameter of the sample determined by the point sampling methods was considerably larger, (twice as large), than the median diameter of the sieved sample (see Figure 3).

It is not immediately clear why Wolman got the results he did, although, what is thought to be a reasonable explanation will be offered as we further develop the new technique of modal analysis of clastic materials, so called because of its similarity to the modal analysis technique of sampling minerals in rocks.

MODAL ANALYSIS OF CLASTIC ROCKS

According to Wolman (1954) it is possible to determine a size-frequency distribution of the clastic material on the bed of a stream based upon an analysis of the relative area covered by particles of a given size. This statement is the key to the unification of modal analysis and particle counting. It is a statement of the Delesse relation which relates areal proportions to volumetric proportions.

The question remains, does the Delesse relation actually hold for clastic rocks? If so, can a technique be developed to yield results comparable to those

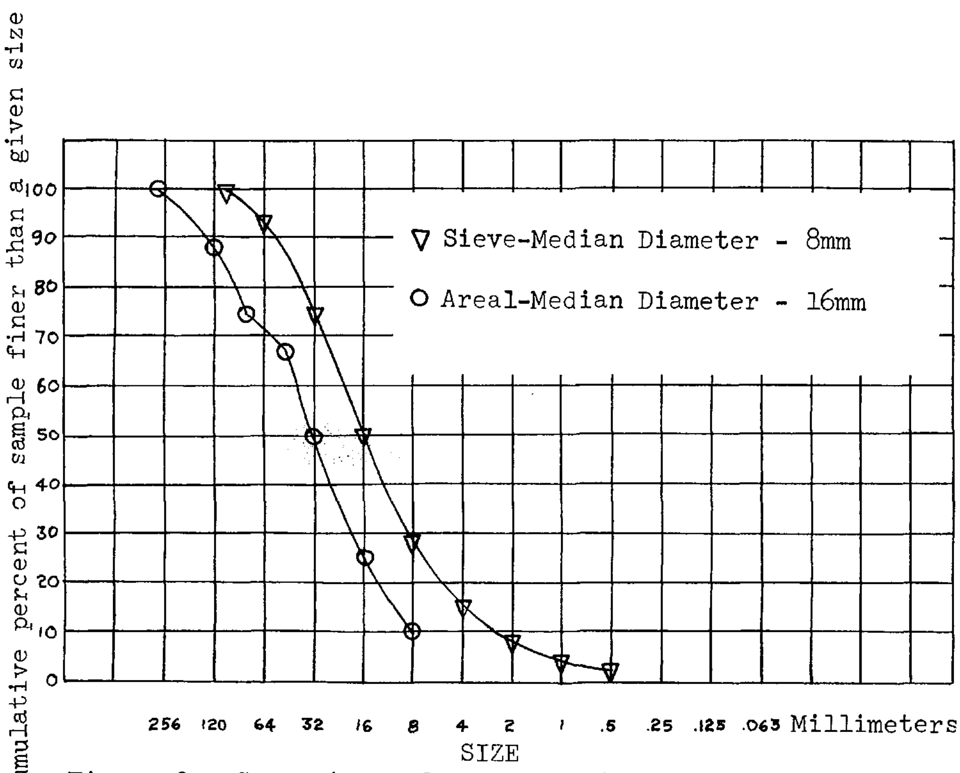


Figure 3. Comparison of samples obtained from sieve and areal analysis (from Wolman, 1954).

obtained by sieving and weighing the same material?

Size is determined directly by measuring in the application of the point sampling technique, however, the weight distribution must be inferred by an inductive argument. Therefore, we are concerned with size and weight, and how to obtain these parameters (sampling).

SIZE

Many techniques, to include sieving, produce measures of "size" which are not "clean," that is, they confound variation from a number of sources. The "size" distribution curves produced by sieving and weighing are a function of the size, shape and composition of the sieved material. Because the measure of size obtained by sieving is to be compared with one based upon a single measurement it is necessary to choose a measure of size that would closely approximate that obtained by sieving. In this study the "b" intermediate axis (see Figure 4) was selected. This is defined as the axis most closely approximating the nominal diameter of the least cross-sectional area which determines whether or not a particle of a given "size" will pass through a sieve opening.

WEIGHT

In modal analysis the volume of minerals in a rock is inferred by the analysis of an area. The relative weights of the minerals are not directly inferred but must be calculated by considering their relative densities. It is immediately apparent that we are faced with a similar situation in the determination of the size-weight distribution of rocks by this method. The calculation of weight from relative volumes has two pitfalls; one has to do with possible differences in porosity within the sampled material and the other has to do with possible differences in density between individual clasts sampled.

POROSITY

Porosity, as such, presents no obstacle to the application of the Delesse relation except for certain cases which are amenable to rational analysis. For example (see Figure 5), consider a sandstone in which the grains are of a uniform size-sand size. This sandstone has a porosity of 25%.

Now, if we scatter 100 points over the surface of the sandstone and select 100 grains lying beneath these points, we will always encounter a grain and never a pore space, because in practice we are sampling the projections of the grains to a plain surface. This characteristic of the sampling technique has important implications in practice. These 100 grains of sand-size represent 100% of the sampled surface. There should be little difficulty, in concept, to extend this proportion (100% sand-size grains) to volume and weight and saying that 100% of the particles by volume and by weight are sand-size.

However, differential porosity could have a deleterious effect on the estimate. The diagram in Figure 6 shows a "horrible example" in which 50% of the mass is solid and 50% of the mass contains 25% pore space. Calculations pertaining to the example in Figure 6 give an indication of the size of the error of the estimate.

If the solid is considered to be a block of a given "size" and the porous material to be composed of fragments of a smaller "size" then it is apparent that although both occupy the same volume (and from the idealized case for the Delesse relation, the same surface area) but, the solid material of the two "sizes" would not weigh the same. In fact, only 37.5 units of the total weight is concentrated in the porous material (considering that 25% of the 50 estimated (units) is 12.5 (pores) and 50 - 12.5 = 37.5). Now, if all the grains in

VARIATE: SIZE AS DEFINED BY "b" AXIS, "b" DEFINED AS THE MAXIMUM INTERMEDIATE DIAMETER THAT WOULD "PASS" A GIVEN SIEVE (⊥ TO GRID DIAGONAL NOT CONSIDERED)

MEASUREMENT WITH CALIPERS (ACCURATE TO .001")

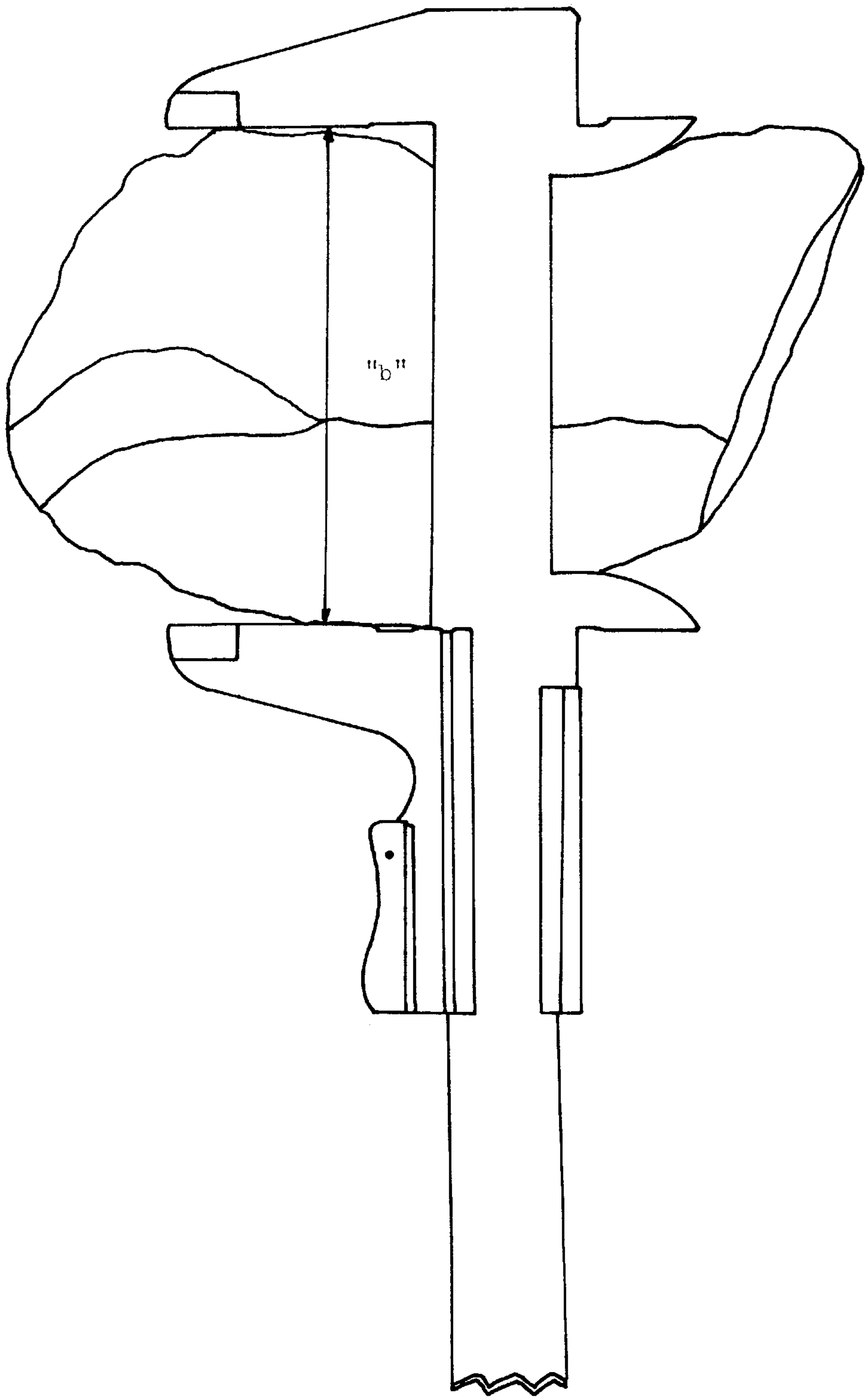


Fig. 4 Measurement of "b" Intermediate Axis of Rock with Calipers

the porous material were packed into a solid, but with the individual grain boundaries still defined, the top surface of the compacted material would be representative of the 37.5 (units) of granular material. Reestimating the relative volumes from the relative surface area (Delesse relation) it is found that the true relative proportions are 57.1% and 42.9% (where 50 units are 57.1% of 87.5 and 37.5 units are 42.9% of 87.5). As a point of interest, it should be noted that this is probably the worst case we are likely to encounter under natural conditions. The absolute error of the estimate of relative proportions drops off rapidly away from 50%. The Delesse relation is based upon relative rather than absolute proportions. It can be seen that the error of the estimate ranges from about 14% in our "horrible example," to zero in the sandstone with 25% porosity. In the example in Figure 6 we would have estimated relative proportions of clasts of different sizes at 50% each instead of their true proportions of 57.1% and 42.9%. However, all that is required to correct this error is an estimate of the porosity of the porous material and the correction can be done in the same way as was done in the preceding example.

DENSITY

At first, differing densities between rocks would seem to be a troublesome point. However, if we are dealing with rocks of essentially the same composition then their density, and hence weight, become a constant and can be ignored. In practice, the range in density of most rocks is not significantly different, and in fact, differences in density of fragments would only become serious, for practical purposes, if there was a significant grouping of fragments of different densities in different size classes. The only suggestion that can be made at this point is that the operator make a preliminary investigation to determine if the aforementioned situation has indeed occurred. If it has, it is a simple matter to note the compositions of the rocks when they are measured and prior to generating a cumulative size-weight distribution curve compensate for their different densities.

SAMPLING

In the practical case, application of this technique becomes a sampling problem. When we sample, we are in effect measuring or counting some fraction of elements of a larger or more numerous entity in order to draw some inference about that entity. Assuming that we have taken precautions to insure that our sampling procedure is unbiased and consistent, it is of considerable interest to know how many samples to take in order to accurately characterize the parent population. Chang (1967) has addressed the problem of determining how many individuals, assigned to a given class, should be used in order to get an accurate percentage representation of that class. The result of Chang's work is presented in Figure 7. He assumed that the variability of the percentage estimation, which causes the error of the population estimate, to be due to the probability associated with random sampling. He then demonstrated that the maximum error of the estimate is likely to occur when two classes are present in the relative proportions of 50% each. Interestingly enough, a similar phenomenon is found to cause the maximum error of the estimate of relative proportions in the case of differential porosity. This maximized standard deviation, d (two classes present in proportions of 50% each, and 1d = 68.27%, 2d = 95.45% and 3d = 99.73% confidence levels), is plotted as a function of the number of samples taken, n. For example, if an investigator samples 500 clasts from a large group of clasts, by referring to Figure 7, he finds that the error of the estimate at the 95.4% confidence level is 4%. Therefore, if the clasts are present in only 2 sizes in the relative proportions of 50% each, 95.4% of the time the percentage of the size clast estimated will be less than or equal to ± 4%. Because this is the maximum error expectable, clasts with sizes present in other proportions will give a smaller error of the estimate. Knowing the maximum error of the estimate likely to occur it is now possible to determine the number

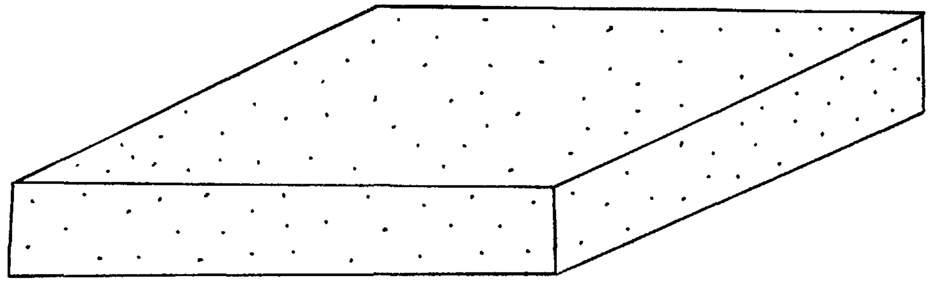
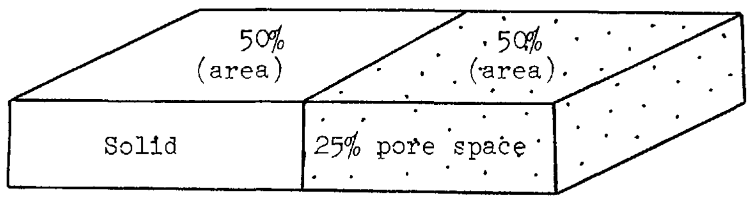


Figure 5. Sandstone, 25% Pore Space.



50.00	units Volume (solid)
+ 37.50	units Volume occupied by solids in porous material
87.50	Total Volume of Solids

Figure 6. Differential Porosity.

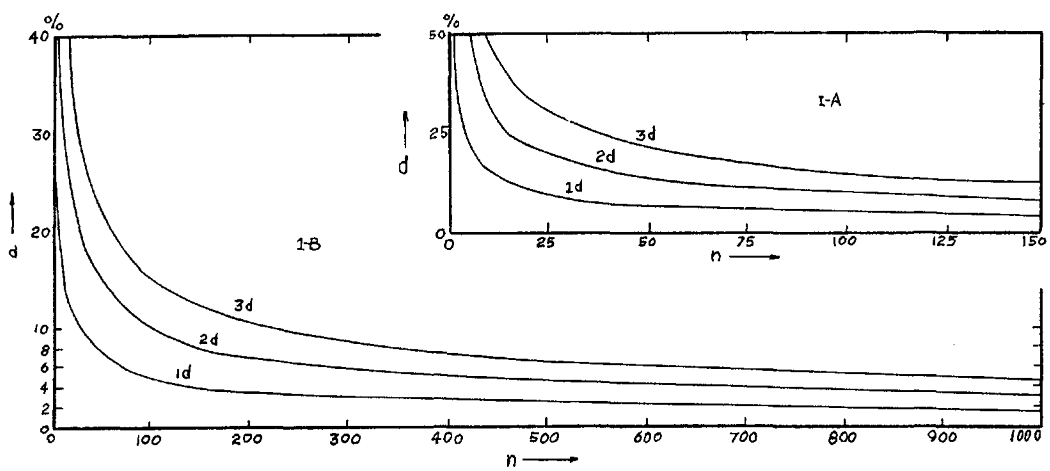


Figure 7. From Chang (1967). Relationship of the maximized standard deviation (d) to the studied population number (n). (1-A). Both d and n are in the same scale (1-B). d and n are in different scales; the n scale is reduced so that it is 10 times smaller than the d scale.

of samples to take, at a given confidence level, to obtain an estimate with minimum statistical error consistent with the objective of the study.

Since the technique proposed herein is not simple random sampling (like drawing colored balls out of a bag) but is a systematic sampling of an area, it is of interest to know the size of the area to sample. Although there are several sophisticated methods to determine the area necessary to examine in order to obtain a representative sample, the formula presented below is both simple and readily applicable in the field. The formula is:

$$\text{Total Sample Area} = n\ (\text{Grid Spacing})^2$$

Where n = number of samples to be taken at a predetermined confidence level (obtained from graph by Chang, 1967, Figure 7)

And Grid spacing is determined by the size of the largest block likely to be encountered (determined by a preliminary reconnaissance of the sample area).

THE EFFECTS OF LAYERING

The example in Figure 8 demonstrates a case in which a sample of the available population, the surface of a gravel deposit, although an unbiased sample of the available population would provide a very poor estimate of the parameters of the whole deposit.

However, it can also be seen that if the samples are taken at any angle to the layering, other than parallel to it, the sampling surface will consist of a series of parallel bands containing rocks of different sizes (see Figure 9).

It can readily be seen that a sample taken in the preceding manner would provide statistical estimators that would slowly converge on their corresponding population parameters. Further, it is apparent that the most efficient sampling program would be one in which the samples were taken perpendicular to the layering. In the absence of layering, or only weakly developed layering, as might occur in crater fallback and ejecta, this sampling problem does not appear to be serious.

APPLICATION OF THE METHOD

SAMPLING PROCEDURES

Comparative Test on a Small Scale

A comparative test between sieving and weighing and the newly developed modal analysis technique for clastic material was conducted using approximately five tons of homogenized gravel. As specified, the gravel ranged in size from about 5 inches down to 1/2 inch. Although the specification of a well-graded mixture was not met, it is believed that this characteristic of the material had little effect on the test results. The gravel was spread out to a uniform depth of approximately 1 foot. The experimental program included sieving and weighing of five samples of 100 pounds of the 5 tons of gravel and conducting 5 separate modal analyses on the gravel using a sample size of n = 100 clasts for each analysis.

Five samples of gravel, each weighing 100 pounds, were removed by shovel from the parent population of five tons of gravel. Three different operators took a total of five different samples on different days. The same three operators sampled the gravel using the modal analysis technique taking five samples of n = 100. Each of the 100 clasts in the five samples was selected from the deposit on the basis of a grid system established by using a 1/4-inch rope

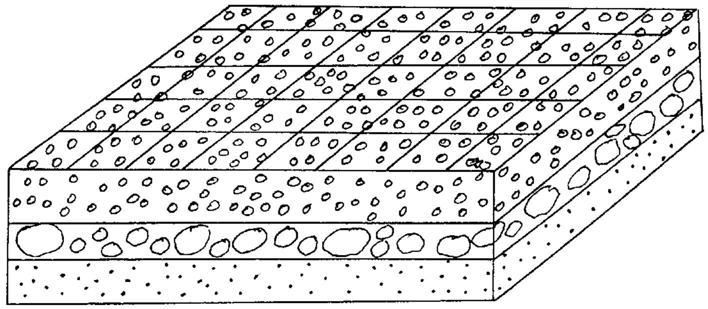


Figure 8. Error of Estimate of Relative Proportions due to Layering.

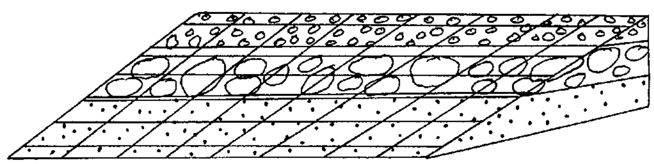


Figure 9. Sampling of Layered deposit to obtain a Representative sample.

marked at 1-foot intervals. The "b" intermediate axis was measured by means of a caliper (see Figure 4). As a further check on the sampling technique the 500 pounds of previously sieved and weighed material was spread out on the ground and a sample of n = 100 was taken in the same manner as the other samples. The results were tallied and plotted. Points were connected by straight lines and curves were not "smoothed" in order to emphasize differences in results.

Application to Craters

Several craters were investigated at the Nevada Test Site. These included both chemical and nuclear explosive craters (Table 1). A systematic grid was laid out on the surface of the ejecta, using a tape and compass for orientation, and samples (measurements) were taken at an interval larger than the largest particle likely to be encountered - ten- to twenty feet. These samples were taken in groups of 100 each over different parts of the fallback and ejecta. Samples totaling 300 to 600 clasts were taken, depending upon the variability in the distributions obtained in the samples. These measurements were grouped into geometric size classes, each class being twice as large as the preceding one, and the numbers of measurements in all classes were summed. These measurements were plotted as cumulative percent using the midpoint of each class size as the data point for that size class.

RESULTS

The results of Site 300 investigations are shown in Figures 10 and 11. These figures are composite plots showing the results of both the point sampling technique and sieving and weighing of material taken from the same parent population. The results of the studies of craters at the Nevada Test Site are presented in Figures 12 through 14. Figures 12 and 13 are composite plots showing the results of the point sampling technique and sieving and weighing material from the same crater. Figure 14 shows the results of applying the point sampling technique to several craters - sieving and weighing data from the DANNY BOY crater only is plotted for comparison.

DISCUSSION

SMALL-SCALE COMPARATIVE TESTS

It is apparent that, within the limits of error of the techniques used, the curves obtained by sieving and weighing and that obtained by modal analysis rather consistently lie on top of each other for the small-scale comparative tests (Figures 10 and 11). Therefore, it is postulated that the ratio of the area occupied by particles of a given size to the area occupied by all other sizes, in the area under investigation, is a consistent estimate of the volume percentage of that size!

These results suggest that Wolman did not sample the same population when he sampled the surface of the stream bottom by his grid point count technique and when he dug into the stream bottom for samples to sieve.

The "fit" of the curves obtained by the two techniques used in the small-scale tests is not perfect. However, what are considered to be reasonable explanations for the observed discrepancies are presented. The variability in the upper end of the sieving size-distribution curves is attributed to two sources. First, it was necessary to use hand sieves. It is a difficult task to obtain reproducible results by hand shaking 100 pounds of gravel through a 40-pound set of sieves. Also, individual fragments weighing as much as 15 pounds were encountered in some of the samples and, therefore, a 100-pound sample is too small. The modal analysis results were considerably more internally consistent than the sieving results. The modal analysis technique forces an operator to take a

TABLE 1

DESCRIPTION OF CRATERS, NEVADA TEST SITE

	CRATER	CHARGES	DOB	MEDIUM	CHARGE SIZE	RADIUS
1.	DANNY BOY	Single	110	Basalt	0.42 kt*	107'
2.	CABRIOLET	Single	171	Rhyolite	2.3 kt	179'
3.	Pre-SCHOONER ALPHA	Single	58	Basalt	20 tons**	50'
4.	Pre-SCHOONER BRAVO	Single	50	Basalt	20 tons	49'
5.	Pre-SCHOONER CHARLIE	Single	66	Basalt	20 tons	Mound
6.	BUGGY	Row	135	Basalt	5 Devices 1.1 kt	Row
7.	SULKY	Single	90	Basalt	.085 kt	Mound
8.	DUGOUT	Row	58	Basalt	5 charges 20 tons each	Row

* kt = nuclear

** tons = high explosive

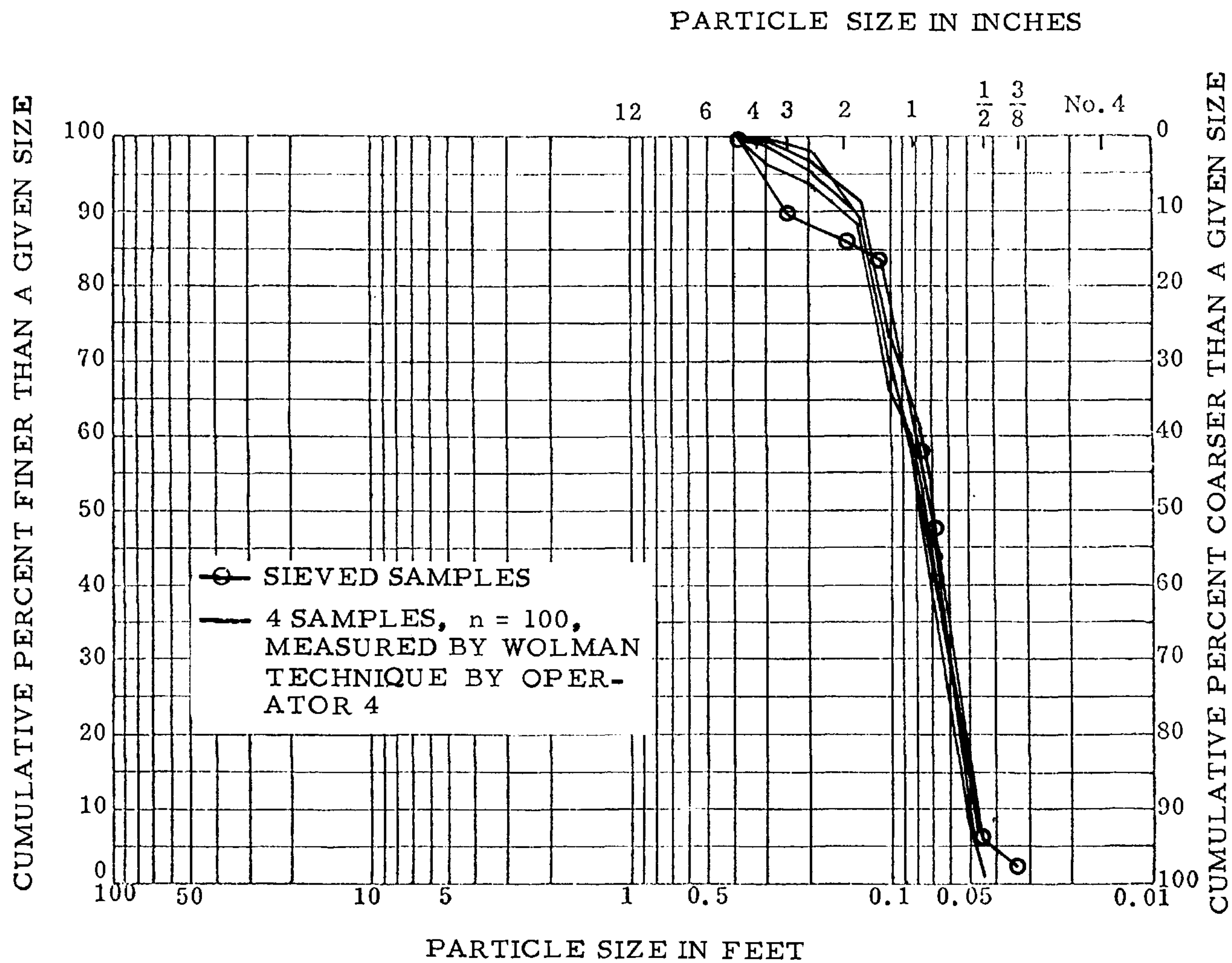


Figure 10. Particle size distribution, Site 300 Test, Operator 4.

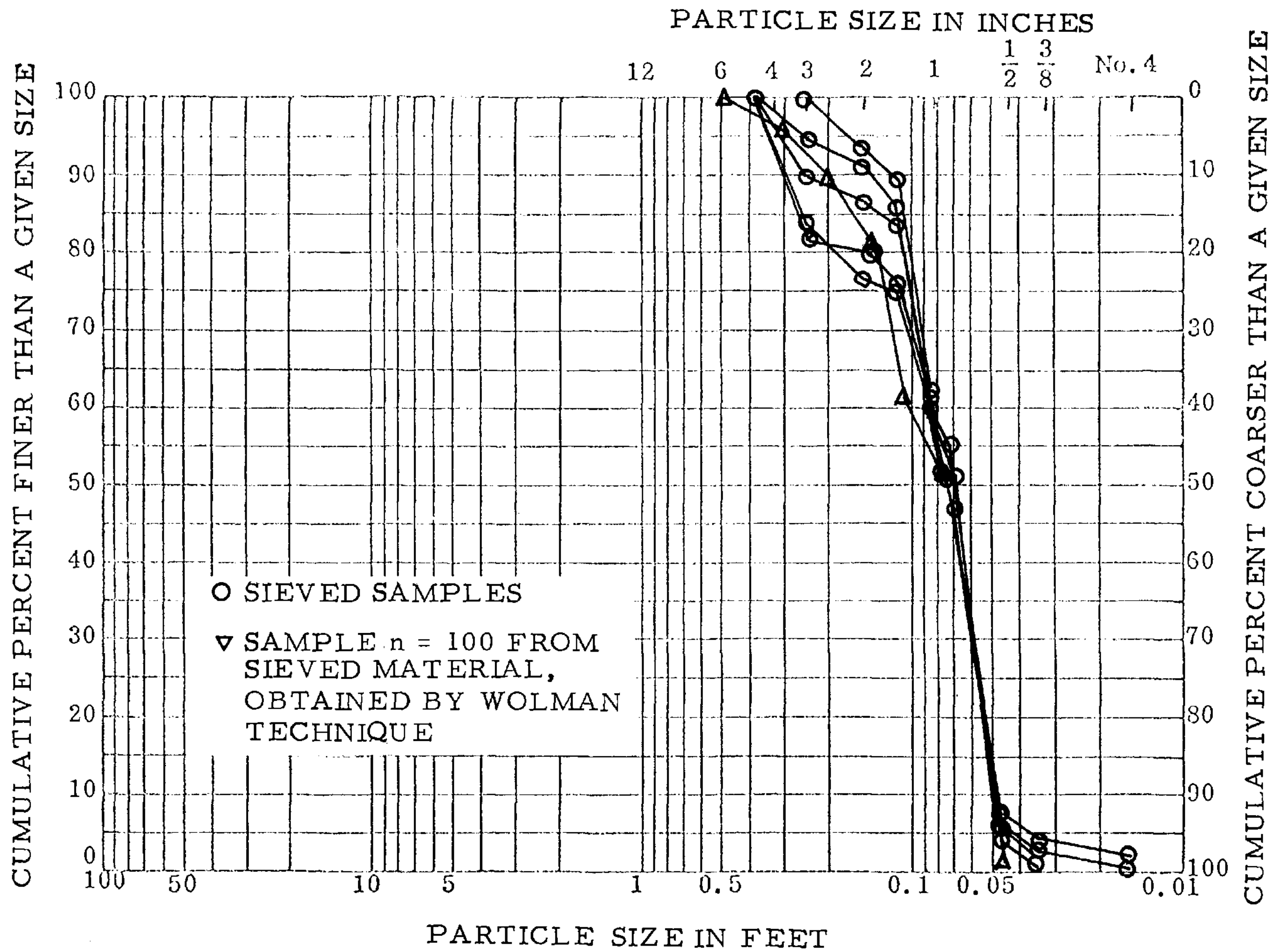


Figure 11. Particle size distribution, Site 300 Test, Sample n = 100 of sieved material obtained by Wolman Technique.

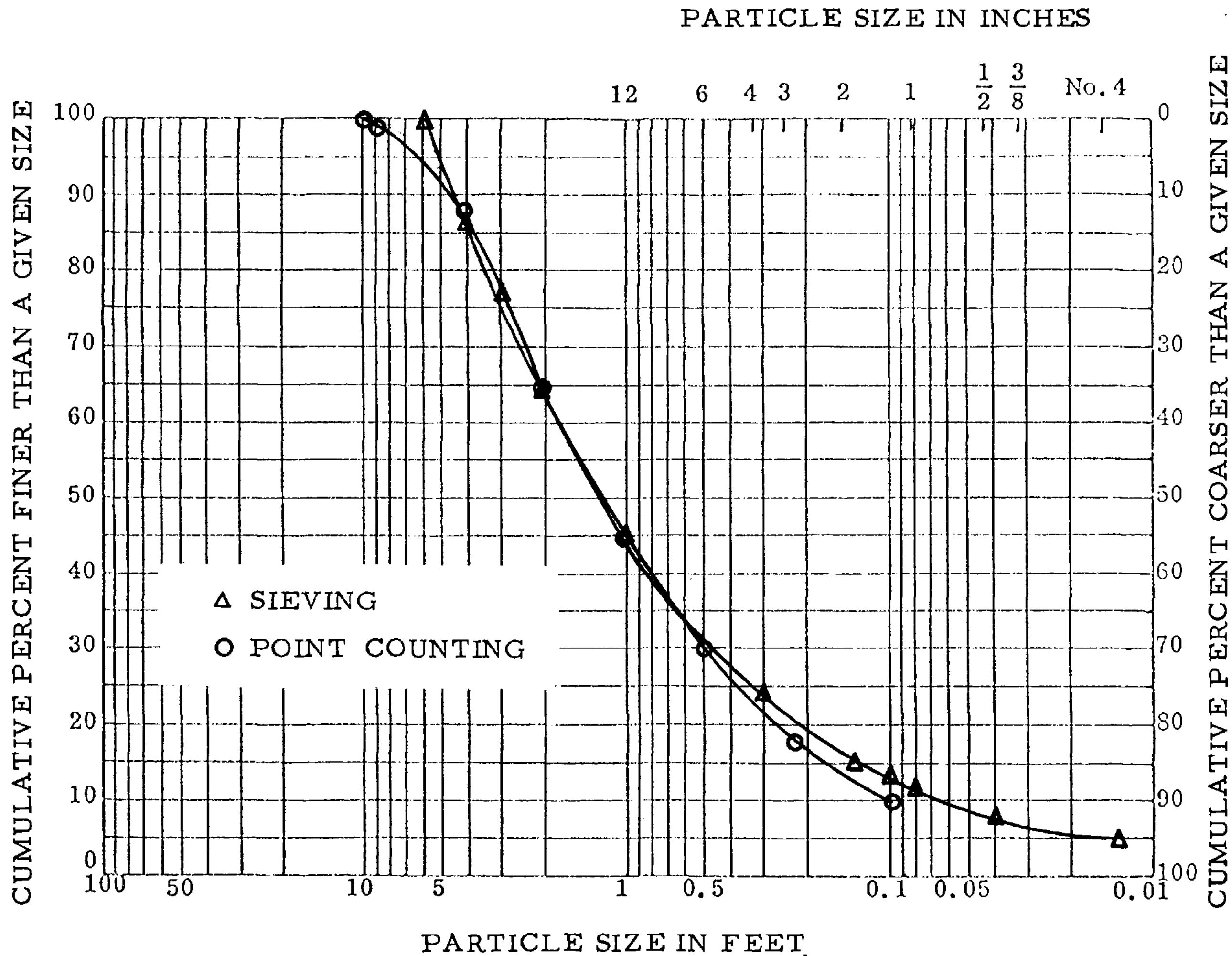


Figure 12. Particle size distribution, DANNY BOY Crater.

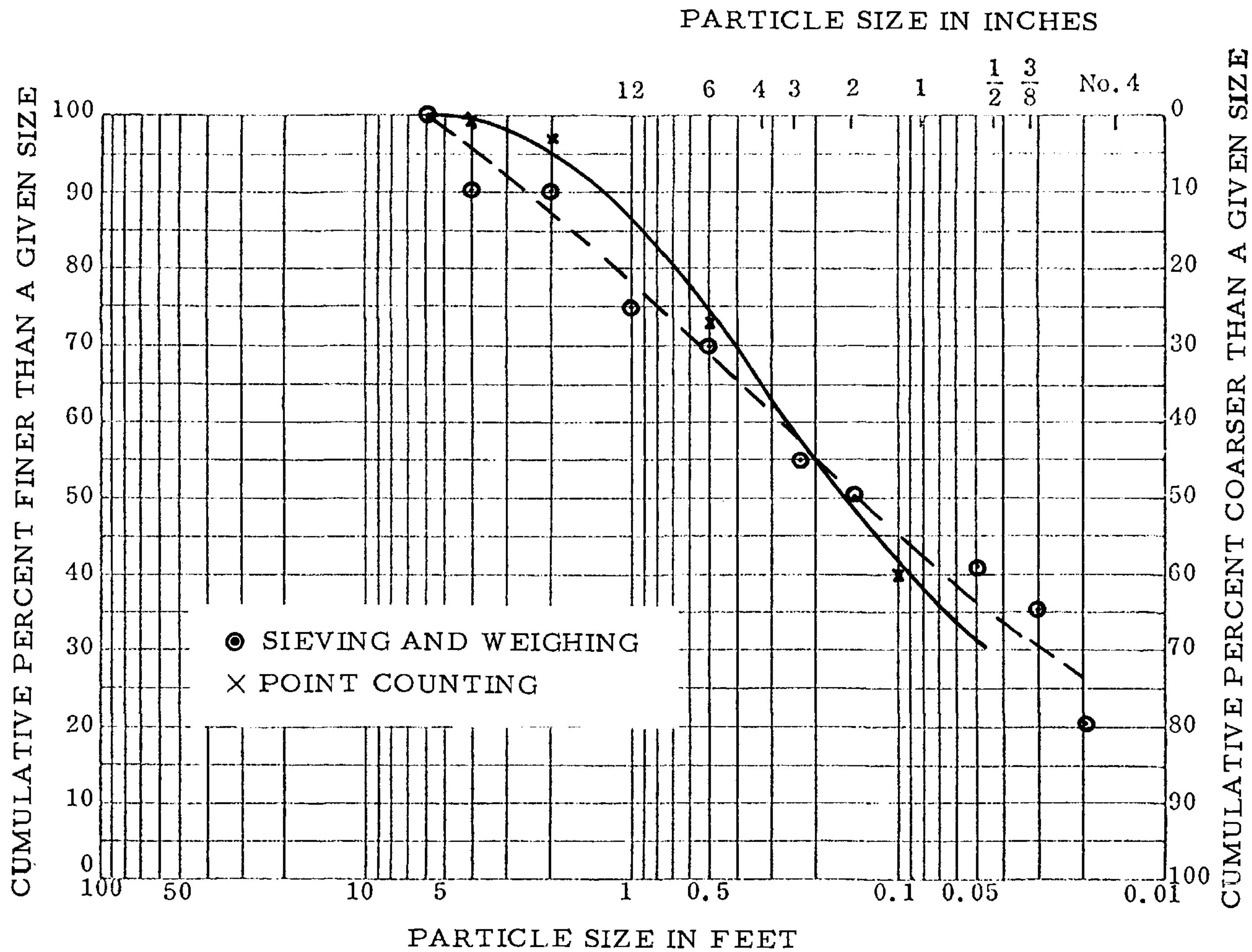


Figure 13. Particle size distribution, CABRIOLET Crater.

1743

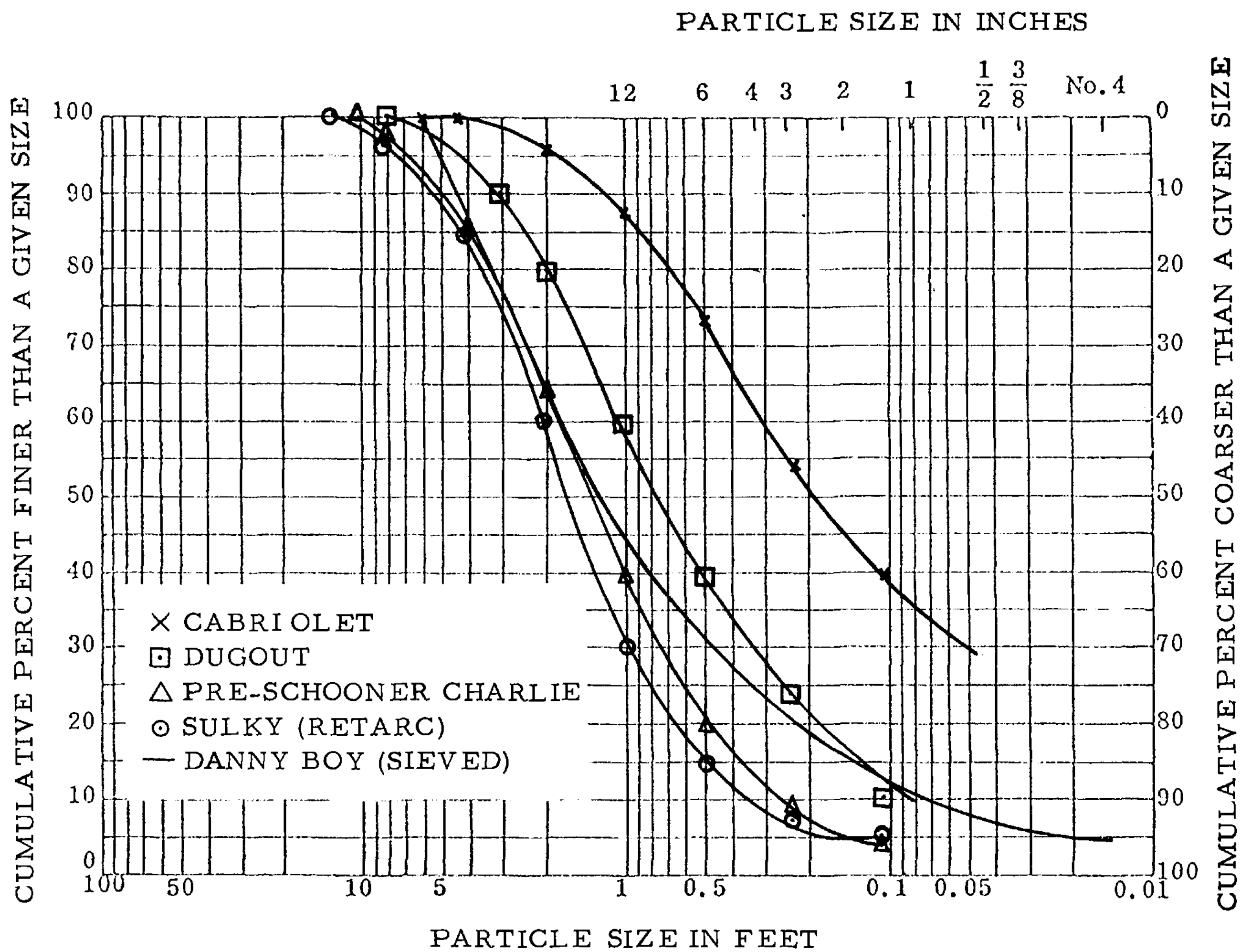


Figure 14. Particle size distribution of five N.T.S. Craters.

sample at a given point in order to avoid allowing personal prejudices to dictate where a "representative" sample should be taken.

Sources of "error" include: the predilection of different operators for selecting pebbles of different sizes thus contributing to differences between sample means; different operators choice of the "b" intermediate axis leading to variation in estimates between samples, and variation between sieving and "b" axis measurements as estimators of the population values.

APPLICATION TO CRATERS

It is apparent that the fit between the size distribution curves obtained at the DANNY BOY Crater (Figure 12) by sieving and weighing, and by modal analysis is quite good. The same comparison of CABRIOLET, Figure 13, is less satisfactory, although the maximum absolute deviation is less than 7%. There is, however, considerable scatter in the sieve data points and the curve, almost a straight line, is not the normal "S" shaped curve one might expect.

Because there is no sieving data to compare with from the other craters, the particle size distributions of the other NTS craters obtained by modal analysis have been plotted on a graph along with a size distribution obtained by sieving ejecta from the DANNY BOY Crater. The data from the other basalt craters seem reasonable in light of the data from the DANNY BOY Crater. As is apparent from visual inspection, the SULKY mound has considerably larger blocks than the craters in the same material.

ACCURACY AND APPLICABILITY

Because samples (measurements) are obtained in different ways by sieving and by the modal analysis, the size distributions obtained by these two techniques will not be exactly the same. However, the real question is, are the observed differences significant? To answer that question we must have an idea of what a "significant" difference should amount to and we probably would like the answer in quantitative terms.

Rogers (1956) has done considerable work investigating the question of how much variation in size distribution can be expected from common geologic sampling techniques. Techniques he investigated were: sieving, size measurement in thin-section, grain mounts and pipette analysis. Rogers concluded that different operators using the different techniques mentioned above should yield means reproducible to within 25% for each of the geometric size classes, i.e., 2", 4", 8", etc., commonly used to designate a set of U. S. Standard Sieves, and standard deviations to within 20%.

The reproducibility of the point sampling technique is certainly within these limits. And, the size distributions obtained by sieving and weighing and by point sampling also lie within the limits expectable for two different techniques. The question whether this stated accuracy is acceptable is a much more subjective question. The answer to this question depends upon the objective of the observations.

The sample size and area determination techniques presented herein are meant to provide the investigator a method by which he can get a preliminary estimate of these parameters. In reality, it is not possible to determine "a priori" how many samples to take to obtain an unbiased and consistent estimate of the size distribution of the clastic material. Generally, it is necessary to take a preliminary sample and test it against some constant probability model like the normal, log-normal or Poisson distribution. If the size distribution does not approximate this model then it is necessary to take more samples or change the sampling technique or the model against which it is being tested. In the case of particle size distributions this approximation can often be accomplished by some suitable transformation of the variate.

CONCLUSIONS

The sampling technique presented herein permits the modal analysis of clastic materials yielding results comparable with those obtained by sieving and weighing of the same materials. It appears that this technique has application to any clastic material from which a representative sample can be obtained. In conclusion it is necessary to point out that the Delesse relation and the point sampling technique provide a very powerful tool for the size analysis of clastic materials and the effects of porosity and layering.

SUMMARY

A sampling technique was developed by Wolman (1954). A small-scale comparative test of this technique was carried out using presized gravel. The sampling technique was reevaluated in light of the results obtained during these tests. The Delesse relation was used to develop a model that theoretically justifies the results achieved. Criteria were established for the number of samples to be taken and the area to cover in sampling. In light of the results achieved, the use of the "b" intermediate axis as a measure of size for clasts seems justified. A test of the new method was accomplished at the AEC Nevada Test Site on several craters. The results achieved during these tests are considered "satisfactory".

REFERENCES

1. Anderson, II, B. D., 1969, An Analysis of the Grid Photography Technique as a Means of Determining the Size Distribution of Crater Fallback and Ejecta, NCG Technical Memorandum 68-15, U. S. Army Corps of Engineers, Nuclear Cratering Group, Lawrence Radiation Laboratory, Livermore, California, p. 24.

2. Chang, Yi-Maw, 1967, "Accuracy of Fossil Percentage Estimation," Jour. Paleo. v. 41, n. 2, p. 500-502.

3. Chayes, F., 1956, Petrographic Modal Analysis, an Elementary Statistical Appraisal, John Wiley & Sons, Inc., New York, 113 p.

4. Griffiths and Kahn, 1967, "Sampling a Geological Population," a pre-meeting short course, American Geological Institute, Washington, D. C.

5. Rogers, J. J. W., 1965, "Reproducibility and Significance of Measurements of Sedimentary Size Distributions," Jour. Sed. Petrol., v. 35, n. 3, p. 722-732.

6. Wolman, M. G., 1954, "A Method of Sampling Coarse River-Bed Materials," Transactions, American Geophysical Union, v. 35, n. 6, 951-956.