Techniques of Water-Resources Investigations of the United States Geological Survey

Optical Method for Determining Particle Sizes of Coarse Sediment

BOOK 5

CHAPTER C3

1969

PRELIMINARY REPORT

OPEN FILE

Techniques of Water-Resources Investigations of the United States Geological Survey

Chapter C3

Optical Method for Determining Particle Sizes of Coarse Sediment

By John R. Ritter and Edward J. Helley

BOOK 5

LABORATORY ANALYSIS

PRELIMINARY REPORT
OPEN FILE

PREFACE

The primary purpose of the manual series "Techniques of Water Resources Investigations" is to provide the personnel of the Water Resources Division with information on procedures that will assist and guide them in planning and executing their work. The series consists of books and chapters, each book being assigned to a specific subject or topic. A chapter describes a particular phase or technique related to the major book topic. A technique may change with time either as experience is gained in its use or as a result of advancement in knowledge or improvement of equipment. When a technique is in a relatively early or development stage, release of information is generally in a preliminary version of one of the chapters. This allows for evaluation and comment on the technique, following which the manual chapter may be released in a final version.

Judgment must be used in deciding how well a technique meets the needs of a particular investigation. A new technique released in preliminary form should generally be used as an alternate means of data collection rather than as a substitute for a more established technique proven through years of experience. A preliminary technique, when used in conjuction with other established techniques, provides a direct means of comparison, and results in the types of data necessary to evaluate effectively the importance of the newer technique. Results of such experience as well as comments on presentation of material in this manual are solicited; these comments will be used in making appropriate revisions as well as in determining the need and justification for final publication of this manual chapter.

Publication of the final edition of each chapter of the manual will be announced in "New Publications of the Geological Survey" and the report (chapter) will be for sale by the Superintendent of Documents.

CONTENTS

SUPPLEMENTAL DATA

ILLUSTRATIONS

CONTENTS

ILLUSTRATIONS—Continued

TABLES

CONTENTS

TABLES—Continued

OPTICAL METHOD FOR DETERMINING PARTICLE SIZES OF COARSE SEDIMENT

By John R. Ritter and Edward J. Helley

ABSTRACT

A particle-size analyzer was used to determine particle sizes of sediment by an optical technique based on an adjustable circle of light which determines the intermediate axis of the sediment particles shown on a photograph. Data from counting particles in various size ranges can be presented either in the form of a particle count or volumetric analysis. Comparison with standard methods of analysis of particles shows that the particle-size analyzer is well suited for measurements of material larger than 8 millimeters in intermediate diameter.

INTRODUCTION

Purpose and Scope

A particle-size analyzer of a type manufactured by Carl Zeiss, Inc. was used to determine particle sizes of sediment shown in a photograph. This technique is particularly useful in analyzing coarse bed material which is difficult to collect for laboratory analysis and is time consuming to measure in the field. The purpose of this report is to describe the photographic technique of analyzing particle sizes of sediment. Emphasis is on the application of the method to coarse bed material in streams. Results of this method were compared with results from standard methods, and the advantages and disadvantages of the method are discussed.

Background

Data on particle sizes of sediments are used by the U.S. Geological Survey in calculating bedload, bed-material load, and total sediment load of streams (Colby, 1963). Grain roughness of a steambed can be determined from size analyses of bed material, and photographs can be used to record long-term changes in bed material. In geological studies, particle sizes of sedimentary deposits are analyzed to determine and describe various depositional environments (Inman, 1952; Folk and Ward, 1957; Friedman, 1961). This report, however, applies mostly to the fluvial environment.

The standard laboratory methods of analyzing particle sizes larger than 62 microns are sieving and determining settling rates of particles in a visual-accumulation tube. Sieve analyses are based on the weight of particles retained by a particular sieve size; visual-accumulation analyses are determined from volume of sediment accumulating at the bottom of a tube in given time intervals assuming that the settling rate of different particle sizes is known (Krumbein and Pettijohn, 1938, p. 91–119). Particles finer than 62 microns usually are analyzed by pipet or hydrometer methods based on the fall velocity and weight of the suspended particles. These last methods are seldom used to analyze bed material as bed material is commonly larger than 62 microns.

Particle sizes larger than 8 mm (millimeters) are difficult to analyze because most laboratories are not equipped to handle coarse sizes and sampling equipment is not easily transported. Wolman's (1954) grid method for field analysis of coarse bed material, consisting of measuring the intermediate axes of 100 randomly selected particles, is time consuming. Furthermore, the analysis is based purely on a particle count related to areal distribution and is not related to the volume or weight of the particles. For example, a grain with an intermediate diameter of 8 mm is weighted the same as one of 128 mm in regard to area covered. The Zeiss particle-size analyzer provides a rapid method of analyzing large numbers of particles over a large surface and does so inexpensively.

DESCRIPTION OF INSTRUMENT

The particle-size analyzer (fig. 1) is semiautomatic and functions in the following manner: Light passing through an iris diaphragm is

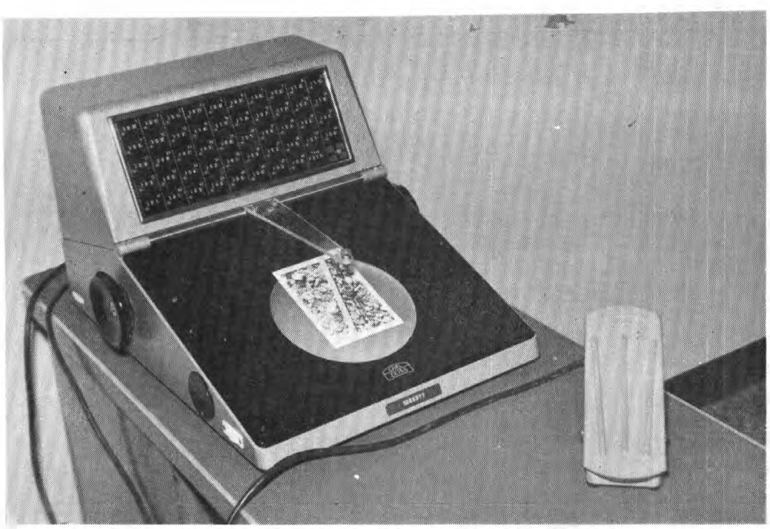


Figure 1.—Zeiss particle-size analyzer

projected to a plexiglass plate (fig. 2) on which a photograph of the particles is placed. Adjusting the diaphragm changes the diameter of the circular spot of light appearing on the photograph. The circular spot is fitted into each particle in the photograph so that its

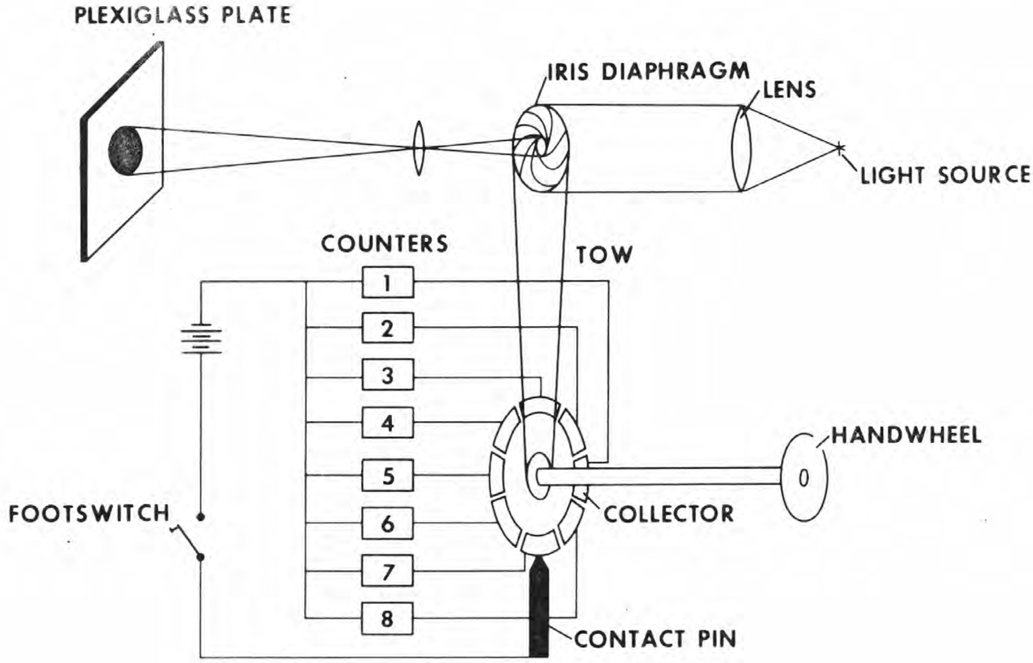


Figure 2.—Diagrammatic sketch of Zeiss particle-size analyzer showing only 8 of the 48 counters.

diameter is equal to the shorter of the two observable axes of the particle. This axis is assumed to be the intermediate or B axis because the shortest or A axis is assumed to be perpendicular to the plane of the photograph—that is, normal to the streambed. The different diameters of the iris diaphragm are correlated by a collector with 48 counters, each of which corresponds to a certain aperature interval of the diaphragm. When the diameter of the spot of light is made equal to the intermediate axis, a foot switch is depressed, the correlated counter is activated, and a puncher marks the counted particle so that the particle will not be recounted. The photograph is shifted until an unmarked particle is above the spot of light and the process is repeated. About an hour is required to analyze 2,000 particles.

The particle-size analyzer has two measuring ranges, 0.4–9.2 mm and 1.2–27.7 mm; however, in the smaller range, measurements are accurate only above 1 mm. The enlargement or reduction of the size of the photograph should be consistent with these limiting values.

Besides the 48 counters that record the particle sizes, the instrument also has a counter that registers the total number of measured particles. Particle sizes can be registered individually or cumulatively by the 48 counters on exponential or linear scales. Thus, eight combinations of counting (table 1) are available, each of which may be appropriate for a particular analyses.

Table 1.—Possible combinations of counting particles with the particle-size analyzer

Combination	Type of particle counting		Type of counting interval		Scale	
	Individual	Cumulative	Linear	Exponential	Standard	Reduced
1	x		x		x	
2	x		x			x
3	x			x	x	
4	x			x		x
5		x	x		x	
6		x	x			x
7		x		x	x	
8		x		x		x

PHOTOGRAPHING BED MATERIAL

Selecting Sample Sites

Generally, photographs of about five randomly selected sites in the channel are sufficient for a representative sample of the bed material. If the sites can be picked at specific reference points, such as under a cableway, the changes in bed material can be recorded on each succesive photograph taken at the sites.

Techniques of Taking Photographs

For photographing bed material, a camera is held or mounted with its lens parallel to the streambed; that is, the picture is taken vertically downward. If held this way, no significant scale distortion should be noted in a photograph. Usually the camera should be 5–6 feet above the bed, but the height depends on the size of the bed material and lens system used. A reference scale, such as a meter stick or stadia rod, is placed in the picture field so that the reduction or magnification factor of the photograph can be determined (fig. 3). Bed material should be photographed when exposure of the streambed is maximum, but suc-

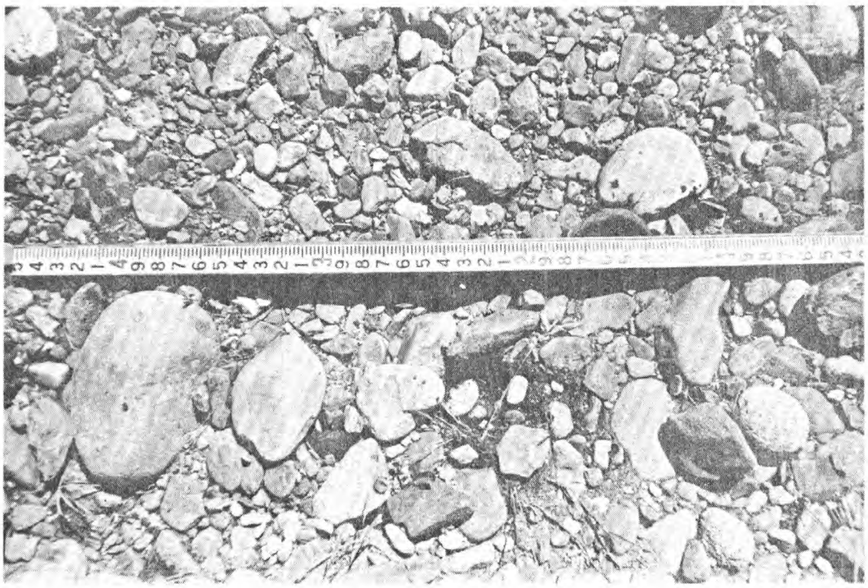


Figure 3.—Bed material, East Fork Chowchilla River at Bailey Flats, Madera County, Calif. Scale is in tenths of feet.

cessful measurements have been made on photographs taken through clear water as much as 2 feet deep without significant refraction.

The photographs are printed on single weight paper so that the circle of light from the particle-size analyzer is not distorted. Size of the photographs depends on the coarseness of the bed material and the maximum size of the measuring circle light of the particle-size analyzer. Generally, postcard size prints (3 x 5 inches) are large enough for bed material of pebbles and cobbles.

Particles in the photograph are counted with the particle-size analyzer and registered according to size on the 48 counters. These data are tabulated on standard evaluation sheets provided by the manufacturer of the analyzer, and the size intervals of the analyzer are adjusted to true sizes by the magnification or reduction factor of the photograph.

The particle-size distribution is determined from the number of particles in each size range. Usually the distribution is biased toward the smaller particles, which tend to be more numerous but occupy less space. However, if it is related to areal distribution, this method of analysis can be used in the manner of the Wolman method mentioned above.

Another method can be used to obtain a relation of the weight of the particles to particle size, assuming that each particle has the same specific weight. This method is adapted and modified from Pashinskiy (1964) and is based on the volume of the particles. The volume is calculated by multiplying the cube of the intermediate axis of the particle by a coefficient determined by the particle shape (table 2). The shape can be determined visually or calculated from field measurements of the long and short axes of particles in the same size interval. The shape of the particle (table 3) is determined from the coefficient of flatness B, defined as $\frac{d\text{max}}{d\text{min}}$

where $d$max and ^{d}min = the long and short axes.

A quick estimate of the weight of a particle in grams can be made by multiplying the cube of its maximum diameter or long axis in centimeters by the shape coefficient (fig. 4A). Estimates for extremely flat particles by this method are not as good as those for other shapes of particles, but still they are reasonably close (fig. 4B). Possibly some of the scatter of the points in figure 4A can be attributed to the differences in specific weights of the rocks.

Pashinskiy (1964) has shown in his studies that the average ratio of the length of longitudinal axis to that of the intermediate axis is 1.3 for prismatic and angular particles, 1.4 for elliptical particles, and 1.5 for flattened particles. These ratios were consistent with those for the rocks indicated in figure 4 except for the flattened rocks collected from the Chowchilla River, which had an average ratio of 1.7. Because the relation between long and intermediate axes is relatively constant, the intermediate axis can be used to relate the volume of the rock to its weight.

Table 2.—Values of shape coefficients

(From Pashinskiy, 1964)

Particle shape	Shape coefficient
Flattened	0.4
Elliptical and spherical	.5
Prismatic and angular	.6

Table 3.—Values of coefficient of flatness for particles of different shapes

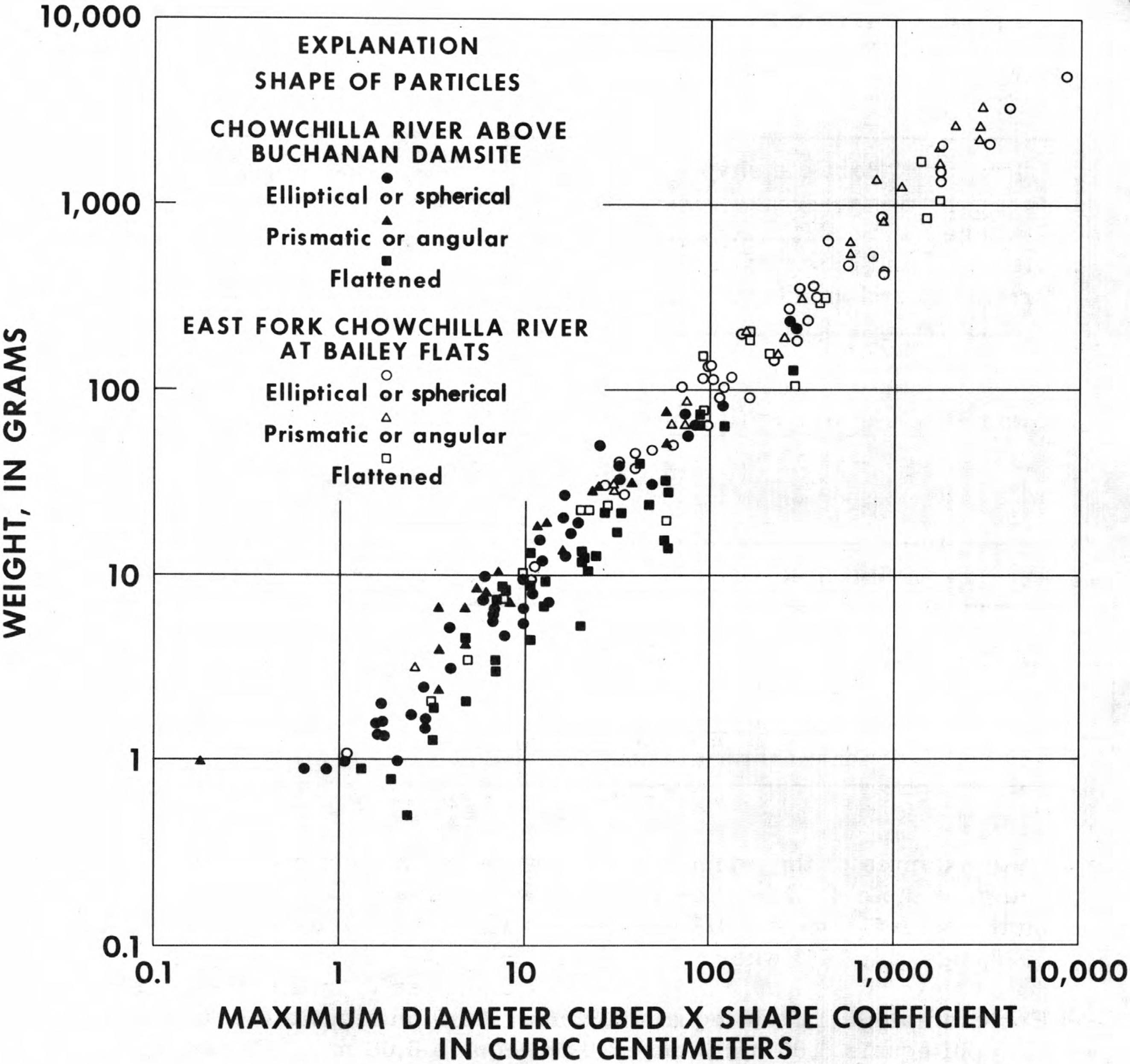
(From Pashinskiy, 1964)

Particle shape	Coefficient of flatness
Spherical	1.0–1.2
Prismatic and angular	1.2–2.0
Elliptical	2.0–3.0
Flattened	>3.0

An example of the computations for the volumetric method is shown in table 4. The size intervals were established as the millimeter equivalents of half phi intervals (Krumbein and Pettijohn, 1938, pgs. 84, 244) where $\phi = -\log_2 D$

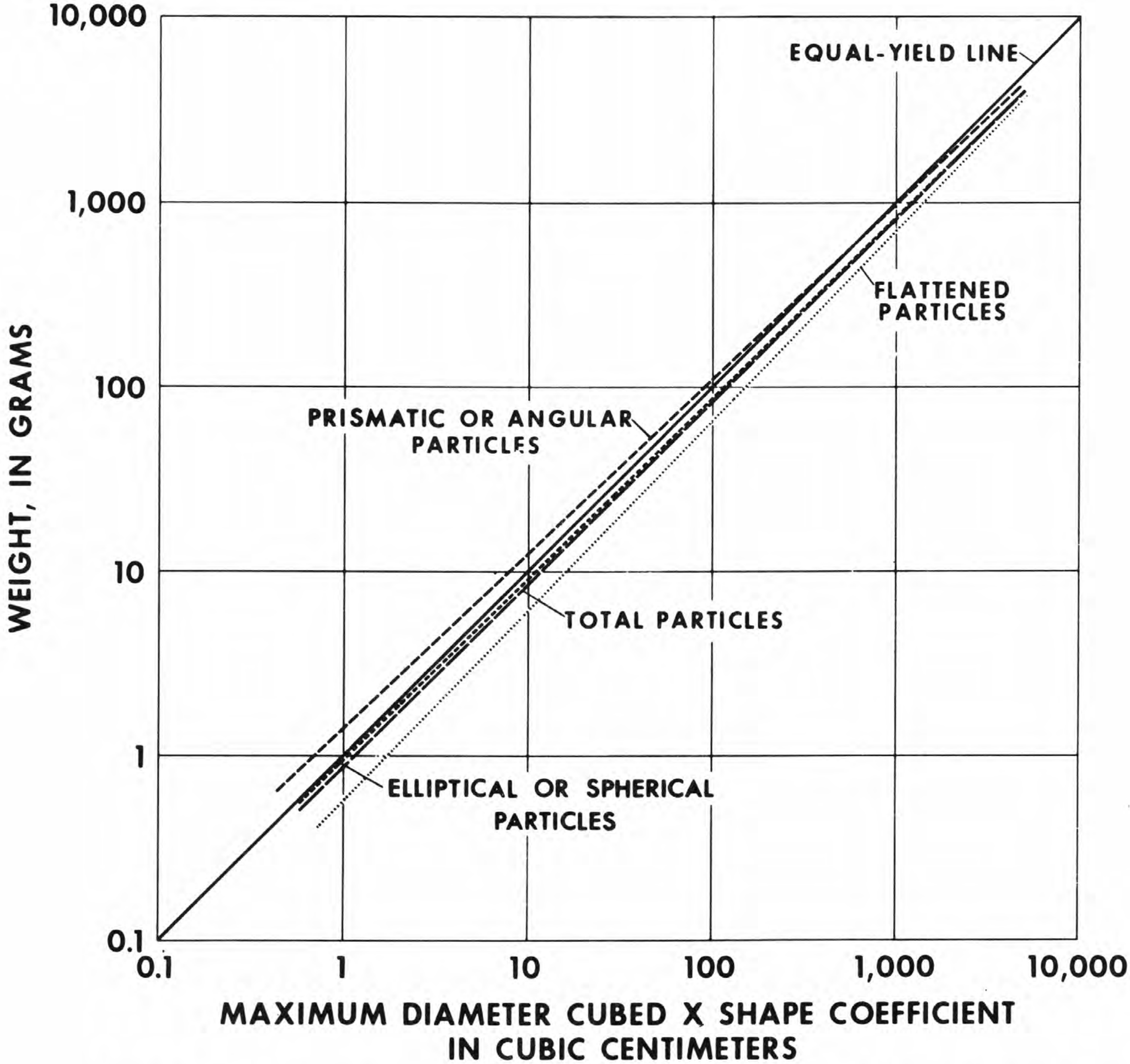
D = diameter in millimeters.

For example: -1.5 phi equals 2.83 mm, -2.0 phi equals 4.00 mm, -2.5 phi equals 5.66 mm, and -3.0 phi equals 8.00 mm. However, the upper limit of 66.5 mm was determined by the largest particle in the photograph. The number of particles in each size interval, as determined with the particle-size analyzer, was determined for each photograph.



A.-- Relation of individual particles collected from gravel bars in the Chowchilla River above Buchanan damsite and East Fork Chowchilla River at Bailey Flats.

Figure 4.--Relation of weight of particle to its maximum diameter cubed times its shape coefficient.



B.--Relation of particles of different shapes, by regression lines based on the least squares method.

Figure 4.--(continued)

Table 4.—Example of volumetric method of calculating particle-size distribution from samples of gravel bar at Chowchilla River above Buchanan damsite, California

Size interval (mm)	Number of particles					Mean diameter of interval (mm)	Cube of mean diameter (cm^3)	Shape coeffi-cient	Volume of mean particle of interval (cm^3)	Volume of all particles of interval (cm^3)	Cumu-lative volume (cm^3)	Cumu-lative percent
	Photo 1	Photo 2	Photo 3	Photo 4	Total							
2.83					79,000	1.4	0.003	0.5	0.0015	120	120	1.3
2.83–4.00	9	40	12	14	75	3.4	.040	.5	.020	--------	120	1.3
4.00–5.66	100	169	139	75	483	4.8	.113	.5	.056	30	150	1.6
5.66–8.00	260	259	255	174	946	6.8	.319	.46	.147	140	290	3.0
8.0–11.3	348	251	327	144	1,070	9.6	.889	.5	.450	480	770	8.2
11.3–16.0	320	220	252	124	916	13.6	2.52	.5	1.26	1,150	1,920	20.3
16.0–22.6	124	110	87	109	430	19.3	7.19	.5	3.60	1,550	3,470	36.7
22.6–32.0	39	58	26	79	202	27.3	20.3	.48	9.74	1,970	5,440	57.6
32.0–45.2	7	27	9	33	76	38.6	57.5	.5	28.8	2,190	7,630	80.7
45.2–64.0	1	3	4	13	21	54.6	163	.45	73.4	1,540	9,170	97.0
64.0–66.5				2	2	65.2	277	.5	138	280	9,450	100

The number of particles smaller than the least size measurable by the analyzer (2.83 mm, in the example) was estimated by using a grid of one hundred points superimposed on the photograph. The total number of these points falling on particles smaller than those that could be measured with the particle-size analyzer gives an estimate of the percentage of the area of the photograph covered by the fine particles. Table 5 is an example of the method used for estimating the number of these particles. The area represented in each photograph was determined and then multiplied by the percentage of the area covered with the fine material. The average intermediate axis of the particles forming this material was assumed to equal one half of the smallest size measurable by the analyzer. The area covered by one particle was calculated by squaring the average intermediate axis. The figure thus derived is divided into the total area covered by the fine particles to calculate the total number of fine particles.

The mean diameter of particles in each size interval is the arithmetic average of the internal limits. The shape coefficient of the particles in each size interval was calculated from field observations of the particle shapes. Note in table 4 that the shape coefficient is about equal for every interval. By multiplying the cube of the average intermediate axis of the particle in each size interval by the shape coefficient, the mean volume of the individual particles of the interval was calculated. The volume of all particles of the interval was calculated by multiplying the mean volume of the individual particles by the total number of particles in the interval. This final figure should be comparable to that of a sieve analysis of the same sample, assuming a constant specific weight of the sediment.

Table 5.—Example of calculation of number of particles smaller than the least size measurable by the particle-size analyzer

Photograph	Percentage of area covered by particles smaller than 2.83 mm	Area represented on photograph (ft^2)	Area covered by particles smaller than 2.83 mm (cm^2)
1	8	5.45	410
2	5	4.50	210
3	13	4.95	600
4	8	4.80	360
Total area covered by particles smaller than 2.83 mm			1,580 cm^2

Average size of the particles smaller than 2.83 mm is assumed to be 1.4 mm and average area covered by this particle is 1.4^2 or 2.0 mm^2.

Therefore, total number of particles smaller than 2.83 mm is $\frac{1580cm^2}{.02cm^2}$ or 79,000.

The procedure in using the volumetric method of determining grain-size distributions, after the particles have been counted and the size classified on the particle-size analyzer, can be summarized as follows (See table 4):

1. Tabulate data on evaluation sheets
2. Correct size limits on evaluation sheet by multiplying them by the magnifications or reduction factor of the photograph
3. Determine the volume of grains finer than the smallest size measurable by the analyzer (See table 5). To do this
   a. Determine area of photograph
   b. With 100-point grid determine the percentage of area covered by fine material (number of points falling on fine material)
   c. Multiply area of photograph by percentage of area covered by fine material
   d. Determine average size of fine material by dividing smallest size measurable by analyzer by two
   e. Square average size
   f. Divide area covered by fine particles by square of average size to obtain number of fine particles
4. Group and sum each number of particles into desired size intervals and tabulate as shown in table 4
5. Determine mean diameter of each size interval
6. Cube mean diameter of size intervals
7. Multiply the cube of the mean diameter of each interval by the shape coefficient to obtain the volume of the mean particle of each interval
8. Multiply volume of the mean particle of each interval by the number of particles in each interval to determine the volume of all particles within that interval
9. Cumulate volumes
10. Determine cumulative percent

The appendix shows a computer program list which performs the above procedure given the data from the evaluation sheets (1) and reduction or magnification factor of the photograph (2).

RESULTS

The particle-size analyzer was used to analyze samples of sedimentary particles of different sizes, such as sand, cobbles, boulders, and mixtures of sand and coarser material for comparison with other methods of analysis.

The first comparison was made using cobbles and boulders placed on the bed of Blue Creek, a northwestern California mountain stream, to study bed-material movement. The rocks were measured first by hand in the field and then by the particle-size analyzer in the office from photographs. Each data point (fig.5) represents the average

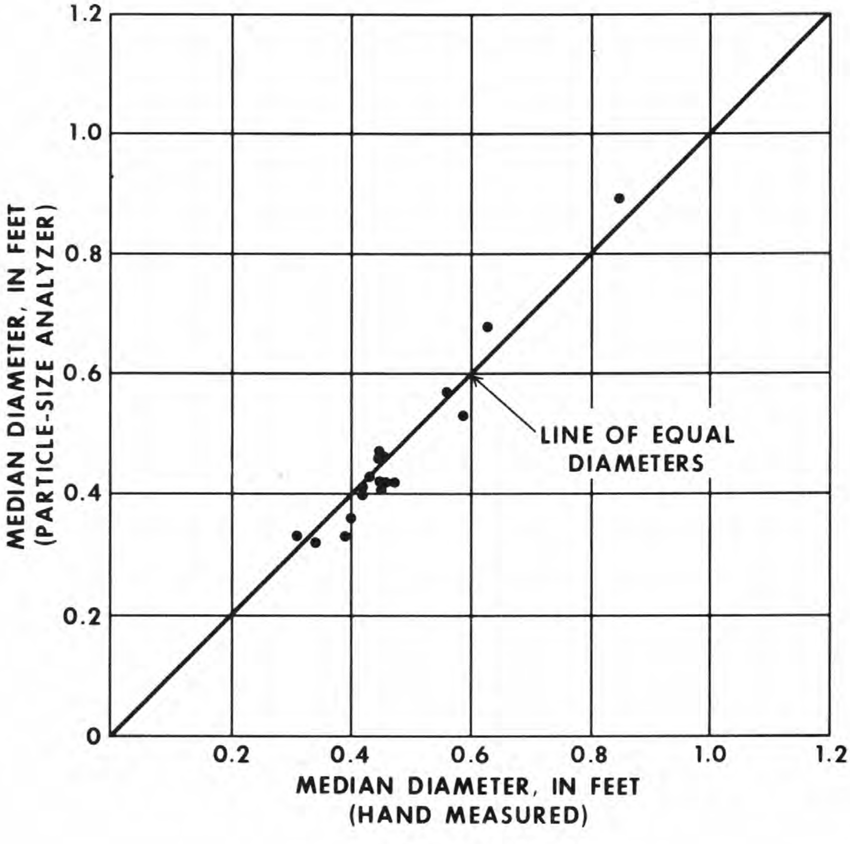


Figure 5.--Relation of field measurements to measurements with the particle-size analyzer of bed material from Blue Creek near Klamath, California.

measured intermediate diameter of ten or more particles. The distribution was based on a particle count rather than a weight or volumetric analysis. Figure 5 shows that the medians of the sets of analyses correlate favorably even though some of the rocks were photographed through water.

Three sand and gravel samples were volumetrically analyzed with the particle-size analyzer. Two were collected from beaches near Eureka, Calif., and one from Ash Slough near Chowchilla, Calif. All samples were analyzed by sieve and compared to the volumetric analysis. For these samples, the shape coefficient was considered to be equal for all ranges of sizes. Figure 6 compares results of the two methods of analysis. For each of the three samples the median diameters determined by sieve analyses are smaller—almost half in two samples—than those determined by the particle-size analyzer. The shapes of the curves are dissimilar; the differences in the percentages of the smaller sizes of the sand are greater than the differences in the coarser sizes.

For beach sample A an analysis of 1,000 particles by the volumetric method was compared with that of the total sample in the photograph (3,551 particles) by the same method. The results were quite similar—much more so than analyses by a direct particle count (fig. 7).

Samples from two gravel bars in the Chowchilla River, Calif., were analyzed by the Wolman and volumetric methods. At one bar 100 particles were selected by a random-walk technique; at the other, by a grid system. Although only the intermediate axis is usually measured in the Wolman method, three axes of each particle were measured and its weight recorded. Particle-size distributions based on the number of particles finer than progressively increasing lengths of the intermediate axis versus the percent of particles and the weights of the particles were drawn. These two distributions are quite different (fig. 8) and indicate that analyses based on weight, such as by sieving, are not closely correlative with analyses by particle counts.

A similar approach was used with the particle-size analyzer. Four photographs were taken of the sediments of the gravel bar in the Chowchilla River above Buchanan damsite (figs. 9 and 10) and five of the bar in the East Fork Chowchilla River at Bailey's Flat (fig. 11). Sites for the photographs were selected randomly. The median particle size determined by weight analysis of the 100 particles measured in the field and that determined by volumetric analysis with the particle-size analyzer differ by less than 20 percent in each case.

Analyses by the volumetric method do not agree closely with those by the sieve method. Both the sieve and volumetric methods are based on the measurement of the intermediate axis of the particles; and if it is assumed that particles in each size interval have equal specific weights, volume is then directly comparable to weight.

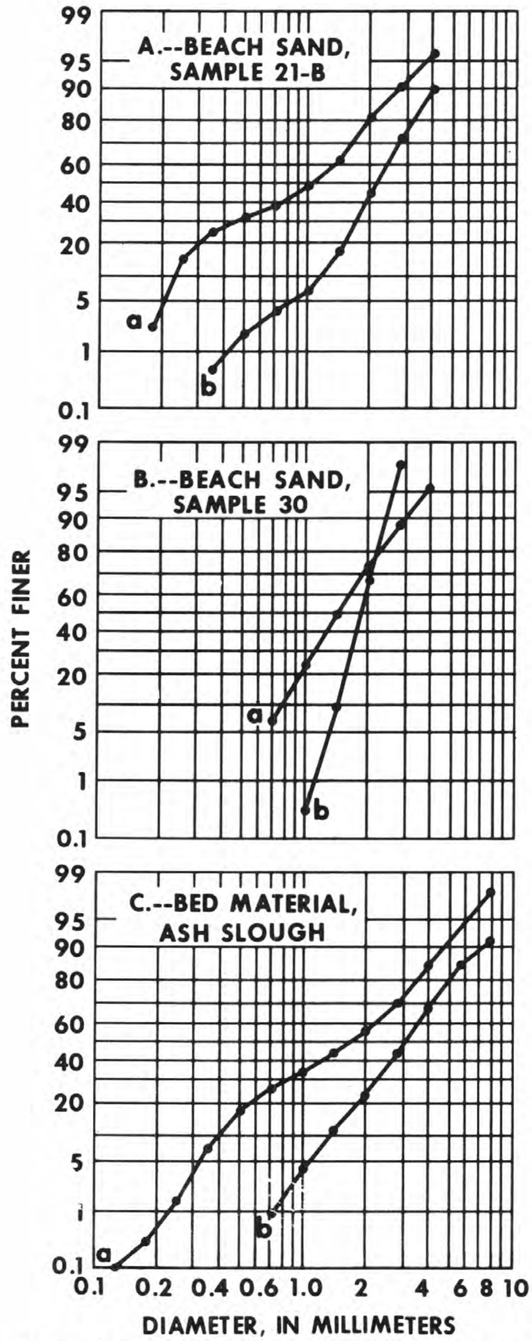


FIGURE 6 COMPARISON OF PARTICLE-SIZE DISTRIBUTIONS FOR THREE SAND SAMPLES DETERMINED BY (A) SIEVE ANALYSIS AND (B) VOLUMETRIC ANALYSIS WITH PARTICLE-SIZE ANALYZER

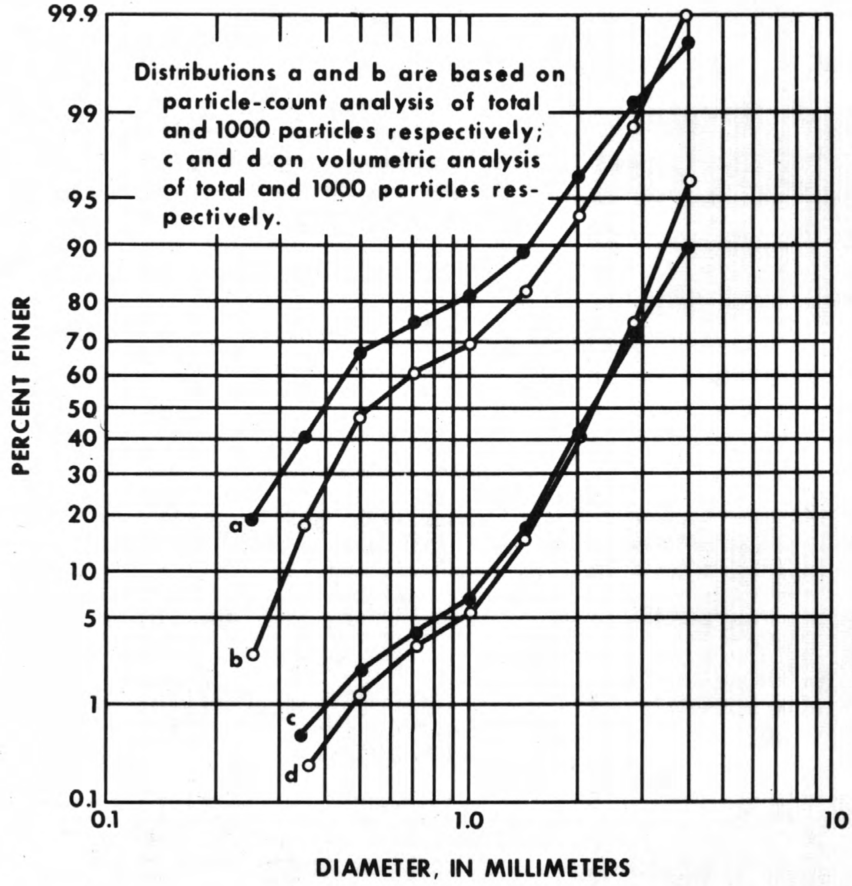


Figure 7.-- Particle-size distributions based on measurements of 1000 particles and total number of particles in sample.

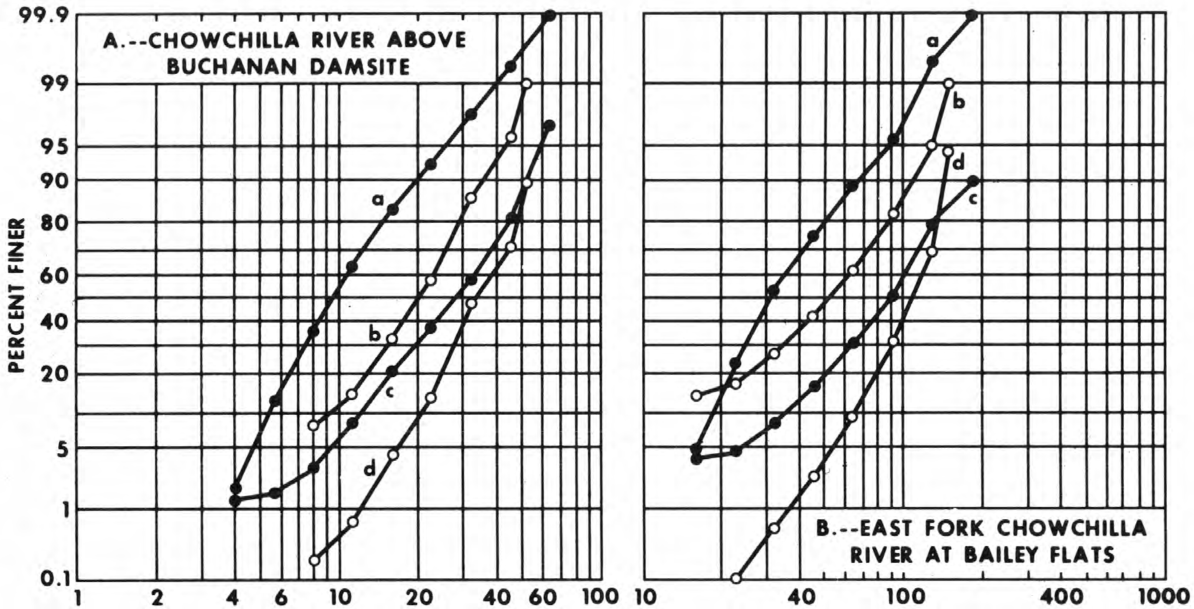


Figure 8 --Comparison of particle-size distribution of two gravel bars determined by the Wolman method and the particle-size analyzer.

Distributions a and c are based on a particle count and a volumetric analysis made with the particle-size analyzer; distributions b and d are based on a particle count related to areal distribution and weight of the counted particles, respectively, by the Wolman method.

Figure 9.—Gravel bar, Chowchilla River above Buchanan damsite, Madera County, Calif., May 1967.

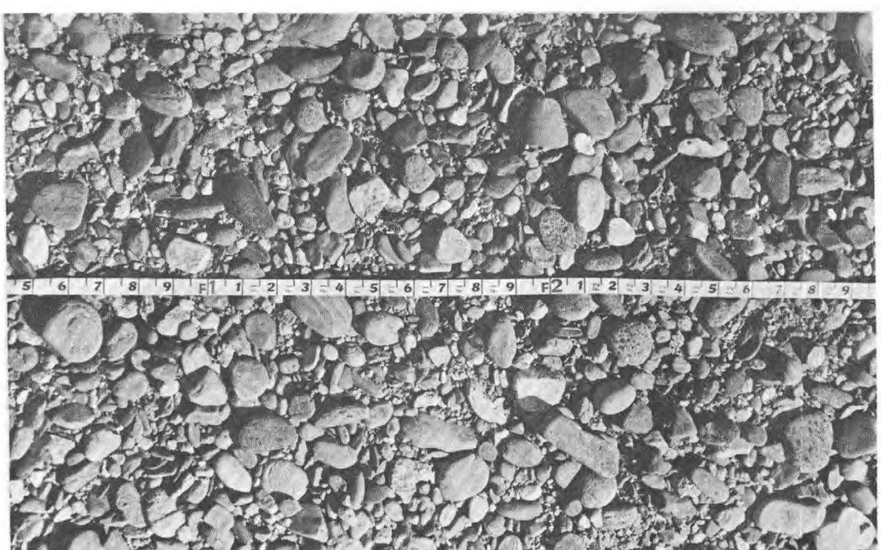


Figure 10.—Bed material, Chowchilla River above Buchanan damsite, Madera County, Calif., May 1967. Scale is in tenths of feet.

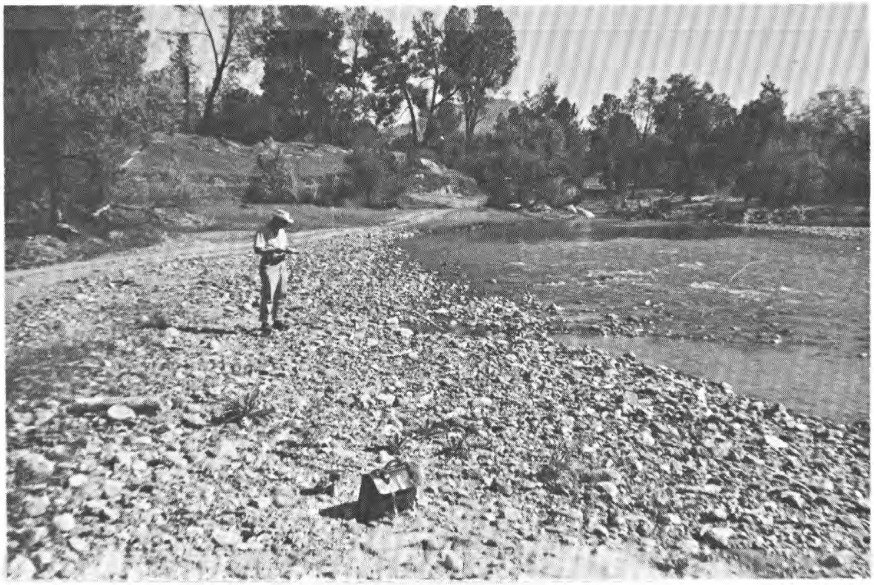


Figure 11.—Gravel bar, East Fork Chowchilla River at Bailey Flats, Madera County, Calif., May 1967.

DISCUSSION

Table 6 shows a comparison of particle-size analyses of sands and gravels made by the volumetric method with analyses made by other methods. The deviations are based on the differences from the volumetric analyses. The largest deviation was between the sieve analyses and volumetric analysis of beach sand B. Generally, in the coarser fractions, the volumetric analysis tended to yield higher values than the sieve analyses. The analyses of the Ash Slough sample, particularly, should have been comparable as every particle (8,030) was counted; however, the median particle size determined by the volumetric method was 0.90 mm larger than that determined by sieving.

Pashinskiy (1964, p. 284) found a similar relation in his work. Perhaps some of the differences can be attributed to the estimation of the number of fine particles; considering the average size of the particles as less than half the size interval increases the estimate of the number of particles but reduces the estimate of their volumes. The assumption of equal shape coefficients for all size intervals in the sand samples produces some error, even though visual inspection of the sand grains suggests that their shapes are approximately the same. Moreover, Poole (1957) has shown that analyses of sands by settling tube give a larger median diameter (about 0.5ϕ coarser) than do sieve analyses. He attributed much of this difference to the fundamental differences in the methods, but pointed out

Table 6.—Comparison of distributions obtained by volumetric

[Figure given, unless otherwise stated,

Size interval (millimeters)	Beach sand, A			Beach sand, B			Bed material, Ash Slough		
	Volumetric	Sieve	Deviation (percent)	Volumetric	Sieve	Deviation (percent)	Volumetric	Sieve	Deviation (percent)
<0.35	0.2	24.5	+24.3	------	------	------	------	------	------
0.35–0.50	1.0	7.2	+6.2	------	------	------	------	------	------
0.50–0.71	1.8	5.4	+3.6	------	------	------	[a]0.9	[a]26.0	+25.1
0.71–1.00	2.4	9.6	+7.2	[b]0.3	[b]22.2	+21.9	3.0	7.4	+4.4
1.00–1.41	10.3	15.0	+4.7	9.0	25.8	+16.8	6.6	9.7	+3.1
1.41–2.00	26.2	18.7	-7.5	56.2	25.0	-31.2	12.4	12.4	0
2.00–2.83	32.7	9.9	-22.8	32.2	15.0	-17.2	20.3	13.6	-6.7
2.83–4.00	21.7	5.3	-16.4	2.3	7.4	5.1	24.1	15.3	-8.8
4.00–5.66	3.7	4.4	+.7	------	4.6	+4.6	17.8	13.4	-11.1
5.66–8.00	------	------	------	------	------	------	6.7		
8.00–11.3	------	------	------	------	------	------	8.2	2.2	-6.0
11.3–16.0	------	------	------	------	------	------	------	------	------
16.0–22.6	------	------	------	------	------	------	------	------	------
22.6–32.0	------	------	------	------	------	------	------	------	------
32.0–45.2	------	------	------	------	------	------	------	------	------
45.2–64.0	------	------	------	------	------	------	------	------	------
64.0–90.5	------	------	------	------	------	------	------	------	------
90.5–128	------	------	------	------	------	------	------	------	------
128–181	------	------	------	------	------	------	------	------	------
181–256	------	------	------	------	------	------	------	------	------
Maximum deviation (percent)	------	------	+24.3	------	------	-31.2	------	------	+25.1
Mean deviation (percent)	------	------	10.4	------	------	16.1	------	------	8.2

[a]Includes all sizes finer than 0.71 millimeters.

[b]Includes all sizes finer than 1.00 millimeters.

analysis with those obtained by other methods of analysis are in percent of total sample.]

Gravel bar, Chowchilla River above Buchanan damsite							Gravel bar, East Fork Chowchilla River at Bailey Flats						
Volumetric	Wolman areal distribution	Deviation from volumetric (percent)	Wolman weight	Deviation from volumetric (percent)	Particle count, particle-size analyzer	Deviation from volumetric (percent)	Volumetric	Wolman areal distribution	Deviation from volumetric (percent)	Wolman weight percent	Deviation from volumetric (percent)	Particle count, particle-size analyzer	Deviation from volumetric (percent)
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
[c]1.3	[c]2.0	+0.7	-----	-1.3	[c]1.8	+0.5	-----	-----	-----	-----	-----	-----	-----
.3	-----	-.3	-----	-.3	10.8	+10.7	-----	-----	-----	-----	-----	-----	-----
1.4	5.0	+3.6	0.2	-1.2	23.0	+21.6	-----	-----	-----	-----	-----	-----	-----
5.2	7.0	+1.8	.5	-4.7	25.4	+20.2	-----	-----	-----	-----	-----	-----	-----
12.1	18.0	+5.9	3.4	-8.7	21.7	+9.6	[d]3.8	[d]14.0	+10.2	-----	-3.8	[d]4.8	+1.0
16.4	25.0	+8.6	9.5	-6.9	10.1	-6.3	.7	3.0	+2.3	0.1	-.6	19.1	+18.4
20.9	29.0	+8.1	32.8	+11.9	4.6	-16.3	3.7	10.0	+6.3	.5	-2.2	28.8	+25.1
23.1	10.0	-13.1	23.9	+.8	1.8	-21.3	8.0	15.0	+7.0	2.0	-6.0	22.3	+14.3
16.3	4.0	12.3	29.7	+13.4	.5	-15.8	14.0	20.0	+6.0	6.6	-7.4	14.0	0
3.0	-----	-3.0	-----	-3.0	.1	-2.9	19.9	20.0	+.1	21.7	+1.8	6.9	-13.0
-----	-----	-----	-----	-----	-----	-----	28.4	13.0	-15.4	37.9	+8.5	3.6	-24.8
-----	-----	-----	-----	-----	-----	-----	11.2	5.0	-6.2	31.2	+20.0	.4	-10.8
-----	-----	-----	-----	-----	-----	-----	10.3	-----	-10.3	-----	-10.3	.1	-10.2
-----	-----	+13.4	-----	+13.4	-----	+21.6	-----	-----	-15.4	-----	+20.0	-----	+25.1
-----	-----	5.2	-----	5.2	-----	12.5	-----	-----	7.1	-----	6.5	-----	13.1

[c]Includes all sizes finer than 4.00 millimeters.
[d]Includes all sizes finer than 16.00 millimeters.

Table 7.—Particle-size parameters determined from different methods of analysis

Particle-size parameters	Beach sand A		Beach sand B		Bed material Ash Slough		Gravel bar, Chowchilla River above Buchanan damsite				Gravel bar, East Fork Chowchilla River at Bailey Flats			
	Volumetric	Sieve	Volumetric	Sieve	Volumetric	Sieve	Volumetric	Wolman particle count	Wolman weight percent	Particle count particle-size analyzer	Volumetric	Wolman particle count	Wolman weight percent	Particle count, particle-size analyzer
Median	-1.10ϕ	-0.10ϕ	-0.90ϕ	-0.55ϕ	-1.65ϕ	-0.75ϕ	-4.85ϕ	-4.35ϕ	-5.05ϕ	-3.30ϕ	-6.50ϕ	-5.70ϕ	-6.70ϕ	-5.00ϕ
Graphic mean	-1.10ϕ	+.20ϕ	-.90ϕ	-.55ϕ	-1.60ϕ	-.75ϕ	-4.75ϕ	-4.35ϕ	-5.05ϕ	-3.30ϕ	-6.50ϕ	-5.60ϕ	-6.70ϕ	-5.00ϕ
Inclusive graphic standard deviation	.70ϕ	1.40ϕ	.30ϕ	.80ϕ	.85ϕ	1.30ϕ	.80ϕ	.70ϕ	.50ϕ	.75ϕ	.90ϕ	1.90ϕ	.50ϕ	.70ϕ
Inclusive graphic skewness	+.10	-.10	0	+.10	-.05	-.15	-.20	-.05	-.10	+.10	-.20	-.40	-.10	+.10
Graphic kurtosis	1.20	.75	1.00	.55	1.05	.80	.90	1.15	.65	1.00	1.10	2.60	.80	1.00

Table 8.—Classification of sorting, skewness, and kurtosis
(From Folk and Ward, 1957)

Inclusive graphic standard deviation	Classification	Inclusive graphic skewness	Classification	Graphic kurtosis	Classification
<0.35ϕ	Very well sorted	+1.00 to +.30	Strongly fine-skewed	<0.67	Very platykurtic
0.35ϕ–.50ϕ	Well sorted	+.30 to +.10	Fine-skewed	0.67–0.90	Platykurtic
.50-.71	Moderately well sorted	+.10 to -.10	Near-symmetrical	.90-1.11	Mesokurtic
.71-1.0	Moderately sorted	-.10 to -.30	Coarse-skewed	1.11-1.50	Leptokurtic
1.0-2.0	Poorly sorted	-.30 to -1.00	Strongly coarse-skewed	1.50-3.00	Very leptokurtic
2.0-4.0	Very poorly sorted	----------------	----------------	>3.00	Extremely leptokurtic
≥4.0	Extremely poorly sorted	----------------	----------------	----------------	----------------

that part of the variation was caused by the rated sieve openings being smaller than the effective openings. In this study the analyses of sand by the volumetric method were not compared with those by settling tube.

In this study, the volumetric analyses compared most closely with the analyses of weights of 100 particles selected by the Wolman method. Results of analyses by the particle-count methods are greatly changed by the number of particles counted. The particle count by the particle-size analyzer for each gravel bar is based on analysis of material greater than the smallest measurable size, but still indicates much finer sizes than that of the 100-particle count of the Wolman method which includes sand. For gravels, the volumetric method of analysis appears to be the best because of the larger number of particles used and the greater extent of the area sampled.

Particle-size parameters determined from the particle-size distributions of each analysis are given in table 7 and explained in table 8. The parameters, calculated according to the equations of Folk and Ward (1957) are based on phi units. The median and graphic mean are measures of the average grain size. For the sand samples, the differences in median between the two methods of analysis average 0.75ϕ. Inclusive graphic standard deviation is a measure of sorting of sediments; inclusive graphic skewness, a measure of asymmetry; and graphic kurtosis, a measure of peakedness of a curve. The parameters from the volumetric method indicate that the Ash Slough bed material would be characterized as gravel, moderately sorted, near symmetrical, mesokurtic. The same sample from the sieve analysis would be described as very coarse sand, poorly sorted, coarse skewed, platykurtic. Thus, in describing sediments the method of analysis must be known, as a given sediment can have different descriptions based on different methods of analysis.

CONCLUSIONS

Although the volumetric analysis of sandy bed material with the particle-size analyzer does not agree closely with analysis by the standard sieving technique, the volumetric analysis is better for gravel and coarser bed material than the Wolman areal method of analysis. Because of the speed with which the analysis can be made and the quantity of material used in the volumetric analysis, this method appears to be the best available for gravel. Furthermore, modern techniques of rapid data processing are applicable to the volumetric method of analysis. A computer program for processing particle-size data by the volumetric method has been written and used successfully.

The advantages of using the particle-size analyzer for analyses of bed material are:

1. It is a fast technique for analyzing gravel, especially if used in conjunction with modern data-processing techniques.
2. Little equipment is needed in the field.
3. Samples do not have to be collected.
4. Photographs taken at different times from the same reference point provide a historical record of bed-material changes.
5. The method is simple and can be easily learned.
6. The number of particles analyzed is restricted only by the number of particles in a photograph.
7. More bed material can be analyzed with the volumetric method than can readily be treated with sieves or the Wolman method.

The disadvantages are:

1. Only the top layer of bed material can be analyzed.
2. For sand samples, the analyses overestimate the number of coarser particles.
3. Volumetric analysis of sand is slower than sieve analysis.
4. Specific weights of the particles are not considered.
5. The assumption that the intermediate axis of the particle is always observable is sometimes erroneous.

We conclude that the particle-size analyzer provides a distinct advantage in enabling a rapid, inexpensive, and areally extensive size analysis of very coarse bed material (greater than 8 mm). Further, use of the Zeiss particle-size analyzer should be made in determining the relation of grain roughness with the hydraulic behavior of rivers.

REFERENCES CITED

Colby, B.R., 1963, Fluvial sediments—a summary of source, transportation, deposition and measurement of sediment discharge: U.S. Geol. Survey Bull. 1181-A, 47 p.

Folk, R.L., and Ward, W.C., 1957, Brazos River bar, a study in the significance of grain-size parameters: Jour. Sed. Petrology, v. 27, no. 1, p. 3–26.

Friedman, G.M., 1961, Distinction between dune, beach, and river sands from their textural characteristics: Jour. Sed. Petrology, v. 31, no. 4, p. 514–528.

Inman, D.L., 1952, Measures for describing the size distribution of sediments: Jour. Sed. Petrology, v. 22, no. 3, p. 125–145.

Krumbein, W.C., and Pettijohn, F.J., 1938, Manual of sedimentary petrography: New York, N.Y., Appleton-Century-Crofts, Inc., 532 p.

Pashinskiy, A.F., 1964, Experience of the study of alluvial deposits of the Psezuapse River: Soviet Hydrology; Selected Papers, no. 3, p. 276–290, translation from the Trans. State Hydrol. Inst. (Trudy GGI), no. 111, p. 156–173.

Poole, D.M., 1957, Size analysis of sand by a sedimentation technique: Jour. Sed. Petrology, v. 27, no. 4, p. 460–468.

Wolman, M.G., 1954, A method of sampling coarse river-bed material: Am. Geophys. Union Trans, v. 35, no. 6, p. 951–956.

SUPPLEMENTAL DATA

COMPUTER PROGRAM FOR DETERMINING GRAIN-SIZE DISTRIBUTION USING THE VOLUMETRIC METHOD

```
       JOB CARD
// EXEC FORTGCLG
//FORT.SYSIN  DD *
C**** PARTICLE SIZE DISTRIBUTION ****
C       C.R.GOODWIN - PROGRAMMER
       INTEGER PHOTO(500)
       REAL CPART(50),LOC(20),DATE(5),ISIZE(500),FSIZE(500),MAG(500),
      1PLTIS(500),NPART(50,50),MEAND(50,40),MEAND3(50,40),MEANV(50,40),
      2INPART(50,40),IV(50,40),CUMV(50,40),PCV(50,40),CUMPCV(50,40),
      3INTVL(50,40,2),SH(50,40),S(3),SIZE(50,50),TV(500),ISIZEM,ISIZE1(40
      4),ISIZE2(40),MEANDT(40),MEAN3T(40),SHA(40),MEANVT(40),IVT(40),CUMV
      5T(40),PCVT(40),CPCVT(40),IPARTT(40)
C READ MEDIAN SIZE INTERVALS.
       READ(5,100)(CPART(K),K=1,50)
  100 FORMAT(26F3.2/6F3.2,15F4.2/3F4.2)
   43 J=0
       N=0
       I=0
       DO 50 KK=1,50
       DO 51 MM=1,40
   51 IV(KK,MM)=0.
   50 CONTINUE
C READ HEADING CARD.
    1 READ(5,200)(LOC(K),K=1,18),(DATE(K),K=1,3)
  200 FORMAT(18A4,2X,3A2)
       PLTIST=0.0
       FSIZEM=0.0
    2 J=J+1
C READ PHOTOGRAPH DATA CARD 1.
       READ(5,300) PHOTO(J),ISIZE(J),FSIZE(J),MAG(J),PLTIS(J),S(1),S(2),
      1S(3)
  300 FORMAT(I4,3(2X,F6.0),2X,F7.0,3(2X,F3.0))
       PLTIST=PLTIST+PLTIS(J)
C A BLANK CARD FOLLOWED BY A CARD WITH 9997 IN THE FIRST 4 COLUMNS IS
C PLACED AT THE END OF THE DATA DECK TO DENOTE THE END OF FILE.
       IF(PHOTO(J).EQ.9997) GO TO 42
C SEVERAL LOCATIONS MAY BE INCLUDED. A BLANK CARD FOLLOWED BY A CARD
C WITH 9998 IN FIRST 4 COLUMNS IS INSERTED BEFOR THE NEXT PHOTOGRAPH
C DATA CARD 1.
       IF(PHOTO(J).EQ.9998) GO TO 43
C IF THERE ARE MORE THAN ONE SET OF PHOTOS PER LOCATION, INSERT A CARD
C WITH 9999 IN FIRST FOUR COLUMNS AFTER THE LAST SET OF DATA
C CARDS 2 AND 3 FOR ONE LOCATION.
       IF(PHOTO(J).EQ.9999) GO TO 3
C READ PHOTOGRAPH DATA CARDS 2 AND 3.
       READ(5,400)(NPART(J,K),K=1,50)
  400 FORMAT(26F3.0/24F3.0)
       WRITE(6,500)(LOC(K),K=1,18),(DATE(K),K=1,3),PHOTO(J)
  500 FORMAT('1',42X,'PARTICLE SIZE DISTRIBUTION'//' LOCATION: ' ,18A4/'
     1 DATE: ',A2,'/',A2,'/',A2/' PHOTOGRAPH NUMBER: ',I3///)
       WRITE(6,600)
```

```
  600 FORMAT(33X,'CUBE OF',11X,'VOLUME OF',36X,'CUMULATIVE'/4X,'SIZE',4X
     1,'NUMBER OF',4X,'MEAN',6X,'MEAN',4X,'SHAPE',5X,'MEAN',7X,'TOTAL',
     25X,'CUMULATIVE',3X,'PERCENT',4X,'PERCENT'/'   INTERVAL',2X,
     3'PARTICLES',2X,'DIAMETER',2X,'DIAMETER',2X,'COEF.',3X,'PARTICLE',
     45X,'VOLUME',6X,'VOLUME',5X,'VOLUME',5X,'VOLUME'/4X,'(MM)',17X,
     5'(MM)',6X,'(CC)',14X,'(CC)',8X,'(CC)',8X,'(CC)'//)
C COMPUTATION OF SIZE INTERVALS,MEAN DIAMETERS,AND MEAN DIAMETERS CUBED.
      INTVL(J,1,2)=ISIZE(J)
      INTVL(J,2,1)=ISIZE(J)
      INTVL(J,2,2)=(2.**.5)*ISIZE(J)
      ISIZEM=ISIZE(J)
      ISIZE1(2)=INTVL(J,2,1)
      ISIZE2(2)=INTVL(J,2,2)
      MEAND(J,1)=ISIZE(J)/2.
      MEANDT(1)=MEAND(J,1)
      MEAND3(J,1)=(MEAND(J,1)**3.)/1000.
      MEAN3T(1)=MEAND3(J,1)
      L=2
      A=INTVL(J,L,1)
      B=INTVL(J,L,2)
      MEAND(J,L)=(A+B)/2.
      MEAND3(J,L)=(MEAND(J,L)**3.)/1000.
      MEANDT(L)=MEAND(J,L)
      MEAN3T(L)=MEAND3(J,L)
      DO 4 JJ=1,1000
      L=L+1
      M=1
      INTVL(J,L,M)=(2.**.5)*A
      A=INTVL(J,L,M)
      M=2
      INTVL(J,L,M)=(2.**.5)*B
      B=INTVL(J,L,M)
      MEAND(J,L)=(A+B)/2.
      MEAND3(J,L)=(MEAND(J,L)**3.)/1000.
      IF(FSIZE(J).GT.FSIZEM) GO TO 5
      GO TO 6
    5 ISIZE1(L)=INTVL(J,L,1)
      ISIZE2(L)=INTVL(J,L,2)
      MEANDT(L)=MEAND(J,L)
      MEAN3T(L)=MEAND3(J,L)
    6 IF(B.GT.FSIZE(J)) GO TO 7
    4 CONTINUE
    7 INTVL(J,L,M)=FSIZE(J)
      B=INTVL(J,L,M)
      MEAND(J,L)=(A+B)/2.
      MEAND3(J,L)=(MEAND(J,L)**3.)/1000.
      IF(FSIZE(J).GT.FSIZEM) GO TO 8
      GO TO 9
    8 ISIZE2(L)=INTVL(J,L,2)
      MEANDT(L)=MEAND(J,L)
      MEAN3T(L)=MEAND3(J,L)
```

```
      FSIZEM=FSIZE(J)
      LL=L
    9 CONTINUE
C DETERMINATION OF SHAPE COEFFICIENT AND VOLUME OF MEAN PARTICLES.
      L=0
      M=2
      DO 10JJ=1,1000
      L=L+1
      IF(INTVL(J,L,M).LE.(FSIZE(J)/9.)) SH(J,L)=S(1)
      IF(INTVL(J,L,M ).GT.(FSIZE(J)/9.).AND.INTVL(J,L,M ).LE.(FSIZE(J)*
     14./9.)) SH(J,L)=S(2)
      IF(INTVL(J,L,M ).GT.(FSIZE(J)*4./9.).AND.INTVL(J,L,M ).LE.FSIZE(J)
     1) SH(J,L )=S(3)
      MEANV(J,L)=SH(J,L)*MEAND3(J,L)
      IF(INTVL(J,L,M).EQ.FSIZE(J))GO TO 11
   10 CONTINUE
C COMPUTATION OF NUMBER OF PARTICLES IN EACH HALF PHI SIZE INTERVAL.
   11 L=2
      K=0
      INPART(J,L)=0.
      DO 12 JJ=1,1000
      K=K+1
      IF(K.EQ.51) GO TO 13
      SIZE(J,K)=MAG(J)*CPART(K)
      IF(SIZE(J,K).GT.INTVL(J,L,M)) GO TO 14
      GO TO 15
   14 L=L+1
      INPART(J,L)=0.
   15 INPART(J,L)=INPART(J,L)+NPART(J,K)
   12 CONTINUE
C COMPUTATION OF VOLUME IN EACH INTERVAL AND CUMULATIVE VOLUME.
   13 L=1
      IV(J,L)=MEANV(J,L)*PLTIS(J)
      CUMV(J,L)=IV(J,L)
      DO 16 JJ=1,1000
      L=L+1
      IV(J,L)=MEANV(J,L)*INPART(J,L)
      CUMV(J,L)=CUMV(J,L-1)+IV(J,L)
      IF(INTVL(J,L,M).GE.FSIZE(J)) GO TO 17
   16 CONTINUE
C COMPUTATION OF PERCENT VOLUME AND CUMULATIVE PERCENT VOLUME.
   17 TV(J)=CUMV(J,L)
      L=0
      CUMPCV(J,L)=0.
      DO 18 JJ=1,1000
      L=L+1
      PCV(J,L)=(IV(J,L)/TV(J))*100.
      CUMPCV(J,L)=CUMPCV(J,L-1)+PCV(J,L)
      IF(INTVL(J,L,M).GE.FSIZE(J)) GO TO 19
   18 CONTINUE
C OUTPUT FORMAT FOR INDIVIDUAL PHOTOGRAPHS.
```

```
   19 IF(ISIZE(J).GT.8.0) GO TO 21
      IF(ISIZE(J).GE.1.0) GO TO 20
      WRITE(6,700) ISIZE(J),PLTIS(J),MEAND(J,1),MEAND3(J,1),SH(J,1),
     1MEANV(J,1),IV(J,1),CUMV(J,1),PCV(J,1),CUMPCV(J,1)
  700 FORMAT(6X,'<',F4.3,2X,F7.0,5X,F4.3,4X,
     11PE8.2,3X,0PF3.2,4X,3(1PE8.2,4X),0PF5.1,5X,F5.1)
      GO TO 22
   20 WRITE(6,800) ISIZE(J),PLTIS(J),MEAND(J,1),MEAND3(J,1),SH(J,1),
     1MEANV(J,1),IV(J,1),CUMV(J,1),PCV(J,1),CUMPCV(J,1)
  800 FORMAT(6X,'<',F4.2,2X,F7.0,5X,F4.2,4X,
     11PE8.2,3X,0PF3.2,4X,3(1PE8.2,4X),0PF5.1,5X,F5.1)
      GO TO 22
   21 WRITE(6,900) ISIZE(J),PLTIS(J),MEAND(J,1),MEAND3(J,1),SH(J,1),
     1MEANV(J,1),IV(J,1),CUMV(J,1),PCV(J,1),CUMPCV(J,1)
  900 FORMAT(6X,'<',F4.1,2X,F7.0,5X,F4.1,4X,
     11PE8.2,3X,0PF3.2,4X,3(1PE8.2,4X),0PF5.1,5X,F5.1)
   22 L=1
      DO 23 JJ=1,1000
      L=L+1
      IF(INTVL(J,L,2).GT.999.) GO TO 24
      IF(INTVL(J,L,2).GT. 99.) GO TO 25
      IF(INTVL(J,L,2).GT. 9.9) GO TO 26
      IF(INTVL(J,L,2).GT. .99) GO TO 27
      WRITE(6,1000) INTVL(J,L,1),INTVL(J,L,2),INPART(J,L),MEAND(J,L),
     1MEAND3(J,L),SH(J,L),MEANV(J,L),IV(J,L),CUMV(J,L),PCV(J,L),
     2CUMPCV(J,L)
 1000 FORMAT(2X,F4.3,'-',F4.3,2X,F7.0,5X,F4.3,4X,
     11PE8.2,3X,0PF3.2,4X,3(1PE8.2,4X),0PF5.1,5X,F5.1)
      GO TO 28
   27 WRITE(6,1100) INTVL(J,L,1),INTVL(J,L,2),INPART(J,L),MEAND(J,L),
     1MEAND3(J,L),SH(J,L),MEANV(J,L),IV(J,L),CUMV(J,L),PCV(J,L),
     2CUMPCV(J,L)
 1100 FORMAT(2X,F4.2,'-',F4.2,2X,F7.0,5X,F4.2,4X,
     11PE8.2,3X,0PF3.2,4X,3(1PE8.2,4X),0PF5.1,5X,F5.1)
      GO TO 28
   26 WRITE(6,1200) INTVL(J,L,1),INTVL(J,L,2),INPART(J,L),MEAND(J,L),
     1MEAND3(J,L),SH(J,L),MEANV(J,L),IV(J,L),CUMV(J,L),PCV(J,L),
     2CUMPCV(J,L)
 1200 FORMAT(2X,F4.1,'-',F4.1,2X,F7.0,5X,F4.1,4X,
     11PE8.2,3X,0PF3.2,4X,3(1PE8.2,4X),0PF5.1,5X,F5.1)
      GO TO 28
   25 WRITE(6,1300) INTVL(J,L,1),INTVL(J,L,2),INPART(J,L),MEAND(J,L),
     1MEAND3(J,L),SH(J,L),MEANV(J,L),IV(J,L),CUMV(J,L),PCV(J,L),
     2CUMPCV(J,L)
 1300 FORMAT(2X,F4.0,'-',F4.0,2X,F7.0,5X,F4.0,4X,
     11PE8.2,3X,0PF3.2,4X,3(1PE8.2,4X),0PF5.1,5X,F5.1)
      GO TO 28
   24 WRITE(6,1400) INTVL(J,L,1),INTVL(J,L,2),INPART(J,L),MEAND(J,L),
     1MEAND3(J,L),SH(J,L),MEANV(J,L),IV(J,L),CUMV(J,L),PCV(J,L),
     2CUMPCV(J,L)
 1400 FORMAT(' ',F5.0,'-',F5.0,2X,F7.0,4X,F5.0,4X,
```

```
     11PE8.2,3X,0PF3.2,4X,3(1PE8.2,4X),0PF5.1,5X,F5.1)
   28 IF(INTVL(J,L,2).GT.(FSIZE(J)*.99))GO TO 2
   23 CONTINUE
C SUMMATION OF PICTURE GROUPS.
    3 J=J-1
      WRITE(6,1500)(LOC(K),K=1,18),(DATE(K),K=1,3),PHOTO(N+1),PHOTO(J)
 1500 FORMAT('1',42X,'PARTICLE SIZE DISTRIBUTION'//' LOCATION: ',18A4/'
     1DATE: ',A2,'/',A2,'/',A2/' PHOTOGRAPHS ',I3,' -',I3///)
      I=J-N
C SUMMATION OF FIRST INTERVAL VOLUMES AND TOTAL VOLUMES.
      N=N+1
      IVT(1)=IV(N,1)
      TVT=TV(N)
      DO 29 JJ=1,1000
      N=N+1
      IVT(1)=IVT(1)+IV(N,1)
      TVT=TVT+TV(N)
      IF(N.EQ.J) GO TO 30
   29 CONTINUE
C THE REMAINDER OF THE FIRST INTERVAL SUMMATIONS.
   30 SHA(1)=1.0
       MEANVT(1)=IVT(1)/PLTIST
      CUMVT(1)=IVT(1)
      PCVT(1)=(IVT(1)/TVT)*100.
      CPCVT(1)=PCVT(1)
      WRITE(6,600)
      IF(ISIZEM.GT.8.0) GO TO 31
      IF(ISIZEM.GE.1.0) GO TO 32
      WRITE(6,700) ISIZEM,PLTIST,MEANDT(1),MEAN3T(1),SHA(1),MEANVT(1),
     1IVT(1),CUMVT(1),PCVT(1),CPCVT(1)
      GO TO 33
   32 WRITE(6,800) ISIZEM,PLTIST,MEANDT(1),MEAN3T(1),SHA(1),MEANVT(1),
     1IVT(1),CUMVT(1),PCVT(1),CPCVT(1)
      GO TO 33
   31 WRITE(6,900) ISIZEM,PLTIST,MEANDT(1),MEAN3T(1),SHA(1),MEANVT(1),
     1IVT(1),CUMVT(1),PCVT(1),CPCVT(1)
C SUMMATION OF REMAINING INTERVALS.
   33 M=1
      CUMVT(M)=CUMVT(1)
      CPCVT(M)=CPCVT(1)
      DO 34 JJ=1,1000
      M=M+1
      II=J-I
      IPARTT(M)=0.
      IVT(M)=0.
      DO 35 JJ=1,1000
      II=II+1
      IVT(M)=IVT(M)+IV(II,M)
      IPARTT(M)=IPARTT(M)+INPART(II,M)
      IF(II.EQ.J) GO TO 36
   35 CONTINUE
```

```
   36 SHA(M)=1.0
      MEANVT(M)=IVT(M)/IPARTT(M)
      CUMVT(M)=CUMVT(M-1)+IVT(M)
      PCVT(M)=(IVT(M)/TVT)*100.
      CPCVT(M)=CPCVT(M-1)+PCVT(M)
      IF(ISIZE2(M).GT.999.) GO TO 37
      IF(ISIZE2(M).GT. 99.) GO TO 38
      IF(ISIZE2(M).GT.9.9) GO TO 39
      IF(ISIZE2(M).GT. .99) GO TO 40
      WRITE(6,1000) ISIZE1(M),ISIZE2(M),IPARTT(M),MEANDT(M),
     1MEAN3T(M),SHA(M),MEANVT(M),IVT(M),CUMVT(M),PCVT(M),CPCVT(M)
      GO TO 41
   40 WRITE(6,1100) ISIZE1(M),ISIZE2(M),IPARTT(M),MEANDT(M),
     1MEAN3T(M),SHA(M),MEANVT(M),IVT(M),CUMVT(M),PCVT(M),CPCVT(M)
      GO TO 41
   39 WRITE(6,1200) ISIZE1(M),ISIZE2(M),IPARTT(M),MEANDT(M),
     1MEAN3T(M),SHA(M),MEANVT(M),IVT(M),CUMVT(M),PCVT(M),CPCVT(M)
      GO TO 41
   38 WRITE(6,1300) ISIZE1(M),ISIZE2(M),IPARTT(M),MEANDT(M),
     1MEAN3T(M),SHA(M),MEANVT(M),IVT(M),CUMVT(M),PCVT(M),CPCVT(M)
      GO TO 41
   37 WRITE(6,1400) ISIZE1(M),ISIZE2(M),IPARTT(M),MEANDT(M),
     1MEAN3T(M),SHA(M),MEANVT(M),IVT(M),CUMVT(M),PCVT(M),CPCVT(M)
   41 IF(ISIZE2(M).GT.(FSIZEM*.99))GO TO 1
   34 CONTINUE
   42 CONTINUE
      STOP
      END
/*
//GO.SYSIN  DD *
1251341431521631741851982112252412582742923123323563804054324624935265615996396
683729778830886941100910771150122713101398149215931700181519372067220723552514
268341566928
NOWHERE RIVER NEAR NOTHING,USA                                          000000
   5  1.00   26.8    1.0 10000..50.50.50
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
   6  1.00   26.8    1.0 10000..52.54.56
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
9999

9997
/*
```

SAMPLE OF COMPUTER OUTPUT

PARTICLE SIZE DISTRIBUTION

LOCATION: NOWHERE RIVER NEAR NOTHING,USA
DATE: 00/00/00
PHOTOGRAPH NUMBER: 5

SIZE INTERVAL (MM)	NUMBER OF PARTICLES	MEAN DIAMETER (MM)	CUBE OF MEAN DIAMETER (CC)	SHAPE COEF.	VOLUME OF MEAN PARTICLF (CC)	TOTAL VOLUME (CC)	CUMULATIVE VOLUME (CC)	PERCENT VOLUME	CUMULATIVE PERCENT VOLUME
<1.00	10000.	0.50	.125E-03	.50	.625E-04	.625E 00	.625E 00	1.4	1.4
1.00-1.41	2.	1.21	.176E-02	.50	.879E-03	.176E-02	.627E 00	0.0	1.4
1.41-2.00	6.	1.71	.497E-02	.50	.249E-02	.149E-01	.642E 00	0.0	1.4
2.00-2.83	5.	2.41	.141E-01	.50	.704E-02	.352E-01	.677E 00	0.1	1.5
2.83-4.00	5.	3.41	.398E-01	.50	.199E-01	.995E-01	.776E 00	0.2	1.7
4.00-5.66	6.	4.83	.113E 00	.50	.563E-01	.338E 00	.111E 01	0.8	2.5
5.66-8.00	5.	6.83	.318E 00	.50	.159E 00	.796E 00	.191E 01	1.8	4.3
8.0-11.3	5.	9.7	.901E 00	.50	.450E 00	.225E 01	.416E 01	5.0	9.3
11.3-16.0	6.	13.7	.255E 01	.50	.127E 01	.764E 01	.118E 02	17.0	26.3
16.0-22.6	5.	19.3	.720E 01	.50	.360E 01	.180E 02	.298E 02	40.1	66.4
22.6-26.8	2.	24.7	.151E 02	.50	.755E 01	.151E 02	.449E 02	33.6	100.0

PARTICLE SIZE DISTRIBUTION

LOCATION: NOWHERE RIVER NEAR NOTHING,USA
DATE: 00/00/00
PHOTOGRAPH NUMBER: 6

SIZE INTERVAL (MM)	NUMBER OF PARTICLES	MEAN DIAMETER (MM)	CUBE OF MEAN DIAMETER (CC)	SHAPE COEF.	VOLUME OF MEAN PARTICLE (CC)	TOTAL VOLUME (CC)	CUMULATIVE VOLUME (CC)	PERCENT VOLUME	CUMULATIVE PERCENT VOLUME
<1.00	10000.	0.50	.125E-03	.52	.650E-04	.650E 00	.650E 00	1.3	1.3
1.00-1.41	2.	1.21	.176E-02	.52	.915E-03	.183E-02	.652E 00	0.0	1.3
1.41-2.00	6.	1.71	.497E-02	.52	.259E-02	.155E-01	.667E 00	0.0	1.3
2.00-2.83	5.	2.41	.141E-01	.52	.732E-02	.366E-01	.704E 00	0.1	1.4
2.83-4.00	5.	3.41	.398E-01	.54	.215E-01	.107E 00	.811E 00	0.2	1.6
4.00-5.66	6.	4.83	.113E 00	.54	.608E-01	.365E 00	.118E 01	0.7	2.3
5.66-8.00	5.	6.83	.318E 00	.54	.172E 00	.860E 00	.204E 01	1.7	4.1
8.0-11.3	5.	9.7	.901E 00	.54	.486E 00	.243E 01	.447E 01	4.9	8.9
11.3-16.0	6.	13.7	.255E 01	.56	.143E 01	.856E 01	.130E 02	17.1	26.0
16.0-22.6	5.	19.3	.720E 01	.56	.403E 01	.202E 02	.332E 02	40.3	66.3
22.6-26.8	2.	24.7	.151E 02	.56	.845E 01	.169E 02	.501E 02	33.7	100.0

PARTICLE SIZE DISTRIBUTION

LOCATION: NOWHERE RIVER NEAR NOTHING,USA
DATE: 00/00/00
PHOTOGRAPHS 5 - 6

SIZE INTERVAL (MM)	NUMBER OF PARTICLES	MEAN DIAMETER (MM)	CUBE OF MEAN DIAMETER (CC)	SHAPE COEF.	VOLUME OF MEAN PARTICLF (CC)	TOTAL VOLUME (CC)	CUMULATIVE VOLUME (CC)	PERCENT VOLUME	CUMULATIVE PERCENT VOLUME
<1.00	20000.	0.50	.125E-03	***	.637E-04	.127E 01	.127E 01	1.3	1.3
1.00-1.41	4.	1.21	.176E-02	***	.897E-03	.359E-02	.128E 01	0.0	1.3
1.41-2.00	12.	1.71	.497E-02	***	.254E-02	.304E-01	.131E 01	0.0	1.4
2.00-2.83	10.	2.41	.141E-01	***	.718E-02	.718E-01	.138E 01	0.1	1.5
2.83-4.00	10.	3.41	.398E-01	***	.207E-01	.207E 00	.159E 01	0.2	1.7
4.00-5.66	12.	4.83	.113E 00	***	.585E-01	.702E 00	.229E 01	0.7	2.4
5.66-8.00	10.	6.83	.318E 00	***	.166E 00	.166E 01	.395E 01	1.7	4.2
8.0-11.3	10.	9.7	.901E 00	***	.468E 00	.468E 01	.863E 01	4.9	9.1
11.3-16.0	12.	13.7	.255E 01	***	.135E 01	.162E 02	.248E 02	17.1	26.1
16.0-22.6	10.	19.3	.720E 01	***	.382E 01	.382E 02	.630E 02	40.2	66.3
22.6-26.8	4.	24.7	.151E 02	***	.800E 01	.320E 02	.950E 02	33.7	100.0