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Record 1972/140

A COMPUTER PROGRAM FOR CALCULATING STATISTICAL PARAMETERS OF GRAINSIZE DISTRIBUTIONS DERIVED FROM VARIOUS ANALYTICAL METHODS

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SUMMARY

The frequency distribution of data values may be indicated by four statistical parameters: mean, standard deviation, skewness, and kurtosis. Statistical moment measures are used here to obtain these. These parameters are applicable not only to sets of classified or unclassified readings, but also to results of grainsize analyses.

The most commonly used methods of grainsize analysis are sieving for the gravel fraction, sieving or using a settling tube for the sand fraction, and using pipette or hydrometer methods for the mud fraction. When the results from a combination of these methods are employed to obtain the required statistical measures there is one major problem: sieving gives results based on actual size, whereas the other methods are based on the hydraulic equivalent concept. Under some conditions this problem is either not significant or can be partly overcome.

Program GRSIZE outputs the four statistical parameters using grainsize data obtained from the above analytical methods, or data which are a set of classified or unclassified readings of a variable. Other relevant options and outputs are also available with the program.

INTRODUCTION

Program GRSIZE was developed to process grainsize data from about 500 sediment samples from Broad Sound, Qld. Analyses were carried out by sieving the gravel fraction, using a settling tube for the sand, and pipetting the mud fraction; the parameters (mean, standard deviation, skewness, and kurtosis) associated with the grainsize distribution of each sample were required for future quantitative analyses.

Once the program was begun, many options such as extrapolations and plots of sample distributions were added. When plots were available, it was thought useful to make these usable with any set of readings. Methods of sieving the sand and using a hydrometer for the mud were also incorporated to make the program compatible with methods commonly used in engineering laboratories. Additions to the program were often a result of other people's requirements. These additions have made the program more useful and comprehensive. For this I would like to thank Dr P.J. Cook, Mr J.F. Marshall, and Mr J. Kellett.

Combining methods of grainsize analysis which are based on different measurements (actual size and hydraulic equivalent) leads to difficult problems. Discussion of these is necessary and relevant for any user of the program and has been included, together with a description of the BMR settling tube and its calibration procedures. A description of the various statistical measures is given in the introductory sections.

STATISTICAL DEVELOPMENT

Often it is necessary to know how the values of a certain variable are distributed. An idea of this distribution can be obtained by classifying the values into a number of classes and drawing a histogram. This frequency distribution can usually be defined more precisely by obtaining some statistical measures of the distribution.

The four most useful measures are the mean, standard deviation, skewness, and kurtosis; these can be obtained on unclassified as well as classified data. These four measures are defined below:-

Mean

The mean for classified data, $\overline{x}$, is defined as,

$$\overline{x} = \frac{1}{n} \sum_{i=1}^{h} x_i f_i$$

where, n = total number of observations

h = number of class intervals

x_i = mid-point of the ith class interval

f_i = frequency (number of observations out of n) in the ith class interval.

If the observations have not been classified, x_i will be the value of the ith observation, f_i will equal 1 for all i and h will equal n. In fact, the mean obtained from classified data is really an approximation, as the observations in each class interval are given the value of that interval's mid-point.

The mean can be imagined as being the point of balance of the distribution.

The other three statistical measures are determined using the second, third, and fourth moments about the mean. This 'moment about the mean' concept, for classified data, is defined as

$$m_k = \frac{1}{n} \sum_{i=1}^{h} (x_i - \overline{x})^k f_i$$

where, m_k = kth moment about the mean

In particular, m_2 is defined as the variance of the sample distribution. Again, if the observations have not been classified the value of x_i, f_i and h will be as set out previously. Moments about the mean for classified data are also again approximations. The above symbols will have the same meaning when the remaining three measures are discussed.

Standard Deviation

The standard deviation, s, which has the same units of measurement as the data, is given by

$$s = \sqrt{m_2}$$

It can be shown that m_2 is a biased estimator of the true population variance, and that

$$m_2 . \frac{n}{n-1}$$ is an unbiased estimator.

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Therefore,

$$S = \sqrt{\frac{n}{n-1} \cdot m_2}$$

is more appropriate for small values of n.

The standard deviation gives an indication of the spread of the distribution. With a normally distributed population, the interval $(\bar{x} - S, \bar{x} + S)$ includes about 68 percent of the values, and the interval $(\bar{x} - 2S, \bar{x} + 2S)$ includes about 95 percent.

Skewness

Skewness, g_1, which is a dimensionless number, is given by,

$$g_1 = \frac{m_3}{S^3}$$

The value of g_1 is zero for a symmetrical distribution and positive for a distribution with an extended right "tail". Care must be taken when using g_1 to interpret the shape of a distribution, as g_1 can also be zero for an asymmetrical distribution.

Kurtosis

Again a dimensionless number, kurtosis (g_2) is given by,

$$g_2 = \frac{m_4}{S^4} - 3$$

As g_2 equals zero for a normal curve with a mean of zero and a standard deviation of 1, and greater than zero for a distribution more peaked than this normal distribution, g_2 is often used as a measure of peakedness of a distribution. Despite this, interpretations from values of g_2 are often questionable and uncertain.

W.T. Sheppard's Corrections for Grouping

When these statistical measures are determined from classified data, they are in error owing to the assumption that the observations are all concentrated at the mid-points of the class intervals. If the distribution is symmetrical or only moderately skewed, and the class intervals are all equal, the m_2 and m_4 can be corrected using,

$$m_2\,(\text{corrected}) = m_2 - \frac{h^2}{12}$$

and,

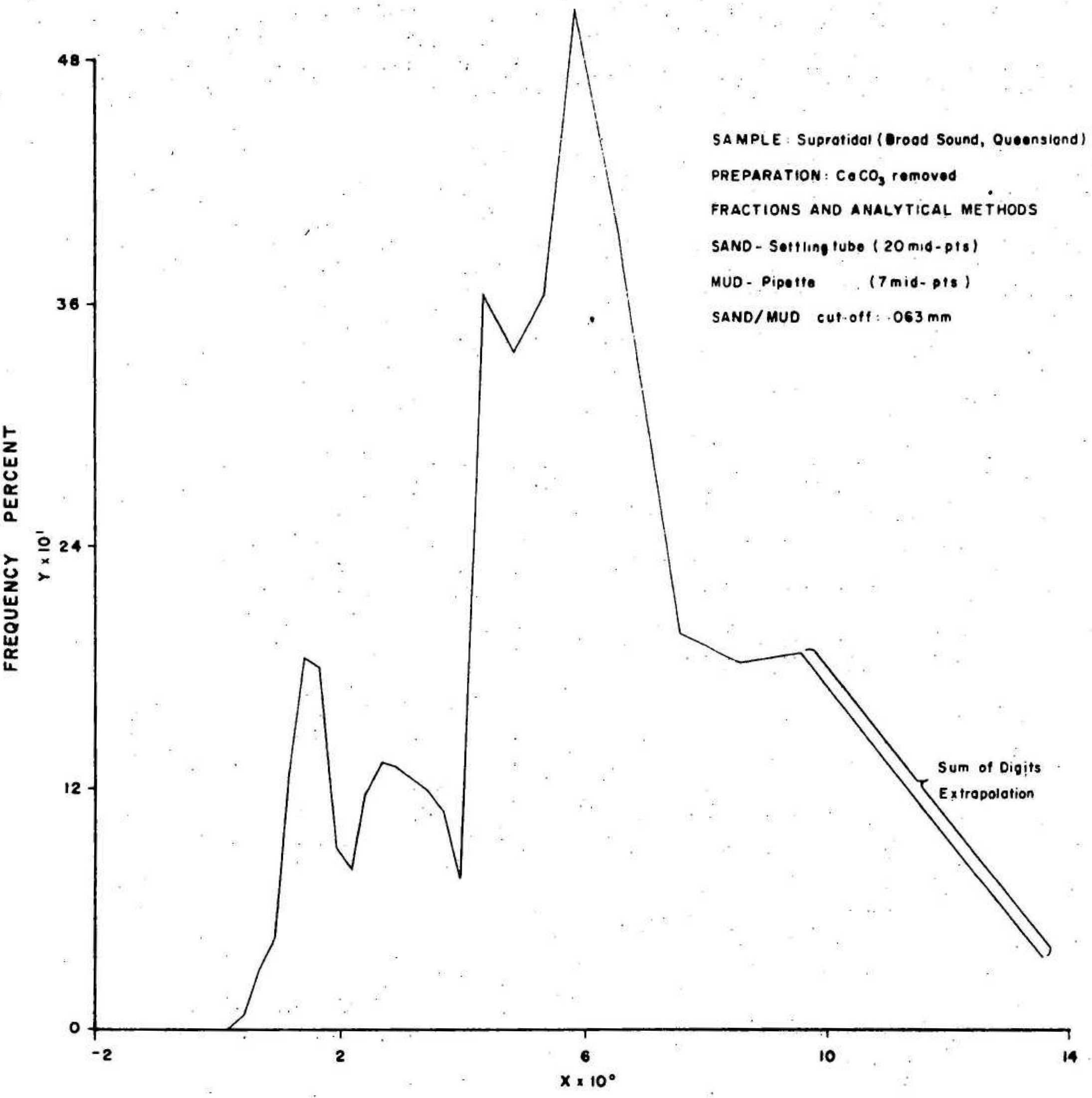
$$m_4\,(\text{corrected}) = m_4 - \frac{1}{2} h^2 m_2 + \frac{7h^4}{240}$$

where h is the size of the class intervals.

These corrections are only warranted if the class intervals are coarser than 1/20 of the total range, and if a large number of sample values were taken.

More detailed treatment of descriptive measures of sample distributions can be obtained in any one of a large range of statistical texts, such as Yule & Kendall (1950).

FIG I-GRAIN SIZE PHI UNITS



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APPLICATION OF STATISTICS TO GRAINSIZE ANALYSIS

Techniques of grainsize analysis can be directly related to the statistical measures defined earlier. Unless each grain is measured separately, n will be the total weight of the sample used in the analysis and f_i will be the weight frequency in the ith class interval. Therefore, although the use of the unbiased estimator of the variance is not applicable with grainsize results, Sheppard's Corrections often are, depending on the points already explained. The uncertainties associated with interpretations of skewness and kurtosis still remain.

Available experimental methods for grainsize analysis often necessitate the division of the total sample into three fractions, gravel, sand, and mud (silt and clay). Separate analyses are then carried out on each fraction. Each method requires an optimum amount of a fraction for meaningful and accurate results. For example, the standard pipette method requires about 15 g of mud. Consequently, analysis of the results must take into account any required splitting of, or adding to, a particular fraction. In practice, it is often convenient to predetermine the percentages of each fraction, analyse the appropriate amount of each fraction, and then calculate the required statistical measures.

Extrapolation Needs

Using available methods, it would take many weeks to analyse the mud fraction of some samples completely. Usually it is not economical to spend more than one day per sample, and as a result, some clay in the sample remains unanalysed. A mathematical technique to extrapolate the remaining clay down to any given size would be useful. Although this extrapolation would only be a rough approximation to the actual sample distribution, it may be considered better to extrapolate than to leave the remaining clay weight out completely.

An appropriate extrapolation technique is the sum of digits method. If the extrapolation is to be made over five class intervals for instance, the five class intervals are numbered 5, 4, 3, 2, and 1, and the sum of these digits obtained. In this case the sum of digits equals 15. The weight frequency in the first extrapolated interval is then set at $^5/_{15}$ of the remaining clay weight; in the second interval at $^4/_{15}$ of this weight; and so on down to the last extrapolated interval, which would be set at $^1/_{15}$ of the remaining clay.

The effect of this extrapolation can be seen in Fig. 1, where the x-axis represents grainsize in phi units. Here the clay remaining after pipette analysis down to 9 phi was extrapolated to 14 phi over five class intervals.

If insufficient gravel, sand or mud is available for a particular analytical method, but it is thought better to incorporate these amounts when determining the statistical measures, the same sum of digits in extrapolation technique could again be used. The errors due to the extrapolation approximations should always be less than the error due to leaving that fraction out entirely.

Graphical Plots

Cumulative Curve

At the completion of the grainsize analysis on all the fractions present in the sample, each class interval mid-point is associated with the corresponding weight frequency for that interval. The cumulative grainsize frequency curve of a sample can be approximated using these, and is obtained by plotting each of these mid-points against the sum of the weight percents corresponding to all mid-points less than or equal to each. Joining the resulting points indicates how much of a sample is likely to be less than a certain grainsize. Unequal class intervals often result from grainsize analysis, but no problems arise from this when plotting the cumulative curve.

An illustration of a cumulative plot is shown in Fig. 2. The cumulative curve has been used by many workers to obtain estimates of the mean, standard deviation, skewness, and kurtosis. These are only approximations to the statistical moment measures. Folk & Ward (1957) discuss these graphical methods and their use in some detail. A review of many mathematical and graphical techniques used to summarize grainsize distributions is given by Folk (1966).

Frequency Curve

An approximation of the grainsize frequency distribution of a sample can also be obtained from these results. A frequency curve indicates the percentage of each grainsize expected in a sample. If the class intervals are all equal, a plot of the mid-points against the corresponding weight percent approximates the grainsize frequency distribution of the sample. The same approximation would be obtained if a histogram of the results was drawn and the mid-points of the upper edges of the histogram rectangles were joined by straight lines.

With unequal class intervals, however, the larger the class interval the larger is the percent frequency associated with that interval mid-point; this percentage cannot be compared with percentages from smaller class intervals. Therefore, the percentages associated with intervals larger than the smallest interval must be scaled down by an amount equal to the ratio of the two interval lengths. This scaled percentage is then plotted against its corresponding mid-point.

To illustrate this complication a sample frequency plot is illsutrated in Fig. 3. The x-axis represents grainsize in phi units, and there are 40 plotted points each representing an interval mid-point and its corresponding weight percent. From the left, the first mid-point represents an interval 1.5 phi units in length and the next two represent 1.0 phi unit intervals, whereas the smallest class interval used in the grainsize analysis was 0.25 phi units. Therefore, the weight percent associated with the first mid-point has been scaled down by a factor of six and the next two by a factor of four.

A true comparison between all class intervals can be made using this scaling method. The scaled percentage associated with a mid-point is taken to represent the percentage of a sample that would have been obtained if the size of the class interval had been that of the smallest interval analysed. The plot, therefore, incorporates errors due to this assumption as well as the errors associated with concentrating the percentage at the mid-point.

FIG 2-GRAIN SIZE PHI UNITS

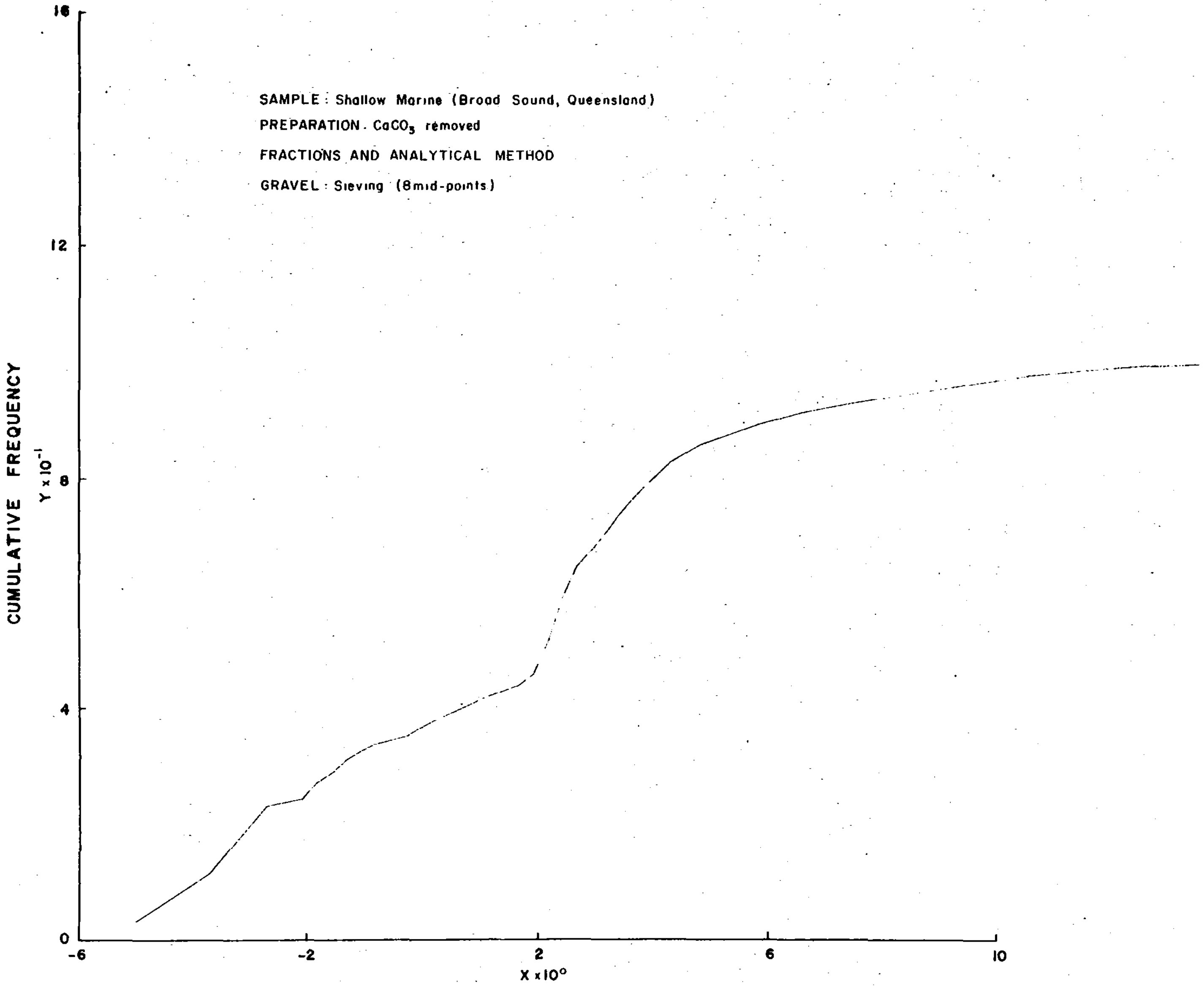

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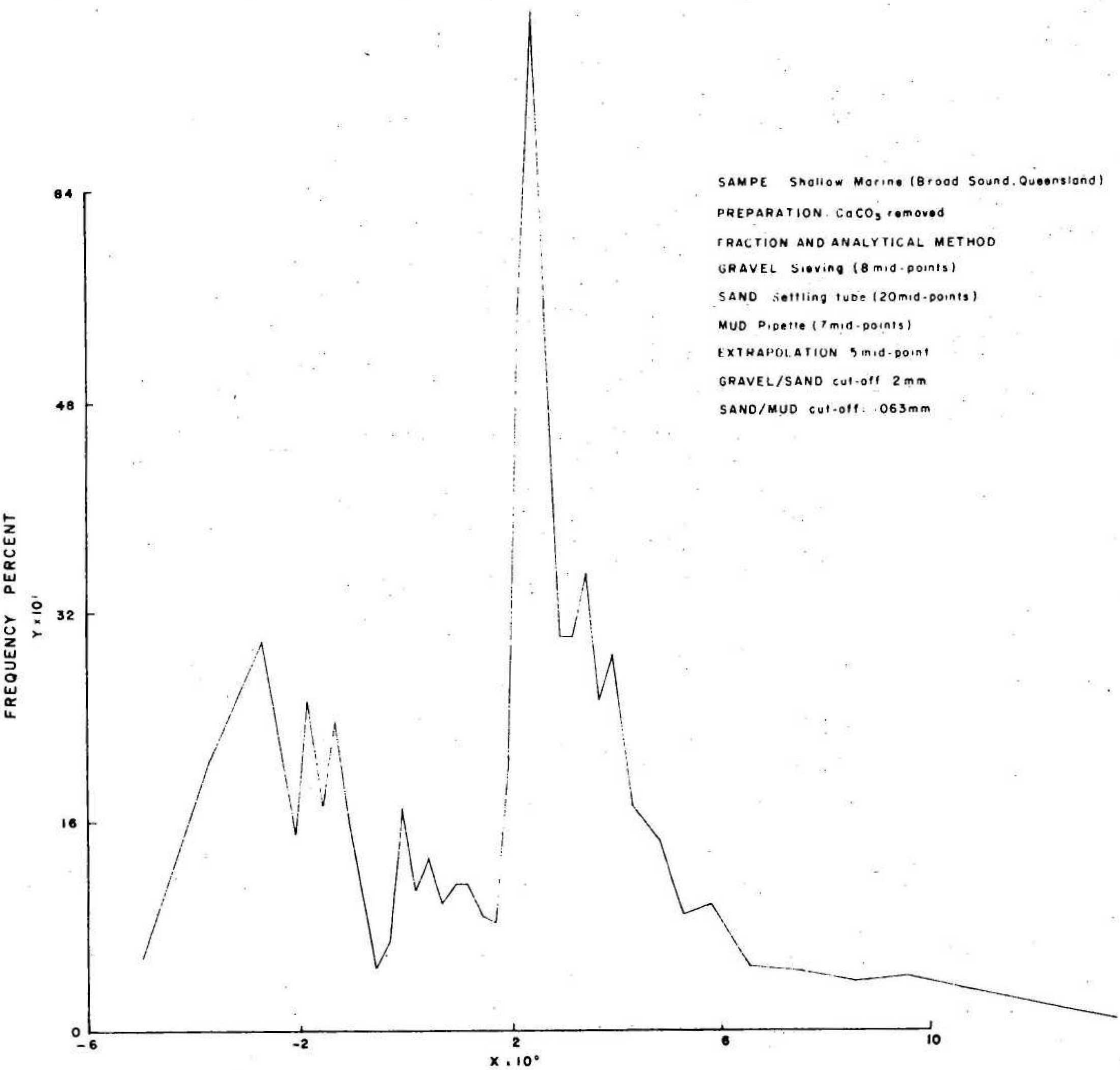
FIG 3 - GRAIN SIZE PHI UNITS



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Despite these errors, this frequency plot is extremely useful for descriptive purposes.

METHODS OF GRAINSIZE ANALYSIS

The method used for grainsize determination depends on the fraction - gravel, sand, or mud - of the sample being analysed. Methods commonly used for each fraction are listed below:

Fraction	Method
Gravel	(i) Sieving
Sand	(i) Sieving
	(ii) Settling tube
Mud	(i) Pipette
	(ii) Hydrometer

With all these methods, the selected size of the class intervals will depend on the accuracy required for the statistical measures. In any case, if a class interval contains more than about 15 percent of the total sample, that interval should be further subdivided and the fraction re-analysed.

Sieving and Pipette Method

Detailed description of sample preparations and techniques for sieving and pipette analyses may be found in Folk (1965). Temperature changes can have a significant effect on the timings for pipette readings, and Appendix I contains these timings at 18, 20, 22, and 24°C. The theoretical grainsizes corresponding to these timings are also given.

Settling Tube

Recently many articles have been written on automatically recording settling tubes. Discussion covers such topics as calibration (equating times of fall with grainsize), accuracy (how close the values of grainsize parameters obtained with the settling tube are to the true values of these parameters for any sample), and precision (reproducibility of results).

Both Cook (1969) and Felix (1969) suggest from empirical studies of the mean and standard deviation that the precision of the settling tube is better than that obtained by sieving. The accuracy of a particular tube, though, obviously depends on the method and accuracy of calibration. Several different ways of calibrating settling tubes have been attempted.

Most methods obtain a graph showing the theoretical rate of fall of quartz spheres of any size in the particular settling tube being used. Cook (1969) used the rate of fall of glass spheres of varying sizes, and adjusted these results for quartz using an equation from Rubey (1933). Gibbs, Mathews, & Link (1971) went one step further and obtained an equation from glass sphere results which they suggest may be used to obtain the rate of fall of spheres of any required diameter and density.

Once the theoretical rates of fall for quartz spheres are obtained, grainsize results for any sample can be determined relative to these. That is, the size obtained for any particle analysed with the settling tube will be equivalent to the diameter of the quartz sphere (hydraulically equivalent size) which would have the same rate of fall as the sample particle. In other words, a large flat shell which if sieved would be classified in the coarse sand size range might be classified in the fine sand size range with the settling tube, because of its slow rate of fall.

Theoretically, then, samples made up of particles of any mineral composition, or of any shape or size, can be analysed by the settling tube and compared on the basis of the hydraulic equivalent concept. However, practical limitations of the experimental method effectively restrict this technique to the sand fraction. Therefore, the hydraulic equivalent concept must be considered with reference to the measurement methods used with the gravel and mud fractions.

Grainsize Measurement Problems

Most methods of grainsize analysis of muds use Stokes' Law applied to quartz spheres as a basis, and therefore also use the hydraulic equivalent idea. The use of settling tube with the sand and hydrometer or pipette with the mud are therefore compatible. Use of such methods produces results that may be used to indicate the energy of the depositional environment. If only these hydraulic methods are used to analyse a sample, results should also be comparable from sample to sample regardless of composition and shape. Problems occur, though, when a combination of sieving the gravel and using a settling tube with the sand is used.

When the gravel fraction is sieved it is subdivided according to the actual size (more exactly, the least cross-sectional area) of the individual particles, whereas the settling tube analysis depends on the hydraulic equivalent concept. Two conflicting types of grainsize measurement are thus used in the analysis of one sample. The same difficulty, but probably to a much lesser extent, also arises if sieving is used for the sand fraction and either the hydrometer or pipette method for the mud. Similarly, the gravel, sand, and mud fractions are normally separated by sieving and not hydraulic methods. If the sample was made up entirely of quartz spheres this difficulty would not arise.

In theory, results from hydraulic equivalent measurements would be comparable whether the total sample or only the quartz grains in the sample were analysed, provided that all particles are in equilibrium with the energy regime of the environment of deposition. The latter condition is frequently not fulfilled; for example fine sediment may be sheltered in shell chambers, shells may themselves be part of the local fauna and not related to current energy, or the sample may represent two or more sedimentary laminae of different regimes.

Where a combination of sieving and hydraulic equivalent methods is used, as is normally necessary, the best results are achieved by analysing only the quartz component. This solution is normally only practicable where the non-quartz particles consist of carbonate which can be removed by acid leaching. Platy and acicular non-carbonate grains, and equidimensional heavy minerals, must also introduce anomalies, but fortunately they are not often quantitatively significant.

Although impracticable at the moment, the overall solution to the problem of mixed measurement types would be to separate the three fractions hydraulically and to have a settling tube capable of analysing the gravel fraction.

Once the difficulty of the two conflicting measurement types is overcome, valid comparison between samples can be obtained. Comparison of results from different laboratories will depend on how these problems have been dealt with in each. Here, of course, consistent calibration of settling tubes is also of paramount importance.

Calibration of BMR Settling Tube

Each individual settling tube should be separately calibrated, as the rate of fall of grains varies significantly with differing construction of the tube. Gibbs (1972) empirically tested these effects, and he suggests the ideal specifications for a settling tube.

The BMR settling tube (Fig. 4) has an inside diameter of approximately 7.5 cm and a length of fall of about 161 cm. Instructions for the use of the settling tube and recorder have been included in Appendix 2.

The tube was calibrated by a simple but accurate method requiring sieved quartz standards. Ideally, the standards should have been quartz spheres of all sizes throughout the sand fraction. As quartz spheres were not readily available, a mixture of well-rounded quartz grains from Broad Sound and Hervey Bay in Queensland, as well as from the Arafura Sea, was used. The tube was calibrated for the range of sizes from 2 mm to 0.063 mm and the calibration procedure was as follows.

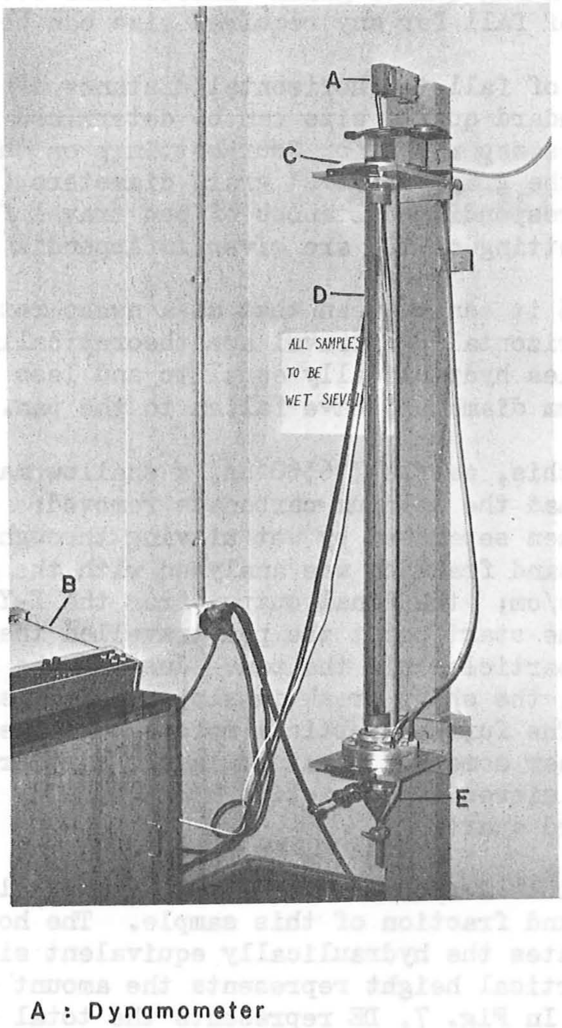
The standard quartz set was sieved carefully through 19 sieves from 2 mm size to 0.053 mm size. This gave 18 standard samples, each having a known size range.

Each was accurately split into between 5 and 11 sub-samples, each of which was analysed with the settling tube, and the pen sweep rate used for each one noted. The average temperature of the water at the top and bottom of the tube was always between 20°C and 22°C.

It was assumed that the first grains of a sub-sample to hit the settling tube pan had a diameter equal to the size of the larger of the two sieves which bounded the sub-sample. The average distance of pen travel (at the appropriate sweep rate) before these first grains hit the pan indicates the time of fall of particles the size of this larger sieve. The actual time of fall of this size is obtained by multiplying the appropriate sweep rate by the average length of travel.

Fig. 5 shows five of the nine traces used to obtain the time of fall of standard quartz grains with a diameter of 0.250 mm. The small arrow on each curve shows the point at which the first grains hit the settling tube pan. The required length of travel for each sub-sample was from the start point to this arrow. When calculated, the average time of fall for the standard quartz grains of 0.250 mm diameter was found to be 42.2 seconds.

FIG 4 - BMR SETTLING TUBE



A : Dynamometer

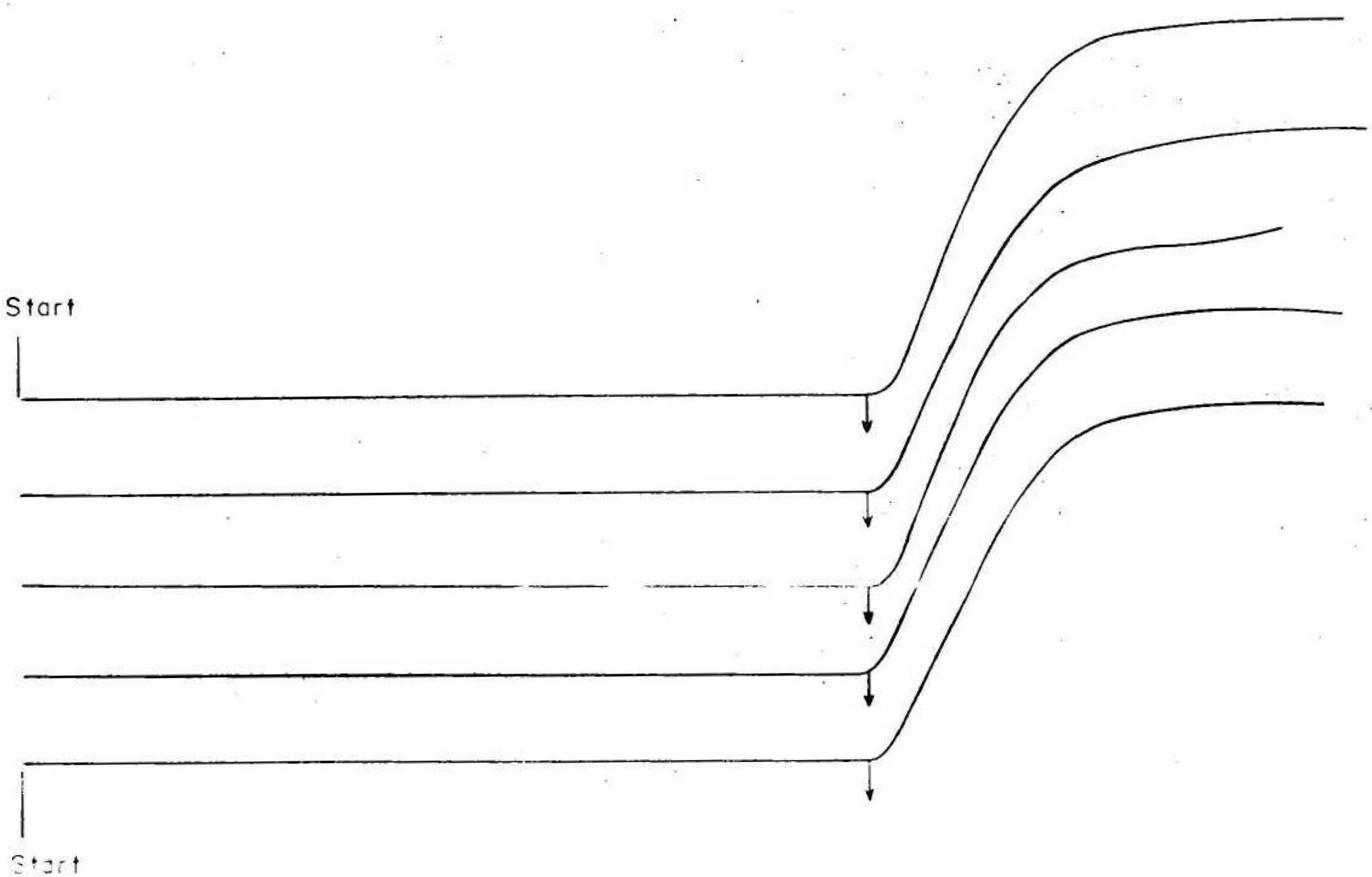
B : X-Y Recorder

C : Wire mesh sample holder

D : Settling tube

E : Sample collection pan

FIG 5-FINAL OUTPUT FROM BMR SETTLING TUBE



Size of Larger Sieve = 250 mm

Sweep rate (setting 10) = 3·65 sec/cm

Average length of travel = 11·55 cm
(of 9 sub-samples)

Therefore average time of fall for 250 mm quartz grains = 42·2 sec.

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Time of fall was determined by this method for each of the eighteen standard samples. From these results a graph of the time of fall against the corresponding quartz grain diameter was obtained (Fig. 6). From the graph the time of fall for any required size can be obtained.

From this time of fall the horizontal distance of pen travel corresponding to the standard quartz size can be determined for any desired sweep rate. The sweep rates for four settings on the BMR recorder; the time of fall - from the graph - for 21 grain diameters (in $\frac{1}{4}$ phi intervals); and the corresponding distances of pen travel for these 21 sizes, at a sweep rate setting of 10, are given in Appendix 3.

From Appendix 3 it can be seen that at a sweep rate of 3.65 s/cm, 47.9 cm of horizontal pen travel are theoretically required, before all sample particles hydraulically equal to and less than standard quartz grains of 0.0625 mm diameter, have fallen to the pan.

To illustrate this, sample 71636018A, a shallow marine sample from Broad Sound, first had the calcium carbonate removed; the gravel, sand, and mud fractions were then separated by wet sieving through 2 mm and 0.063 mm sieves and the sand fraction was analysed with the settling tube at a sweep rate of 3.65 s/cm; the final output from the X-Y recorder is shown in Fig. 7. From the start point the pen travelled the expected 2.0 cm before the first particles hit the pan. Just to the left of E, the 47.9 cm travel point, the sharp break in slope indicates the cut-off of the 0.063 mm sieve. The further vertical movement of the pen past this point indicates that either some mud remained in the sand fraction or there were grains in the sieved sand fraction hydraulically smaller than 0.063 mm diameter standard quartz.

Between the points A and E on Fig. 7 the graphical output can be used to analyse the sand fraction of this sample. The horizontal distance of travel indicates the hydraulically equivalent size of standard quartz; the vertical height represents the amount of sample greater than this size. In Fig. 7, DE represents the total weight of sand in the sample and BC represents the proportion of this fraction greater than or equal to the size hydraulically equivalent to 0.250 mm diameter standard quartz (OB representing the time of fall for 0.250 mm standard quartz grains).

The complete size distribution in the sand fraction is given by this graphical output. When using this to determine the statistical measures required, the amount of information obtained from this graph is limited only by the number of measurements taken from the graph. For example, 21 readings of vertical height are needed to classify the sand fraction into $\frac{1}{4}$ phi class intervals. With the BMR Settling Tube these 21 readings would be taken at the horizontal distances from the start given in Appendix 3.

Complete details showing how to incorporate a series of gravel weights from sieving, a set of measurements from a settling tube graph, and pipette weights from the mud fraction to obtain statistical measures and graphical plots, will be explained later. This will be done using a computer program called GRSIZE.

FIG 6- SETTLING TIMES WITH BMR SETTLING TUBE FOR STANDARD QUARTZ SET

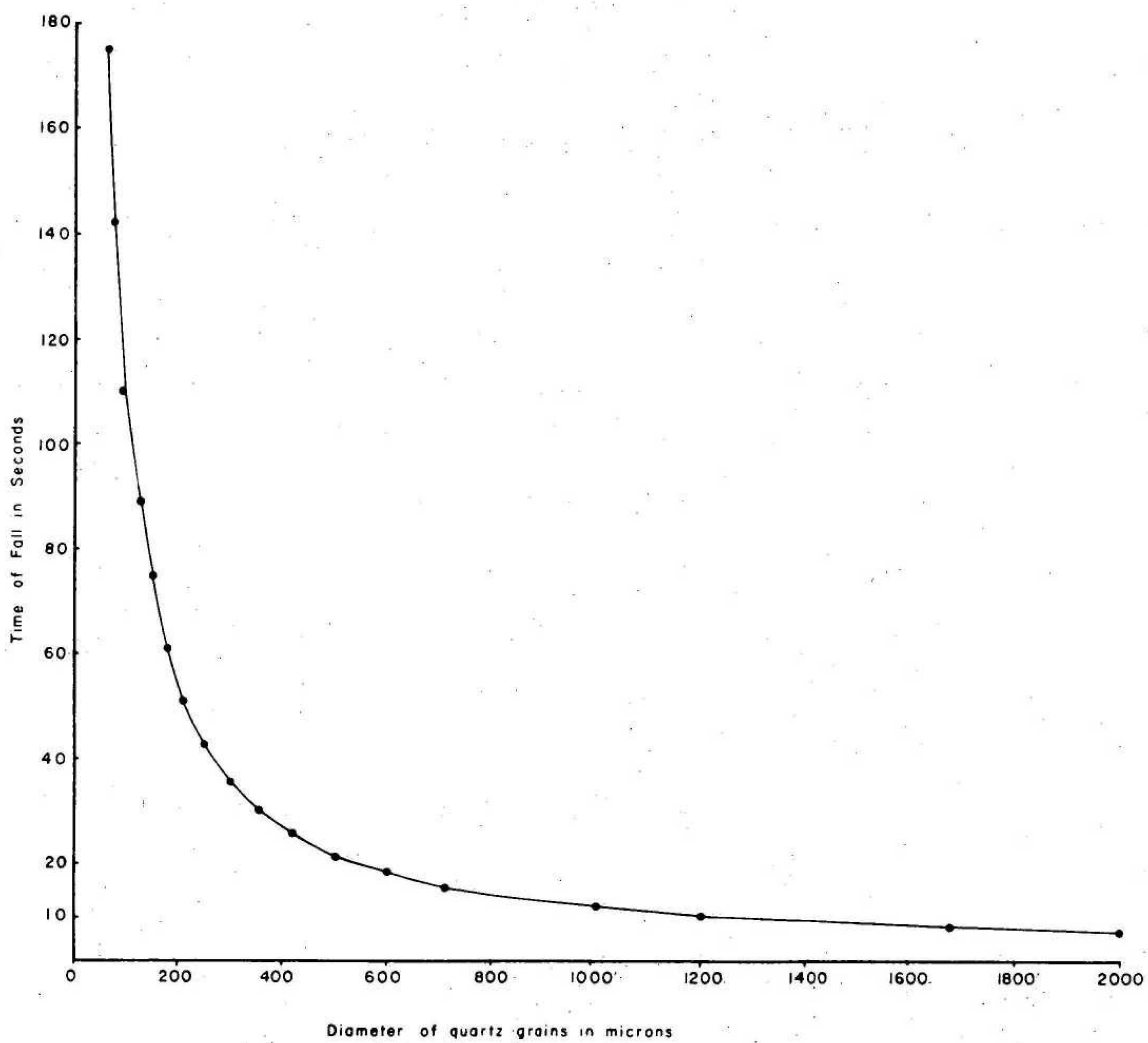

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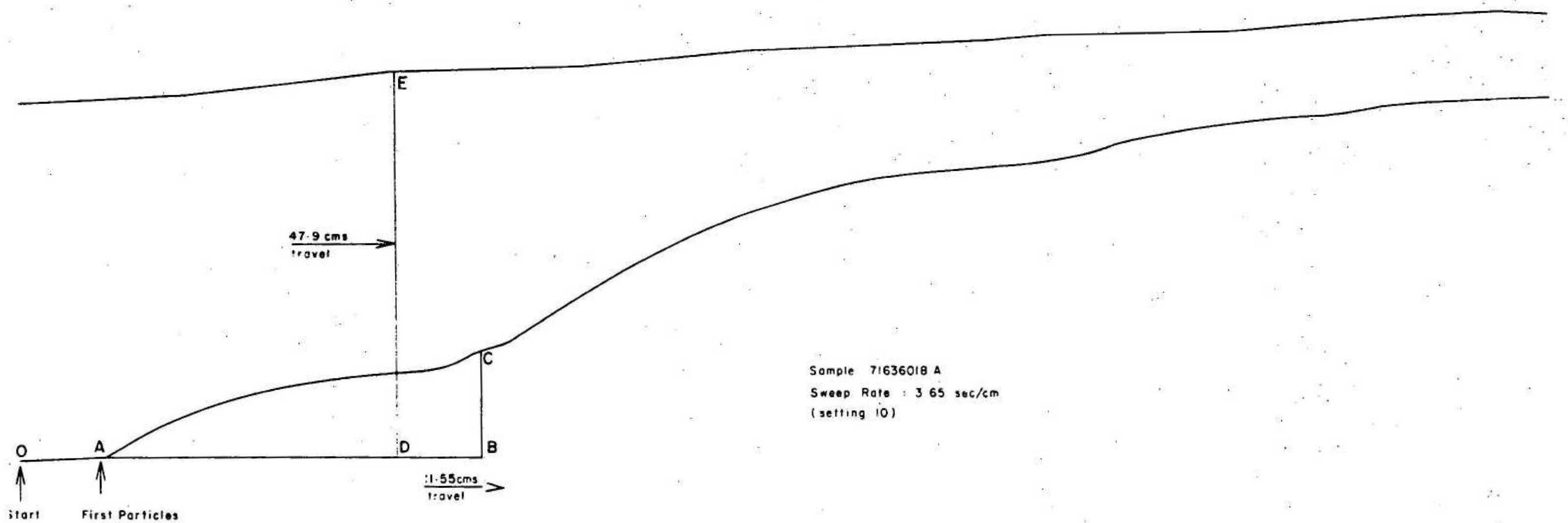
FIG 7 - FINAL OUTPUT FROM BMR SETTLING TUBE



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An alternative to measuring the settling tube graph at the selected positions would be to have the electrical impulses, which produce the graph, converted to a digital output. This would save time and also reduce the measuring errors. Of course, the grainsizes corresponding to the times selected for digital output must be determined as before from the calibration curve (Fig. 6).

Accuracy and Precision

The accuracy of a particular settling tube, depends on the method of calibration. With the method outlined in the previous section, the accuracy would be related to that of the quartz standard set, the sieves used, and the experimental technique. Problems with the quartz standards would include non-spherical grains and an incomplete range of sizes.

Papers which compare the precision (reproducibility of results) of sieving with that obtained with a settling tube have been referred to previously. It is useful to consider the precision of a settling tube relative to the precision of the methods used with the gravel and mud fractions. Table 1 shows the results for three repeat analyses of two samples, one with sand and mud fractions, the other with gravel, sand, and mud. The gravel was sieved, the mud analysed by the pipette method, and the settling tube used for the sand. The range of the mean grainsize for the total sample and for the sand fraction only is also shown.

TABLE 1

PRECISION OF RESULTS FROM SIEVE, PIPETTE, AND SETTLING TUBE ANALYSES

Sample Number	Fractions Present	Mean (total)	Range Grainsize in phi Units	Mean (sand fraction)	Range
15C	Sand - 46%	5.307		2.173	
15X	Mud - 54%	5.473	0.225	2.193	.087
15Y		5.248		2.107	
18C	Gravel - 40%	1.133		2.172	
18X	Sand - 45%	0.384	0.749	1.980	.192
18Y	Mud - 15%	0.759		2.036	

Using the range of the three repeat analyses as a measure of precision, that of the settling tube results is less than that of the results from the three methods combined by a factor of 2.6 times in the case of sample 15 and by a factor of 3.9 times in the case of sample 18. This example indicates that the experimental error with the settling tube is much less than that obtained by sieving the gravel and using the pipette method with the mud. Although more detailed empirical testing would be required to show this conclusively, it seems that the settling tube precision is certainly adequate compared to the precision of the other grainsize measurement techniques.

Hydrometer Method

The hydrometer method for mud grainsize analysis is not as accurate as the pipette method, and is also somewhat more difficult to carry out. This method is mostly used in engineering laboratories for soils. It appears that with these soil analyses the cumulative distribution of the grainsize is usually the only output used. Such measures as the mean grainsize and standard deviation of the sample distribution would be helpful in some cases in distinguishing differences in soils more precisely. For this reason the hydrometer method has been included here.

Engineering laboratories are normally interested in the distribution of the actual sizes of the grains in a sample, as opposed to the hydraulic equivalent sizes. Consequently, the sand and gravel fractions are sieved. The hydrometer method is based on Stokes' Law, and therefore the problem of using two different measurement techniques on one sample again arises.

Using the standard soil grainsize analysis the effects of this problem will probably be minimized. For a start, the carbonates are removed before the grainsize analysis is carried out, and the average specific gravity of the sample is used in the calculations. Thus, only differing grain shapes will affect the results.

Two types of hydrometer are in common use: one is graduated from -2 to 60 g/l of soil in the suspension; the other is graduated from 0.995 to 1.038 g/ml and calibrated to read 1.000 in distilled water at 20°C. A nomographic chart for the solution of Stokes' Law is used to obtain the hydraulically equivalent particle size for each reading of the hydrometer. From each reading the amount of the sample smaller than the corresponding equivalent particle size is also determined. These results are handled similarly to the pipette results in determining the required grainsize statistics. Complete details of the hydrometer method, as well as suggested sample preparation, are given in the publication produced by the Standards Association of Australia (1966).

The first reading made with the hydrometer may be taken to represent the total weight of the sample being analysed, as with the pipette method. Normally, though, the equivalent particle size corresponding to the first reading is significantly less than the size of the sieve used to separate the mud fraction. In this case, the amount of the sample between the size of this sieve and the equivalent particle size of the first reading must be obtained using the known weight of the mud fraction used in the analysis.

An example of the use of program GRSIZE when sieving has been used with the gravel and sand fraction and the hydrometer method with the mud fraction is given later. The output from this includes: the four statistical measures discussed previously; percent gravel, sand, and silt and clay; and the sample frequency and cumulative curves.

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Before samples are analysed to obtain the four grainsize parameters, the following questions should be asked.

Are these parameters necessary for the study being carried out? Perhaps other indicators of the grainsize of the samples, such as percent sand or gravel-sand-mud ratios, would be adequate. See, for example, Davis (1970).

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What measurement type is to be used with the samples? A choice must be made between hydraulic equivalent measurements and actual size measurements.

Do the analytical methods available for grainsize analysis mean that both these conflicting measurement types have to be used when analysing a sample? If this is so perhaps the problem can be overcome to some extent.

Given the selected analytical methods, are the results compatible with the requirements of program GRSIZE? The remaining sections outline these requirements in detail.

PROGRAM GRSIZE

Program GRSIZE uses the statistical moment measures to calculate the parameters mean, standard deviation, skewness, and kurtosis. The input for the program can be either grainsize analysis results, classified sets of values of any variables, or sets of values of any variables.

The experimental methods used to obtain the grainsize data may be any combination of 1) sieving the gravel fraction, 2) sieving, or using a settling tube for, the sand fraction and 3) using the pipette or hydrometer method for the mud (silt plus clay) fraction. With this input the program also determines the gravel, sand, silt and clay percentages. All class intervals with mid-points greater than 8 phi units (or less than 0.003 mm) are included in the clay fraction. Percentages of the sample in each class interval and the corresponding mid-point are also given in this case.

Graphical output consists of the frequency curve and cumulative curve on the lineprinter or plotter as required. With sets of unclassified values, the values are classified if these plots are required. The statistical parameters, together with fraction percentages if the data are from grainsize analyses, may also be punched on data cards.

Examples of input and output of the program are given in a later section, and the program is listed in Appendix 4.

Program Options

The following explanatory notes will aid in the use of the options available with grainsize analyses when using program GRSIZE.

Extrapolations

If the mud fraction is analysed by pipette or hydrometer, and if the interval boundaries are in phi units, the remaining mud at the end of the analysis may be extrapolated. This extrapolation is based on the sum of digits method and each extrapolated interval is one phi unit. The size limit for the extrapolations is specified by the user.

If the mud fraction is not analysed, and the interval boundaries of the other fractions are in phi units, the same automatic extrapolation of the total mud weight is carried out if required.

Extrapolation of the total gravel, sand or mud fractions is also carried out, if required, over any range, with any number of intervals, and in any units of measurement. This may be applied to the mud remaining after analysis, if the above automatic extrapolation is not convenient. Again the sum of digits method is used, but here the boundaries of the extrapolated intervals must be specified.

Sheppard's Corrections

Sheppard's corrections are made on the statistical parameters if all the class intervals are equal and the interval size specified, and if the skewness is between -0.5 and +0.5.

Graphical Output

Cumulative and frequency curves may be plotted on the line printer or plotter. The plots on the line printer have an accuracy of ± 0.5% and on the plotter 0.05%, but output is about ten times faster on the line printer. The plotting subroutines, QUIKPLOT (line printer) and AUTOPLOT (plotter), are library service programs for use with the CDC 3600 Computer at CSIRO Canberra. With unequal class intervals, the frequency curve is scaled as explained in a previous section.

When the frequency curve is obtained on the line printer, the summary statistics are printed below the graph. In this way the output for one sample fits onto one output page, unless the cumulative curve is also required when the output will be two pages. All other graphical options produce the statistics in normal format.

Use of phi units makes the scaling of the plots ideal. However, if untransformed measurements such as millimetres are used for the interval boundaries, the frequency plot often is virtually unreadable in the section corresponding to the mud fraction. Consequently, if required, the interval mid-points, x_i, are transformed by,

$x_i = -\log_e x_i$, to produce a more convenient plot.

This transformation will also produce a plot which has the coarser sizes to the left, as is normal with grainsize plots. If untransformed measurements not in phi units are used, the curves will not conform to this convention.

Options with Sets of Readings

If plots are required for a set of unclassified data, the size of the class interval to be used to classify the readings may be given by the user. If this is not supplied, the readings will be classified according to a class interval of 0.3 standard deviations.

Although not relevant to grainsize results, the method of obtaining an unbiased estimate of the variance, as previously outlined, is used with classified or unclassified sets of readings.

USE OF PROGRAM GRSIZE

The program is written in ANSI FORTRAN language except for the use of two branched logical IF statements. There are four data card types and these are explained below. The section describing program GRSIZE should clarify this section and detailed examples of input and output are given later.

Card Type A

Columns	Description of Requirements (leave blank[1] if not applicable; right-justify[2] unless specified as decimal).
5	0 : to end program. 1 : if data from grain-size results and settling tube not used. 2 : if data from grain-size results and settling tube used. 3 : if data are an unclassified set of readings. 4 : if data are a classified set of readings.
6 - 10	Number of gravel readings.
11 - 15	Number of readings with sand fraction.
16 - 20	Number of readings with mud fraction.
21 - 25	Number of class interval boundaries with grain-size results or a classified set of readings. The value here is equal to the number of readings on Card Type B. Number of readings with a set of unclassified readings.
26 - 30	Grain-size lower limit in phi units for automatic extrapolation of mud fraction. The total weight (or percentage) of mud must be entered in Card Type C if the whole of the mud fraction is to be extrapolated.
31 - 35	Number of class intervals for extrapolation of total gravel weight (or percentage). Boundaries of extrapolation intervals must be supplied on Card Type B, and total weight (or percentage) given on Card Type C.
36 - 40	Number of class intervals for extrapolation of total sand weight (or percentage). Enter intervals and weight as above.

[1] A blank has the same effect as 0 or 0.0.

[2] This means as the input value is an integer, the integer must be placed at the right-hand end of the columns allocated for this input.
If the input is required as a decimal number this value can be placed anywhere in the columns allocated for it, and the decimal point must be included.

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Columns	Description
41 - 45	Number of class intervals for extrapolation of total mud weight (or percentage) or weight of mud remaining after analysis. This can only be relevant if cols. 26-30 are blank. Boundaries of extrapolated intervals must be given on Card Type B. Weight (or percentage) is entered on Card Type C if the total amount of mud is to be extrapolated. This weight is not entered if the mud remaining after pipette or hydrometer analysis is to be extrapolated, automatically unless the mud has been split or added to (see Card Type C).
50	1 : if output on punched cards is required.
60	1 : if variable format cards are to be placed before data Card Types B and D, either to read the data in unusual format or to select certain fractions (such as, the sand fraction only) for independent analysis. For repeated similar analyses no further variable format cards are required.
65	Single digit numbering type of punched output card. The digit is punched in column 11 of the output card.
66 - 75	Size of class intervals if, and only if, all class intervals are equal. Enter the width as a decimal number.

Card Type B

The class interval boundaries are placed on these cards, each boundary being entered as a decimal number in a field of eight. Therefore, ten boundaries are entered per data card, unless the digit 1 has been entered in column 60 on Card Type A.

The boundaries, in any units are entered in order with the upper boundary of the coarsest size interval entered first. For unclassified sets of readings the readings are entered on these cards.

Card Type C

Columns	Description of Requirements (leave blank if not applicable; right-justify unless specified as decimal).
1 - 10	Enter WT1 (see below) as a decimal number.
11 - 20	Enter WT2 (see below) as a decimal number.
21 - 30	Enter WT3 (see below) as a decimal number.

The amounts of the gravel, sand, and mud fractions used in grainsize analysis are either:

(a) represented by percentages and the analyses are alone on any amount of each fraction. In this case, WT1, WT2, and WT3 are the percentages of the gravel, sand and mud fractions respectively.

(b) a result of splitting, or adding to, the fractions as required (see Section 4). Here WT1, WT2 and WT3 are the original weight of the gravel, sand and mud fractions respectively which have been split or added to.

(c) the total weight of each fraction in the original sample. In this case,

(i) WT1 is not entered

(ii) WT2 is not entered, unless the settling tube has been used, and then WT2 is equal to the total weight of sand in the original sample.

and (iii) WT3 is not entered, unless the hydrometer is used to analyse the mud fraction and the first reading does not represent the total weight of mud. If this is the case, WT3 equals the total weight of mud in the original sample.

31 - 40 Alphanumeric sample number which does not need to be right-justified.

45 1 : if the next analysis is different. That is, if a different Card Type A is needed for the next sample.

2 : if this analysis is on a set of unclassified readings and the next analysis is the same.

3 : if this analysis is on any set of data (except a set of unclassified readings), and the next analysis is the same.

48 blank: if no graphical output is required.

1 : for frequency curve on line printer with associated results.

2 : for frequency and cumulative curves on the line printer with associated results.

3 : for frequency curve on the plotter and printed output.

4 : for frequency and cumulative curves on the plotter plus printed output.

5 : for (i) frequency and cumulative curves on line printer and associated results.

(ii) frequency and cumulative curves on the plotter and

(iii) normal printed output.

51 1 : if the mid-points are to be transformed to minus the natural log to give more readable graphical output.

The remainder of Card Type C is blank unless the hydrometer method is used.

52 - 60 Average specific gravity of the sample as a decimal number.

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Column	Description
61 - 70	If the mud weight is split before analysis with the hydrometer, and if the first reading does not represent the total weight of mud in the sample, enter the weight of the split used in the analysis as a decimal number.
75	1 : if the first hydrometer reading is taken to represent the total weight of mud being analysed.
80	1 : if the hydrometer used is calibrated in grams of mud per litre.
	2 : if the hydrometer used is calibrated in grams per ml density.

Card Type D

Either observations from grainsize analyses or the frequencies with classified sets of readings are placed on this card type. These data values are entered in the order corresponding to the interval boundaries on Card Type B. That is, with grainsize results, the first reading entered corresponds to the coarsest grainsize interval. Each value must be entered as a decimal number in a field of eight, unless variable formats are used (see Card Type A, Column 60).

With grainsize data, the units of these observations depend on the analytical methods used. With sieving these are the weight of sample on each sieve and with the settling tube they are either measurements from a graph or automatic digital readings. When using the pipette methods the observations are the weights of the dried 20 ml. aliquots (minus any dispersant weight if the remaining mud is to be extrapolated), and with the hydrometer method the corrected hydrometer readings are used.

There is no Card Type D with sets of unclassified readings.

Deck Structure

Fig. 8 shows the structure of the data deck to be used with program GRSIZE. The method of incorporating sets of data, whether repetitions of the same type of analysis or the addition of data from a completely new type of analysis, is also given.

From this layout it can be seen that the most advantageous way of setting up data sets is to group together all the results which would require the same information on Card Type A. If this is done for grainsize data or classified sets of readings, each group then only requires one Card Type A and one set of cards with Card Type B format. Each group of unclassified sets of readings would require only one Card Type A.

The structure of a complete job deck for running program GRSIZE with the CDC 3600 Computer at CSIRO in Canberra is given in Fig. 9.

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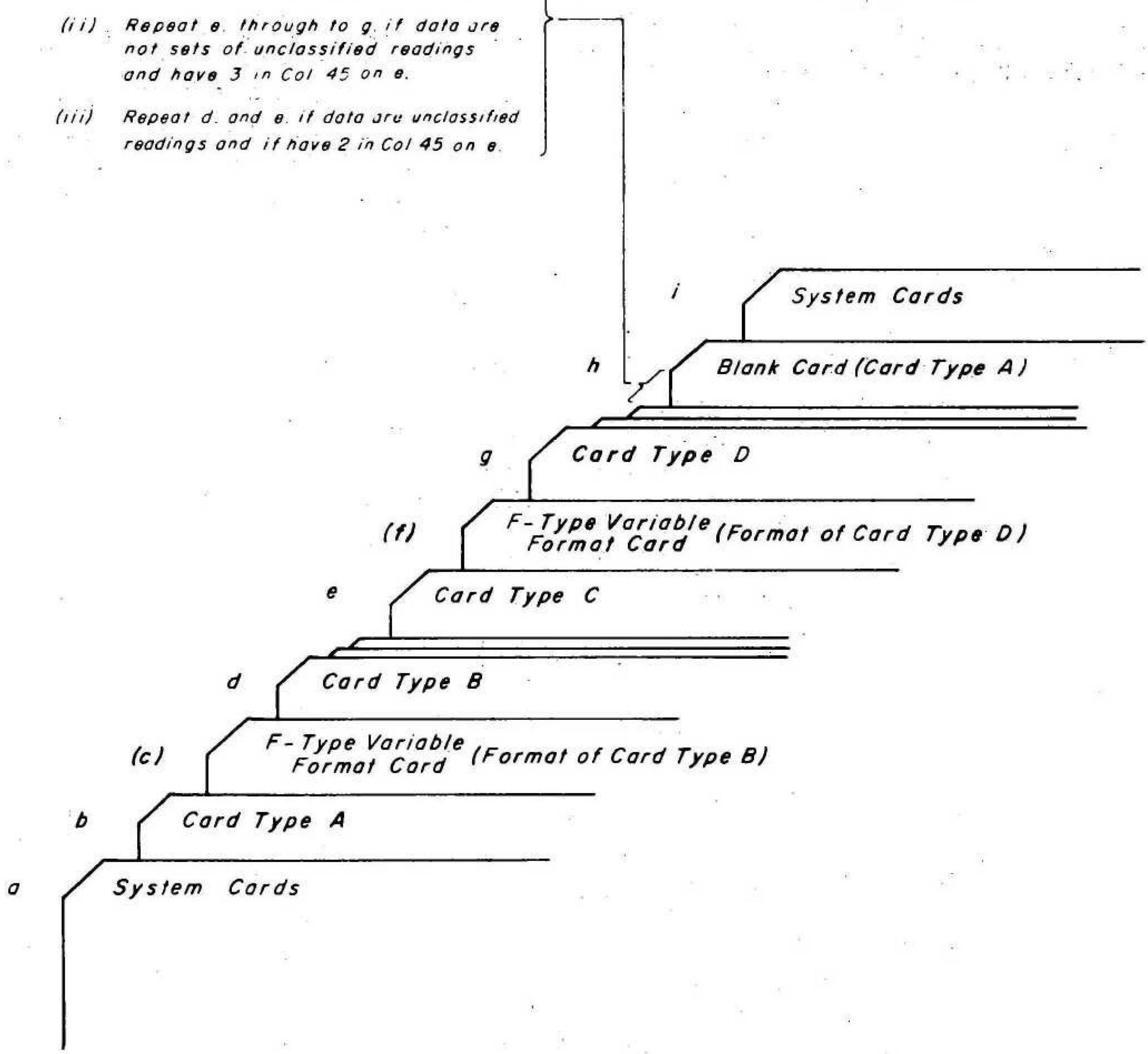
FIG 8 - DATA DECK STRUCTURE

FOR DATA REPETITION

(i) *Repeat b. through to g. as required if have 1 in Col 45 on e.*

(ii) *Repeat e. through to g. if data are not sets of unclassified readings and have 3 in Col 45 on e.*

(iii) *Repeat d. and e. if data are unclassified readings and if have 2 in Col 45 on e.*



c and f. are optional (used if have 1 in Col 60 on b.) g. is not used with unclassified data

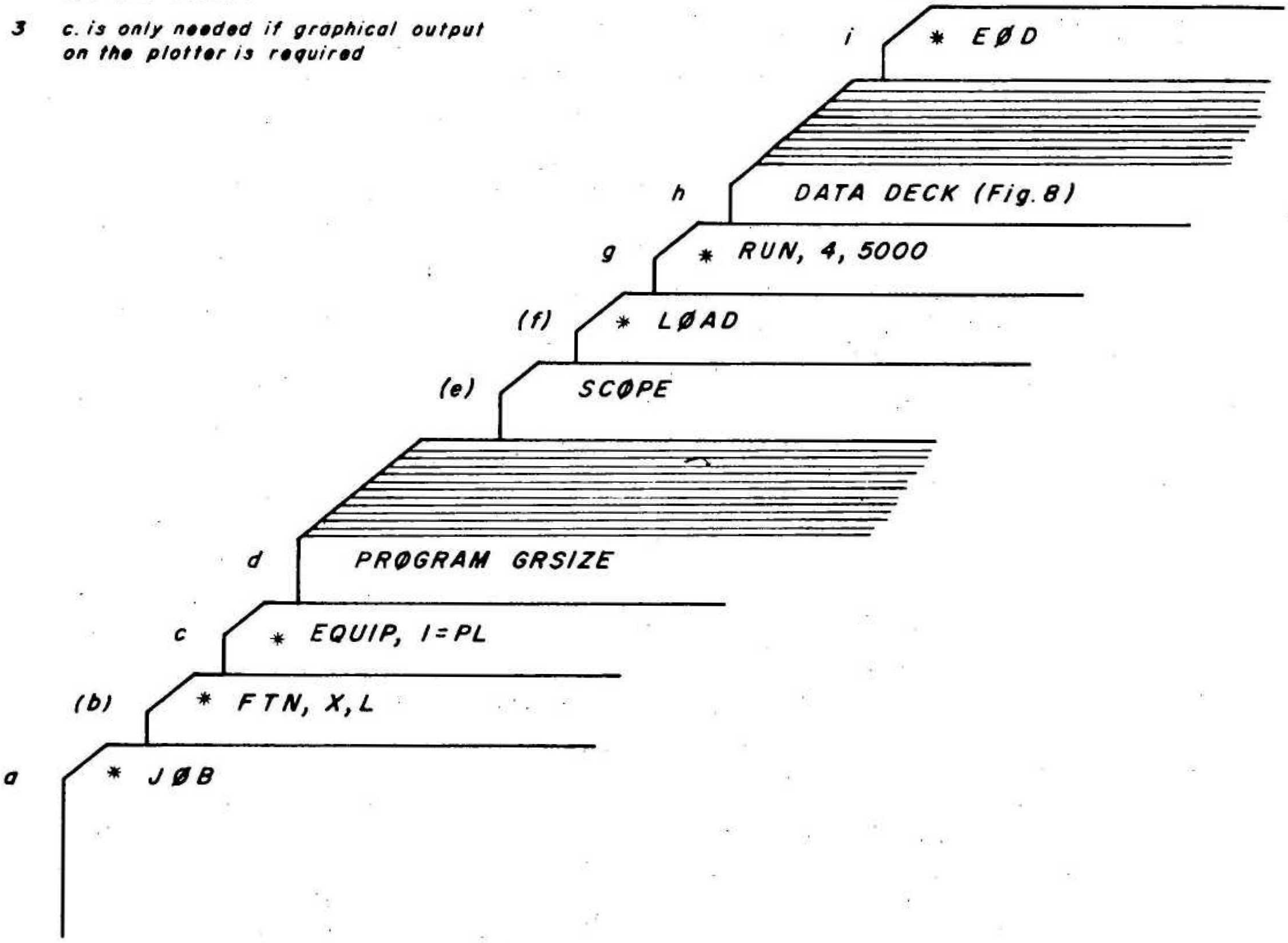
FIG 9 - JOB DECK FOR CDC 3600, CANBERRA

NOTES

1 d. may be either a FØRTRAN or a BINARY deck

2 If d. is a BINARY deck, b., e. and f. are not needed

3 c. is only needed if graphical output on the plotter is required



PROGRAM INPUT AND OUTPUT EXAMPLES

The input for four examples is shown on data sheets in Fig. 10. The type of analysis and the options required for these are indicated below.

Example 1 (71635018 A)

This is an example of a grainsize analysis where the gravel was sieved (eight readings), the sand was analysed with a settling tube (twenty one readings), and the pipette method was used with the mud fraction (eight readings). Neither the gravel nor the mud fraction had been split or added to and the total weight of sand in the sample was 61.044 grams. The twenty one readings for the sand fraction were measured from the graphical output shown in Fig. 7.

The options which have been requested are: automatic extrapolation of the remaining mud down to 14 phi; plotted cumulative curves (Fig. 3) and frequency curves (Fig. 2), plus the normal printed output (Fig. 11); and punched card output (Fig. 10). The mean, standard deviation, skewness, and kurtosis plus the percentage gravel, sand, mud, silt, and clay are punched on this card.

Example 2 (HYDROMETER)

This is another example of a grainsize analysis, but here both the gravel and sand were sieved and the mud was analysed by the hydrometer method. The mud fraction had been split from 170.0 grams to 66.0 grams before analysis, the hydrometer was calibrated in gm/c.c., and the first hydrometer reading was not taken to represent the total weight of mud being analysed.

With this analysis the options selected were plotted frequency curves (Fig. 12) and cumulative curves (Fig. 13) with the grainsizes gransformed by taking logarithms to the base e; and the normal printed output (Fig. 11). Although the class interval size was given, Sheppard's corrections were not carried out as the skewness was greater than 0.5.

Example 3 (EXAMPLE 1)

Here the data are a selected set of readings classified into 18 class intervals. The output options are again the frequency (Fig. 14) and cumulative curves plus the normal printed output (Fig. 11). The variance has been recomputed to the unbiased estimate and the parameters have been corrected using Sheppard's corrections.

Example 4 (PHOSPHATE 1)

A set of 28 readings of phosphate levels - of Broad Sound sediments - is used here to illustrate the analysis of an unclassified set of readings. The normal printed output is shown in Fig. 11. Again the variance is unbiased and Sheppard's corrections have been made.

As the cumulative and frequency curves were requested and no class interval size was given, the readings were classified with an interval size of 0.3 standard deviations. The resulting frequency curve is shown in Fig. 15.

FIG 10–EXAMPLE DATA SET
GRSIZE

EXAMPLE I

										COMMENT
CARD TYPA 'A':										
2	8	21	8	36	14			1	7	
Data from grain-size analyses and settling tube used										
8 gravel readings (sieving)										
21 sand readings (settling tube)										
8 mud readings (pipette)										
36 class internal boundaries										
Automatic extrapolation of mud remaining after pipette analysis (down to 14 phi)										
Output on punched card required with 7 punched in col 11										
CARD TYPE 'B':										
-5.75	-4.25	-3.25	-2.25	-2.0	-1.75	-1.5	-1.25	-1.0	-0.75	
-0.50	-0.25	0.0	0.25	0.5	0.75	1.0	1.25	1.5	1.75	
2.0	2.25	2.5	2.75	3.0	3.25	3.5	3.75	4.0	4.5	
5.0	5.5	6.0	7.0	8.0	9.0					
CARD TYPE 'C':										
	61.044			71635018 A	1 4					
The total weight of both the gravel and mud fractions were analysed										
The total weight of the sand fraction was 61.044 grams										
The next analysis type is different										
Plotted frequency and cumulative curves plus normal line printer output required										
CARD TYPE 'D':										
4.345	10.702	15.488	1.954	3.275	2.237	3.070	2.085	0.0	0.21	
0.31	0.45	0.80	1.02	1.29	1.49	1.72	1.95	2.13	2.30	
2.71	3.85	5.45	6.59	7.21	7.83	8.55	9.07	9.66	0.531	
0.442	0.366	0.320	0.270	0.219	0.172	0.133				
PUNCHED CARD OUTPUT										
	Mean	St.Dev.	Skewness	Kurtosis	%Gravel	%Sand	%Mud	%Silt	%Clay	
71635018 A7	1.493	3.895	0.461	-0.002	33.01	46.69	20.31	13.73	6.58	

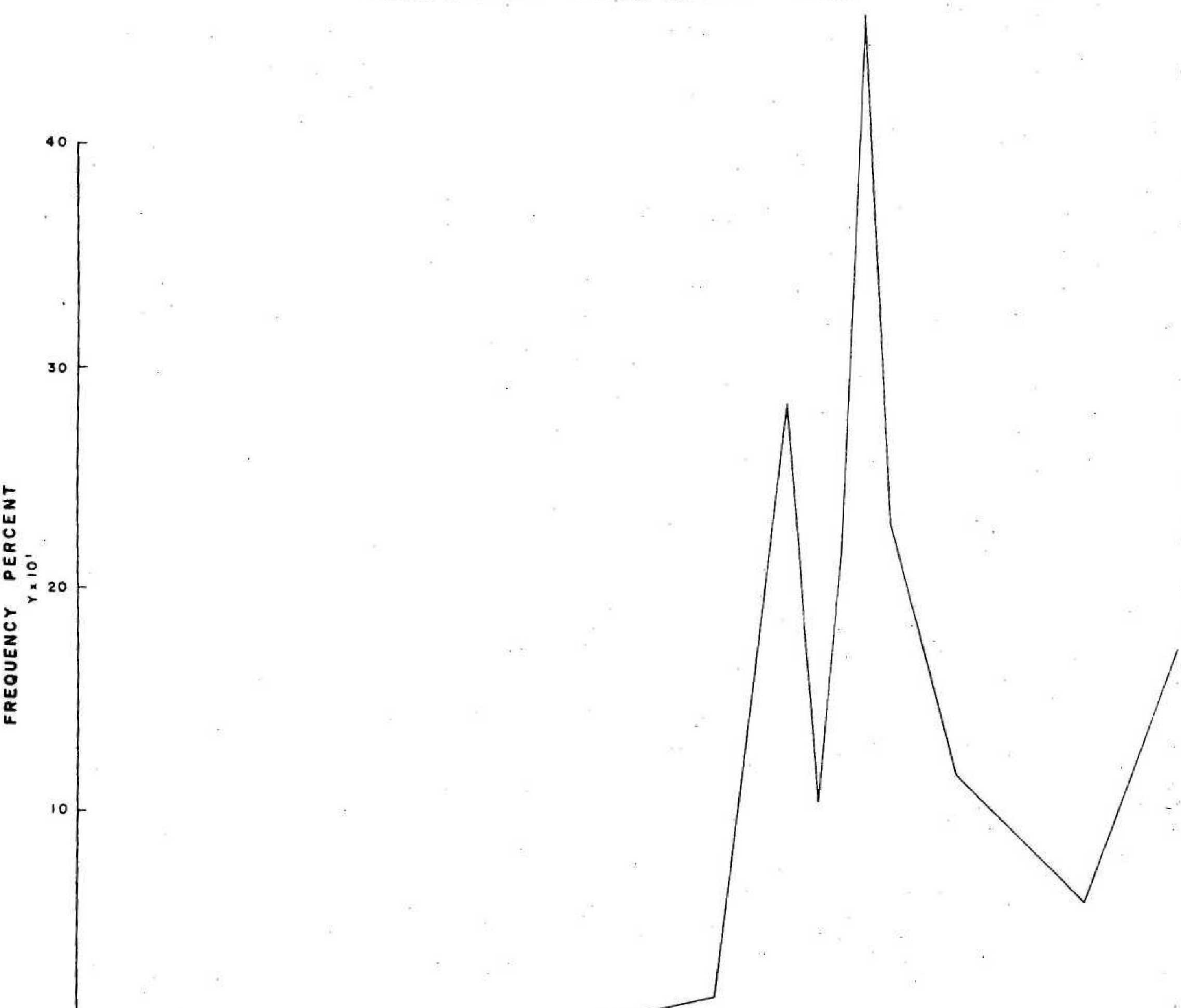
FIG 10A & 10B - EXAMPLE DATA SET
GRSIZE

1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80	COMMENT
				EXAMPLE 2				
CARD TYPE 'A':								
1 3	5 8	17						
CARD TYPE 'B':								
6.70	4.76 2.	83 1.41	0.71	0.50	0.30 0.	149 0.07	4 0.058	
0.048	0.040 0.	034 0.02	8 0.0106	0.005	0.003			
CARD TYPE 'C':								Need only these for next sample if have 3 in Col 45 on Card Type C
		170.0	HYDROMETER	1 4	1 2.658	66.0	0 2	
CARD TYPE 'D':								
1.26	3.58 13.	62 13.82	7.38	5.76 1	2.21 14.	36 1.02	8 1.025	
1.020	1.012 1.	008 1.00	2 1.001	1.000				
				EXAMPLE 3				
CARD TYPE 'A':								
4		18						
CARD TYPE 'B':								
58.5 5	9.5 60.	5 61.5	62.5	63.5 6	4.5 65.	5 66.5	67.5	
68.5 6	9.5 70.	5 71.5	72.5	73.5 7	4.5 75.	5		
CARD TYPE 'C':								As above for repetition
			EXAMPLE 1	1 4				
CARD TYPE 'D':								
3.0	3.5 8.	0 17.0	33.5	61.5 9	5.5 142.	0 137.5	154.0	
141.5 11	6.0 78.	0 49.0	28.5	4.0	5.5			
				EXAMPLE 4				
CARD TYPE 'A':								
3		28						
CARD TYPE 'B'								
970.0 78	0.0 630.	0 720.0	670.0	430.0 93	0.0 630.	0 720.0	550.0	As above for repetitions
670.0 73	0.0 820.	0 400.0	400.0	930.0 65	0.0 870.	0 550.0	1020.0	
650.0 97	0.0 630.	0 750.0	520.0	580.0 80	0.0 390.	0		
CARD TYPE 'C':								
			PHOSPHATE 1	1 4				

FIG II-PRINTED OUTPUT OF PROGRAM GRSIZE

```
SAMPLE NO.= 71635018 A
SIEVING FOR GRAVEL,SETTLING TUBE FOR SAND,PIPETTE FOR MUD
MUD RESULTS EXTRAPOLATED TO 14PHI
UNCORRECTED PARAMETERS
PERCENT GRAVEL = 33,007 PERCENT SAND = 46.688 PERCENT MUD = 20,306(CLAY% =  6,577)
PERCENT FREQUENCIES
    3,3231    8.1851   11.8455    1.4945    2,5048    1.7109    2,3480    1.5946
    1,0149    0.4833    0.6766    1.6916    1.0633    1.3049    0,9666    1.1116
    1.1116    0.8700    0.8216    1.9816    5.5097    7.7329    5,5097    2,9965
    2,9965    3.4798    2.5132    2.8515    3,4034    2.9063    1,7991    1,9120
    1,9503    1.7973    1.4914    1.6953    1.3563    1.0172    0,6781    0,3391
MID-POINTS
   -5,0000   -3.7500   -2.7500   -2.1250   -1,8750   -1,6250   -1,3750   -1.1250
   -0,8750   -0.6250   -0.3750   -0.1250    0.1250    0,3750    0,6250    0,8750
    1.1250    1.3750    1,6250    1.8750    2.1250    2.3750    2,6250    2,8750
    3,1250    3.3750    3.6250    3,8750    4.2500    4.7500    5,2500    5.7500
    6,5000    7.5000    8.5000    9,5000   10,5000   11.5000   12,5000   13,5000
MEAN      =   1.4933
VARIANCE  =  15.1678
STD.DEV.  =   3.8946
SKEWNESS  =   0.4606
KURTOSIS  =  -0,0024


SAMPLE NO.= HYDROMETER
SIEVING FOR GRAVEL,SIEVING FOR SAND,HYDROMETER FOR MUD
UNCORRECTED PARAMETERS
PERCENT GRAVEL =  7.628 PERCENT SAND = 22.121 PERCENT MUD = 70.251(CLAY% =  1.766)
PERCENT FREQUENCIES
    0.5207    1.4794    5.6283    5.7110    3.0497    2,3803    5,0457    5.9341
   22,4719    5.1192    8.5319   13.6511    6,8256   10.2383    1,7064    1.7064
MID-POINTS
    5,7300    3.7950    2.1200    1.0600    0.6050    0.4000    0,2245    0.1115
    0,0660    0.0530    0.0440    0.0370    0.0310    0.0193    0,0078    0.0040
MEAN      =   0.3424
VARIANCE  =   0.6037
STD.DEV.  =   0.7770
SKEWNESS  =   3.7116
KURTOSIS  =  16.4022


SAMPLE NO.= EXAMPLE  1
PARAMETERS FROM CLASSIFIED SET OF READINGS
CORRECTED PARAMETERS
VARIANCE UNBIASED
MEAN      =   67.6976
VARIANCE  =    7.3228
STD.DEV.  =    2.7061
SKEWNESS  =   -0.1141
KURTOSIS  =   -0.0976


SAMPLE NO.= PHOSPHATE1
PARAMETERS FROM SET OF READINGS
CORRECTED PARAMETERS
VARIANCE UNBIASED
MEAN      =   698.5714
VARIANCE  = 33634.9206
STD.DEV.  =   183.3983


SKEWNESS  =   -0.0318
KURTOSIS  =   -1.0490
```

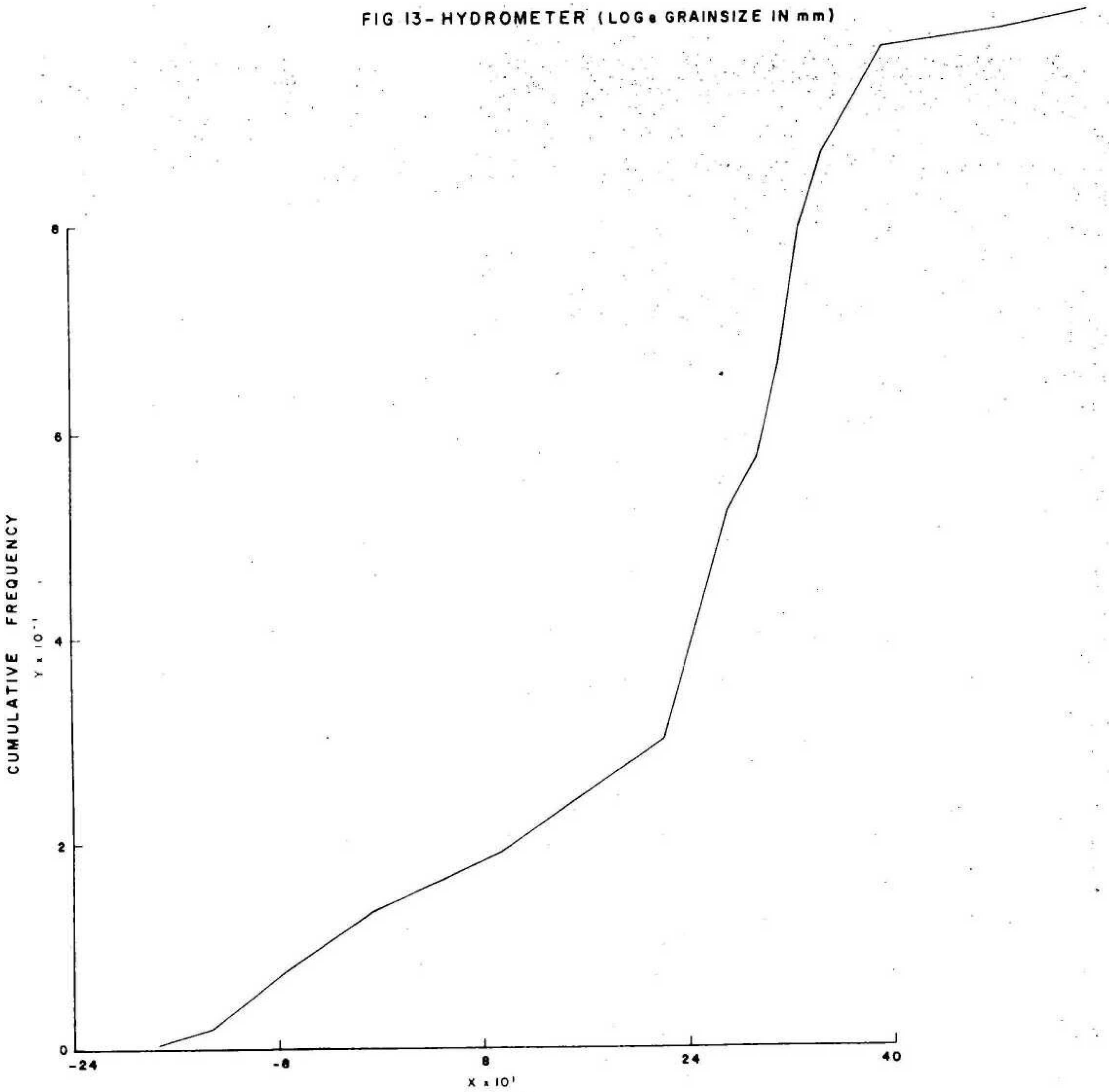
FIG 12-HYDROMETER (LOGe GRAINSIZE IN mm)



To accompany Record 1972/140

M(G) 249

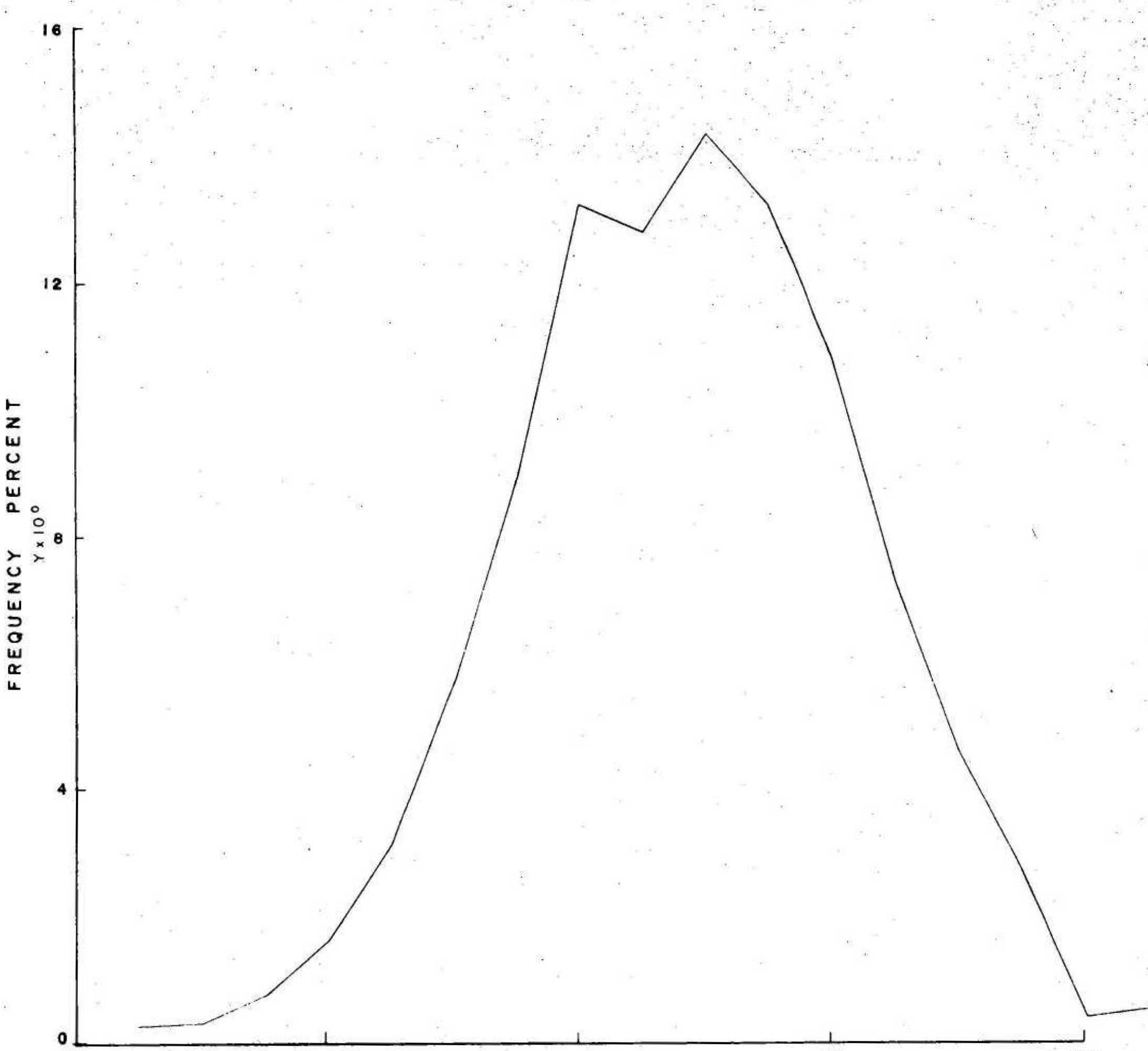
FIG 13- HYDROMETER (LOGe GRAINSIZE IN mm)



To accompany Record 1972/140

M(G)250

FIG 14 - EXAMPLE 1



To accompany Record 1972/140

M(G)251

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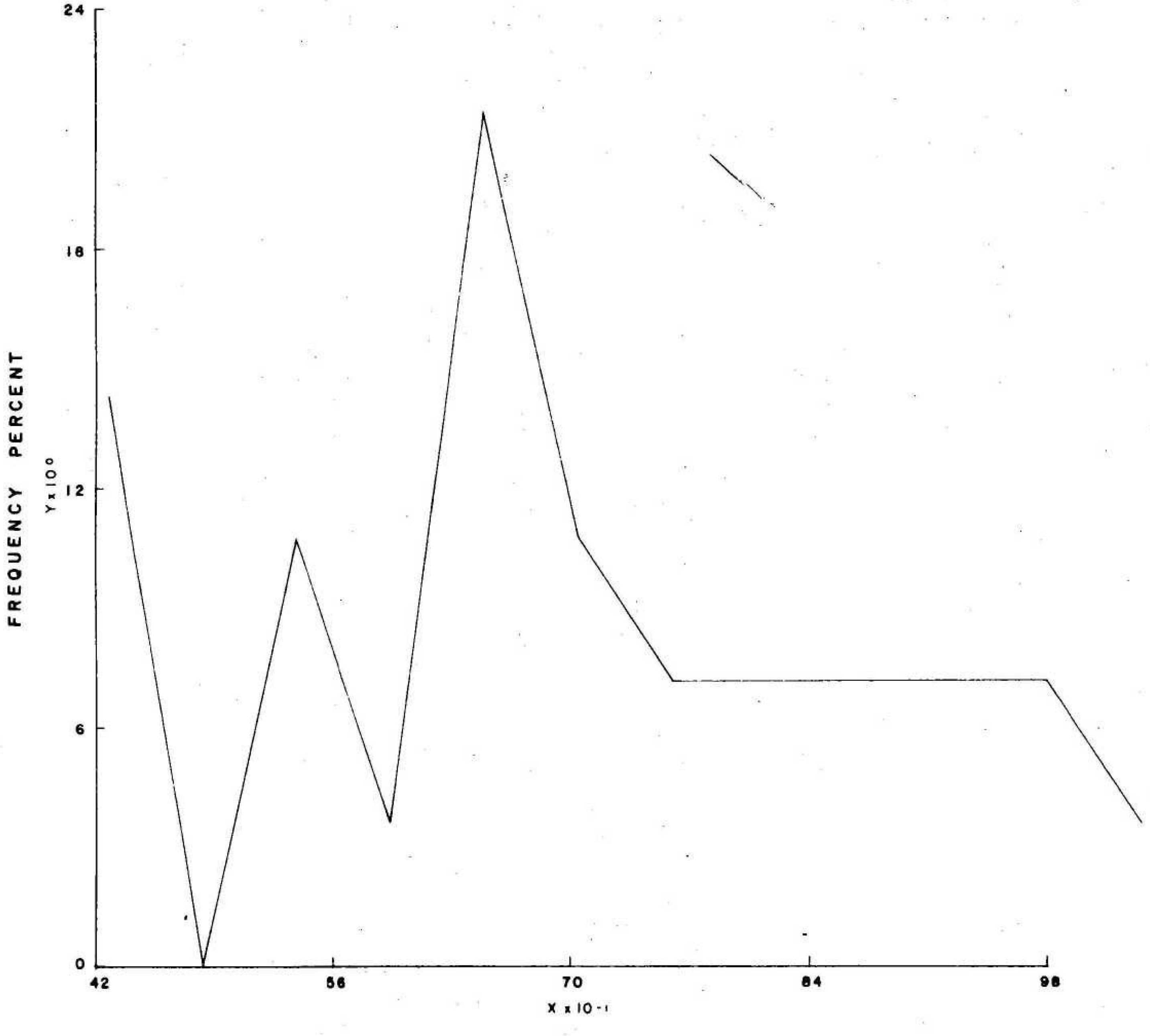
FIG 15 - PHOSPHATE I P.P.M.



To accompany Record 1972/140

M(G)252

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APPENDIX I

Stokes' Law

$$t = \frac{18 h \eta}{(\sigma - \rho) g d^2}$$

Where t = time of fall in secs.

η = viscosity of water in poise (at T °C)

σ = density of quartz in gm/c.c.

ρ = relative density in gm/c.c. (at T °C)

d = grain-size diameter in cms.

g = acceleration due to gravity in cm/sec^2.

Temperature °C	$\frac{18 \eta}{(\sigma - \rho) g}$
18	.0001174
19	.0001145
20	.0001114
21	.0001091
22	.0001065
23	.0001040
24	.0001016
25	.00009931

TIMINGS FOR PIPETTE READINGS

Diameter (phi)	h (cms)	Diameter (cms)	18°C	20°C	22°C	24°C
4.0	20	.00625	Initial reading at 20 sec (represents total mud)			
4.5	20	.00442	2 m 0s	1 m 54 s	1 m 49 s	1 m 44 s
			RE - STIR SAMPLE			
5.0	10	.00313	2 m 0s	1 m 54 s	1 m 49 s	1 m 44 s
5.5	10	.00221	4 m 0s	3 m 48 s	3 m 38 s	3 m 28 s
6.0	10	.00156	8 m 2s	7 m 38 s	7 m 18 s	6 m 58 s
7.0	10	.000782	32 m 0s	30 m 22 s	29 m 2 s	27 m 41 s
8.0	10	.000391	2 hr 8m	2hr 1 m	1hr 56 m	1hr 51 m
9.0	10	.000195	8 hr 35m	2hr 8 m	7hr 47 m	7hr 25 m

APPENDIX II

INSTRUCTIONS FOR BMR SETTLING TUBE

1. Remove sizes greater than 2 mm (-1 phi) and less than 0.0625 mm (4 phi) by wet sieving.

2. Split off approximately 2 g of this sample.

3. Wet sponge with distilled water.

4. Sprinkle sample evenly over the wire mesh and wet sample by pushing mesh on to the sponge.

5. Ensure the average temperature of the water at the top and bottom of the tube is between 20°C and 22°C.

6. Use only distilled water in tube and ensure tube is completely topped up.

OPERATING INSTRUCTIONS

1. Switch on both wall mounted switches.

2. Depress 'power' switch on recorder and wait a few seconds.

3. Insert paper and depress 'chart' switch.

4. Depress 'servo' switch and adjust to approximate starting position with the two 'zero' knobs. (DO NOT TOUCH VERNIER KNOBS - X VERNIER KNOB AFFECTS SWEEP RATE AND MUST BE KEPT IN THE FULLY CLOCKWISE POSITION)

5. Press 'pen' switch and adjust pen to exact start position with the two 'zero' knobs.

6. If necessary test ink level using 'start' and 'reset' buttons - if needed fill through hole in drum.

7. Press 'pen' switch to lift pen from paper.

8. Set sweep rate on 5, 10, or 20 depending on grain-size range expected and range expected and range on convenient (usually 1) setting for amount of vertical movement.

9. Rotate wire mesh on to tube mouth with a smooth even movement (too fast disturbes the water; too slow starts recorder prematurely).

10. After sufficient time has been allowed for the 4 phi sized particles to fall (about three minutes on sweep rate setting 10), press 'servo' switch,

11. Lift wire mesh from tube.

12. Press 'servo' again.

13. Repeat for next sample after any finer particles have fallen.

14. Sediment should be cleared from the sample collecting pan (with the moveable rod at the base of the tube) regularly. If the 'servo' switch is on when this cleared the right-hand zero knob will have to be turned quickly clockwise TO AVOID POSSIBLE DAMAGE TO THE RECORDER.

APPENDIX III

Sweep Rate Setting on BMR Recorder	Actual Sweep Rate
2	0.73 ± .01 sec/cm
5	1.83 ± .04 sec/cm
10	3.65 ± .04 sec/cm
20	7.30 ± .04 sec/cm

DISTANCES OF PEN TRAVEL CORRESPONDING TO DIAMETER OF STANDARD QUARTZ GRAINS

Diameter (microns)	Diameter (phi units)	Time of fall (secs)	Distance in cms for sweep rate setting of 10
2000	-1.0	7.4	2.03
1680	-0.75	8.2	2.25
1410	-0.5	9.1	2.49
1190	-0.25	10.1	2.77
1000	0.0	11.6	3.18
840	0.25	13.3	3.64
710	0.5	15.4	4.22
590	0.75	18.0	4.93
500	1.0	21.5	5.89
420	1.25	25.5	7.00
350	1.5	30.0	8.22
300	1.75	35.0	9.60
250	2.0	42.2	11.55
210	2.25	50.0	13.70
177	2.5	60.0	16.44
149	2.75	71.5	19.59
125	3.0	85	23.3
105	3.25	100	27.3
88	3.5	117	32.0
74	3.75	140	38.3
62.5	4.0	175	47.9

This sweep rate setting of 10 is the most convenient as the output page is 38 cm wide.

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APPENDIX IV

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      PROGRAM GRSIZE
C     THIS PROGRAM USES STATISTICAL MOMENT MEASURES TO CALCULATE THE PARAMETERS,
C  MEAN,STANDARD DEVIATION,SKEWNESS AND KURTOSIS FROM -
C              (1) GRAINSIZE RESULTS
C              (2) CLASSIFIED SETS OF VALUES OF VARIABLES
C          AND(3) SETS OF VALUES OF VARIABLES
C     THE EXPERIMENTAL METHODS USED TO OBTAIN THE GRAINSIZE RESULTS MAY BE ANY
C  COMBINATION OF -
C              (1) SIEVING THE GRAVEL FRACTION
C              (2) SIEVING OR SETTLING TUBE WITH THE SAND FRACTION
C              (3) PIPETTE OR HYDROMETER WITH THE MUD(SILT+CLAY) FRACTION
C     WHEN GRAINSIZE RESULTS ARE ANALYSED,THE PERCENTAGES OF GRAVEL,SAND,SILT
C  AND CLAY ARE ALSO DETERMINED
C     CUMULATIVE FREQUENCY AND FREQUENCY PLOTS,ON EITHER THE LINE-PRINTER OR
C  PLOTTER,FOR ANY DATA SET MAY ALSO BE OBTAINED
      DIMENSION OBS(100),FREQU(100),PTS(100),BOUND(100),JFORM(10),IFM(10
     1),NUM(4)
      REAL KURT
C  READ CARD TYPE A
   10 READ(60,20)(NTYPE,NA,NB,NC,N,NPIPE,NGRAV,NSAND,MUD,NCARD,NSOLY,NC
     1D,CLINT)
   20 FORMAT(10I5,5X,I5,4X,A1,F10.0)
      IF(NTYPE.EQ.0)GO TO 1450
      JUMP=2
      IF(NTYPE.NE.3) GO TO 50
   30 READ(60,40)(PTS(I),I=1,N)
   40 FORMAT(10F8.4)
      GO TO 120
C  READ CARD TYPE B
   50 IF(NSOLY.EQ.0) GO TO 70
      READ(60,60) JFORM
   60 FORMAT(10A8)
      READ(60,JFORM)(BOUND(I),I=1,N)
      GO TO 90
   70 READ(60,80)(BOUND(I),I=1,N)
   80 FORMAT (10F8.4)
   90 DO 110 I=2,N
      IF(BOUND(I-1).GT.BOUND(I)) GO TO 100
      PTS(I-1)=ABS(BOUND(I-1)-BOUND(I))/2.0+BOUND(I-1)
      GO TO 110
  100 PTS(I-1)=ABS(BOUND(I-1)-BOUND(I))/2.0+BOUND(I)
  110 CONTINUE
C  READ CARD TYPE C
  120 READ(60,130) WT1,WT2,WT3,NUM(2),NUM(3),NRET,NGRAF,LNG,SPGRAV,HSWT,
     *N
     1TOT,NHYDRO
  130 FORMAT(3F10.6,A8,A2,I5,2I3,F9.0,F10.0,2I5)
      IF(NTYPE.EQ.3) GO TO 590
      N=N-1
  140 NO=NA+NB+NC
      IF(NTYPE.EQ.4) NO=N
C  READ CARD TYPE D
      IF(NSOLY.EQ.0) GO TO 170
      IF(JUMP.EQ.3) GO TO 160
      READ(60,150) IFM
  150 FORMAT(10A8)
  160 READ(60,IFM)(OBS(I),I=1,NO)
      GO TO 190
  170 READ(60,180)(OBS(I),I=1,NO)
  180 FORMAT (10F8.4)
  190 IF(NTYPE.EQ.4) GO TO 610
C  DETERMINE WEIGHT FREQUENCY CORRESPONDING TO EACH INTERVAL MID-POINT
C  FOR GRAVEL FRACTION
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      TOTG=0.0
  200 IF(NA.EQ.0) 210,220
  210 IF(NGRAV.EQ.0) GO TO 250
      NEXT=1
      CALL EXTRAP(NGRAV,WT1,FREQU,NEXT)
      GO TO 250
  220 IF(WT1.EQ.0.0) GO TO 230
      NAQ=1
      NBQ=NA
      NSPL=0
      CALL SPLIT(NAQ,NBQ,WT1,OBS,FREQU,NSPL)
      GO TO 250
  230 DO 240 J=1,NA
      FREQU(J)=OBS(J)
  240 CONTINUE
C  DETERMINE WEIGHT FREQUENCIES FOR SIEVED SAND FRACTION
  250 TOTS=0.0
      IF(NB.EQ.0) 260,270
  260 IF(NSAND.EQ.0) GO TO 300
      NEXT=1
      CALL EXTRAP(NSAND,WT2,FREQU,NEXT)
      GO TO 300
  270 IF(NTYPE.EQ.2) GO TO 410
      NAQ=NA+1
      NBQ=NA+NB
      IF(WT2.EQ.0.0) GO TO 280
      CALL SPLIT(NAQ,NBQ,WT2,OBS,FREQU,NSPL)
      GO TO 300
  280 DO 290 J=NAQ,NBQ
      JNS=J+NGRAV
      FREQU(JNS)=OBS(J)
  290 CONTINUE
C  DETERMINE WEIGHT FREQUENCIES FOR MUD FRACTION
  300 IF(NC.EQ.0) 310,320
  310 IF(NMUD.EQ.0) GO TO 440
      NEXT=NA+NB+NGRAV+1
      IF(NTYPE.EQ.2) NEXT=NEXT-1
      CALL EXTRAP(NMUD,WT3,FREQU,NEXT)
      GO TO 450
  320 NAQ=NA+NB+1
      NBQ=NA+NB+NC
      IF(SPGRAV.EQ.0.0) GO TO 330
      CALL HYDROM(NAQ,NBQ,WT3,SPGRAV,NHYDRO,NTYPE,NTOT,HSWT,NSAND,OBS,FR
     1EQU,NGRAV,NMUD)
      IF(NPIPE.EQ.0) 440,360
  330 DO 340 J=NAQ,NBQ
      OBS(J)=OBS(J)*50.0
  340 CONTINUE
      IF(NMUD.EQ.0) GO TO 350
      WT=OBS(NBQ)
      NEXT=NBQ+NGRAV
      IF(NTYPE.EQ.2) NEXT=NEXT-1
      CALL EXTRAP(NMUD,WT,FREQU,NEXT)
      GO TO 370
  350 IF(NPIPE.EQ.0) GO TO 370
  360 CALL PIPETTE(NBQ,MZ,PTS,FREQU,OBS,NPIPE,NC,WT3,ISAND,NGRAV,N,NTYPE
     1,BOUND)
      IF(NC.EQ.0.AND.WT3.NE.0.0) GO TO 450
      IF(SPGRAV.NE.0.0) GO TO 440
  370 NAQ=NAQ+1
      DO 390 J=NAQ,NBQ
      IF(NTYPE.EQ.2) GO TO 380
      JNS=J+NSAND+NGRAV
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      FREQU(JNS-1)=OBS(J-1)-OBS(J)
      IF(FREQU(JNS-1).LT.0.0) FREQU(JNS-1)=0.0
      GO TO 390
  380 JNS=J+NGRAV
      FREQU(JNS-2)=OBS(J-1)-OBS(J)
      IF(FREQU(JNS-2).LT.0.0) FREQU(JNS-2)=0.0
  390 CONTINUE
      IF(WT3.EQ.0.0) GO TO 440
      NAQ=NAQ-1
      IF(NTYPE.EQ.2) NAQ=NAQ-1
      NBQ=NBQ-1
      IF(NTYPE.EQ.2) NBQ=NBQ-1
      IF(NPIPE.NE.0) NBQ=NBQ+MZ
      DO 400 J=NAQ,NBQ
      JNS=J+NSAND+NGRAV
      FREQU(JNS)=FREQU(JNS)*WT3/OBS(NA+NB+1)
  400 CONTINUE
      GO TO 440
C  DETERMINE WEIGHT FREQUENCIES FOR SAND FRACTION ANALYSED WITH SETTLING TUBE
  410 NAQ=NA+1
      NBQ=NA+NB
      IF(WT2.EQ.0.0) WT2=1.0
      DO 420 J=NAQ,NBQ
      OBS(J)=OBS(J)*WT2/OBS(NA+NB)
  420 CONTINUE
      NAQ=NA+2
      DO 430 J=NAQ,NBQ
      JNS=J+NGRAV
      FREQU(JNS-1)=OBS(J)-OBS(J-1)
      IF(FREQU(JNS-1).LT.0.0) FREQU(JNS-1)=0.0
  430 CONTINUE
      IF(NC.EQ.0) 310,320
C  DETERMINE TOTAL OF WEIGHT FREQUENCIES AND THEN GRAVEL,SAND,MUD AND
C  CLAY PERCENTAGES.
  440 IF(NC.EQ.0.AND.WT3.NE.0.0) GO TO 360
  450 TOT=0.0
      IF(NPIPE.NE.0) N=N+MZ
      DO 460 J=1,N
      TOT=TOT+FREQU(J)
  460 CONTINUE
      IF(NGRAV.NE.0) TOTG=WT1
      IF(NA.EQ.0) GO TO 480
      DO 470 J=1,NA
      TOTG=TOTG+FREQU(J)
  470 CONTINUE
  480 IF(NB.EQ.0) GO TO 500
      JB=NA+NB+NGRAV
      IF(NTYPE.EQ.2) JB=JB-1
      JA=NA+NGRAV+1
      DO 490 J=JA,JB
      TOTS=TOTS+FREQU(J)
  490 CONTINUE
  500 IF(NSAND.NE.0) TOTS=WT2
      TOTM=TOT-TOTG-TOTS
      TOTS=TOTS*100.0/TOT
      TOTG=TOTG*100.0/TOT
      TOTM=TOTM*100.0/TOT
      TOTSI=0.0
      IF(NC.EQ.0.AND.NPIPE.EQ.0) 510,520
  510 IF(NC.EQ.0.AND.NMUD.EQ.0) GO TO 560
  520 IF(NB.EQ.0) JB=0
      JB=NSAND+JB+1
      IF(PTS(JB).GT.3.0) GO TO 540
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      DO 530 J=JB,N
      NVPTS=IFIX(PTS(J)*1000.0)
      IF(NVPTS.LE.3) GO TO 570
  530 CONTINUE
      TOTC=0.0
      GO TO 640
  540 DO 550 J=JB,N
      IF(IFIX(PTS(J)).GE.8) GO TO 570
  550 CONTINUE
  560 TOTC=0.0
      TOTSI=TOTM
      GO TO 640
  570 NNJ=J-1
      DO 580 I=JB,NNJ
      TOTSI=TOTSI+FREQU(I)
  580 CONTINUE
      TOTSI=TOTSI*100.0/TOT
      TOTC=TOTM-TOTSI
      GO TO 640
C   DETERMINE TOTAL AND FREQUENCIES FOR SETS OF READINGS
  590 DO 600 J=1,N
      FREQU(J)=1.0
  600 CONTINUE
      TOT=FLOAT(N)
      GO TO 640
  610 DO 620 J=1,N
      FREQU(J)=OBS(J)
  620 CONTINUE
      TOT=0.0
      DO 630 J=1,N
      TOT=TOT+OBS(J)
  630 CONTINUE
C   NORMAL PARAMETER COMPUTATION STARTS HERE
C   OBTAIN FIRST FOUR MOMENTS ABOUT THE ORIGIN
  640 SUM1=0.0
      SUM2=0.0
      SUM3=0.0
      SUM4=0.0
      DO 650 J=1,N
      SUM1=SUM1+FREQU(J)*PTS(J)
      SUM2=SUM2+PTS(J)**2*FREQU(J)
      SUM3=SUM3+PTS(J)**3*FREQU(J)
      SUM4=SUM4+PTS(J)**4*FREQU(J)
  650 CONTINUE
      SUM1=SUM1/TOT
      SUM2=SUM2/TOT
      SUM3=SUM3/TOT
      SUM4=SUM4/TOT
C COMPUTE FIRST FOUR MOMENTS ABOUT THE MEAN
      RSUM1=SUM1
      RSUM2=SUM2-SUM1**2
      RSUM3=SUM3-3.  *SUM1*SUM2+2.0*SUM1**3
      RSUM4=SUM4-4.  *SUM1*SUM3+6.0*SUM1**2*SUM2-3.0*SUM1**4
C   COMPUTE UNBIASED SECOND MOMENT ABOUT MEAN
      NNB=0
      IF(NTYPE.EQ.3.OR.NTYPE.EQ.4) 660,670
  660 RSUM2=RSUM2*TOT/(TOT-1.0)
      NNB=1
C   OBTAIN STANDARD DEVIATION,SKEWNESS AND KURTOSIS
  670 STDEV=SQRT(RSUM2)
      SKEW=RSUM3/STDEV**3
      KURT=RSUM4/RSUM2**2-3.0
      IF(CLINT.EQ.0.0.OR.NTYPE.EQ.3) GO TO 680
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      IF(CLINT.EQ.0.0) GO TO 680
      IF(SKEW.GT.0.5.OR.SKEW.LT.-0.5) GO TO 680
C  CORRECT MOMENTS USING SHEPARDS CORRECTIONS
      NNN=1
      RSUM2=RSUM2-CLINT**2/12.0
      RSUM4=RSUM4-CLINT**2*RSUM2/2.0-CLINT**4*7.0/240.0
      STDEV=SQRT(RSUM2)
      KURT=RSUM4/RSUM2**2-3.0
C  SWITCH CONTROL DEPENDING ON DATA TYPE AND PLOTS REQUIRED
  680 IF(NTYPE.EQ.3.AND.NGRAF.EQ.0) GO TO 710
      IF(NTYPE.EQ.4.AND.NGRAF.EQ.0) GO TO 710
      IF(NTYPE.EQ.3)CALL TYPE3(PTS,N,CLINT,STDEV,NXX,FREQU)
C  ADJUST FREQUENCIES TO A PERCENTAGE BASIS
      DO 690 I=1,N
  690 FREQU(I)=FREQU(I)*100.0/TOT
      IF(NGRAF.NE.0) 700,710
  700 CALL GRPLOT(NUM,FREQU,BOUND,N,PTS,RSUM1,STDEV,SKEW,KURT,TOTG,TOTS,
     1TOTSI,TOTC,NGRAF,CLINT,NTYPE,LNG)
      IF(NTYPE.EQ.3) N=N+NXX
  710 IF(NGRAF.EQ.1.OR.NGRAF.EQ.2) GO TO 1380
      WRITE(61,720) NUM(2),NUM(3)
  720 FORMAT(1X/13H SAMPLE NO.= ,A8,A2)
      IF(JUMP.EQ.3) GO TO 1310
      IF(NTYPE.EQ.3) WRITE(61,730)
  730 FORMAT (33H PARAMETERS FROM SET OF READINGS )
      IF(NTYPE.EQ.4) WRITE(61,740)
  740 FORMAT (44H PARAMETERS FROM CLASSIFIED SET OF READINGS )
      IF(NNB.EQ.1) GO TO 1240
C  PRINT OUT TYPE OF EXPERIMENTAL METHOD USED
      IF(NTYPE.EQ.1) 750,990
  750 IF(NC.EQ.0) 760,840
  760 IF(NB.EQ.0) 770,790
  770 WRITE (61,780)
  780 FORMAT (20H SIEVING FOR GRAVEL   )
      GO TO 1140
  790 IF(NA.EQ.0) 800,820
  800 WRITE (61,810)
  810 FORMAT (18H SIEVING FOR SAND )
      GO TO 1140
  820 WRITE (61,830)
  830 FORMAT (29H SIEVING FOR SAND AND GRAVEL )
      GO TO 1140
  840 IF(NA.NE.0.AND.NB.NE.0) 850,890
  850 IF(SPGRAV.EQ.0.0) GO TO 870
      WRITE (61,860)
  860 FORMAT(55H SIEVING FOR GRAVEL,SIEVING FOR SAND,HYDROMETER FOR MUD)
      GO TO 1140
  870 WRITE (61,880)
  880 FORMAT (53H SIEVING FOR GRAVEL,SIEVING FOR SAND,PIPETTE FOR MUD )
      GO TO 1140
  890 IF(NB.EQ.0) 900,950
  900 IF(SPGRAV.EQ.0.0) GO TO 930
  910 WRITE (61,920)
  920 FORMAT (20H HYDROMETER FOR MUD )
      GO TO 1140
  930 WRITE (61,940)
  940 FORMAT (17H PIPETTE FOR MUD )
      GO TO 1140
  950 IF(SPGRAV.EQ.0.0) GO TO 970
      WRITE(61,960)
  960 FORMAT(37H SIEVING FOR SAND,HYDROMETER FOR MUD )
      GO TO 1140
  970 WRITE (61,980)
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  980 FORMAT (34H SIEVING FOR SAND,PIPETTE FOR MUD )
      GO TO 1140
  990 IF(NC.EQ.0) 1000,1050
 1000 IF(NA.EQ.0) 1010,1030
 1010 WRITE (61,1020)
 1020 FORMAT (24H SETTLING TUBE FOR SAND )
      GO TO 1140
 1030 WRITE (61,1040)
 1040 FORMAT (43H SIEVING FOR GRAVEL,SETTLING TUBE FOR SANDS )
      GO TO 1140
 1050 IF(NB.NE.0.AND.NA.NE.0) 1060,1100
 1060 IF(SPGRAV.EQ.0.0) GO TO 1080
      WRITE (61,1070)
 1070 FORMAT(61H SIEVING FOR GRAVEL,SETTLING TUBE FOR SAND,HYDROMETER FO
     1O MUD)
      GO TO 1140
 1080 WRITE (61,1090)
 1090 FORMAT (58H SIEVING FOR GRAVEL,SETTLING TUBE FOR SAND,PIPETTE FOR
     1MUD)
      GO TO 1140
 1100 IF(SPGRAV.EQ.0.0) GO TO 1120
      WRITE (61,1110)
 1110 FORMAT (42H SETTLING TUBE FOR SAND,HYDROMETER FOR MUD)
      GO TO 1140
 1120 WRITE (61,1130)
 1130 FORMAT (39H SETTLING TUBE FOR SAND,PIPETTE FOR MUD )
C  PRINT EXTRA OPTIONS USED.
 1140 IF(NPIPE.EQ.0) GO TO 1160
      WRITE (61,1150) NPIPE
 1150 FORMAT(25H MUD RESULTS EXTRAPOLATED TO,I3,3HPHI)
      GO TO 1150
 1160 IF(NMUD.EQ.0) GO TO 1180
      WRITE(61,1170)
 1170 FORMAT(25H MUD RESULTS EXTRAPOLATED)
 1180 IF(NSAND.EQ.0) GO TO 1200
      WRITE (61,1190)
 1190 FORMAT (25H SAND WEIGHT EXTRAPOLATED)
 1200 IF(NGRAV.EQ.0) GO TO 1220
      WRITE(61,1210)
 1210 FORMAT(25H GRAVEL RESULTS EXTRAPOLATED)
 1220 IF(NSOLY.EQ.0) GO TO 1240
      WRITE(61,100)
  100 FORMAT(25H SOME OBSERVATIONS OMITTED)
 1240 IF(NNN.EQ.1) GO TO 1260
      IF(NTYPE.EQ.3) GO TO 1280
      WRITE (61,1250)
 1250 FORMAT (24H UNCORRECTED PARAMETERS )
      GO TO 1280
 1260 WRITE(61,1270)
 1270 FORMAT (22H CORRECTED PARAMETERS )
 1280 IF(NNB.EQ.1) 1290,1310
 1290 WRITE(61,1300)
 1300 FORMAT (18H VARIANCE UNBIASED)
 1310 IF(NNB.EQ.1.OR.NSOLY.NE.0) GO TO 1330
C  PRINT PERCENTAGES OF GRAVEL,SAND,MUD(=SILT+CLAY) AND CLAY
      WRITE(61,1320) TOTG,TOTS,TOTM,TOTC
 1320 FORMAT(1X,16HPERCENT GRAVEL =,F7.3,1X,14HPERCENT SAND =,F7.3,1X,
     113HPERCENT MUD =,F7.3,8H(CLAY% =,F7.3,1H))
 1330 IF(NNB.EQ.1) GO TO 1360
C  PRINT FREQUENCY-PERCENT CORRESPONDING TO EACH MID-POINT
      WRITE (61,1340)(FREQU(I),I=1,N)
 1340 FORMAT(20H PERCENT FREQUENCIES/(1X,8F10.4))
      IF(JUMP.EQ.3) GO TO 1360
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C  PRINT EACH INTERVAL MID-POINT
      WRITE (61,1350)(PTS(I),I=1,N)
 1350 FORMAT(12H MID-POINTS /(1X,8F10.4))
C  PRINT MEAN,VARIANCE,STANDARD DEVIATION,SKEWNESS AND KURTOSIS
 1360 WRITE (61,1370) RSUM1,RSUM2,STDEV,SKEW,KURT
 1370 FORMAT(11H MEAN      =,F12.4/11H VARIANCE =,F12.4/11H STD.DEV. =,F1
     12.4/11H SKEWNESS =,F12.4/11H KURTOSIS =,F12.4//)
 1380 IF(NCARD.EQ.0) GO TO 1430
      IF(NNB.EQ.1.OR.NSOLY.NE.0) 1390,1410
C  PUNCH SAMPLE NUMBER,CARD IDENTITY NUMBER,MEAN,STANDARD DEVIATION,SKEWNESS AND
C  KURTOSIS
 1390 WRITE(62,1400) NUM(2),NUM(3),NCD,RSUM1,STDEV,SKEW,KURT
 1400 FORMAT(A5,A2,A1,4F8.3)
      GO TO 1430
C  PUNCH CARDS WITH MEAN,STANDARD DEVIATION,SKEWNESS AND KURTOSIS,
C  PERCENT GRAVEL,SAND,MUD,SILT AND CLAY
 1410 WRITE(62,1420) NUM(2),NUM(3),NCD,RSUM1,STDEV,SKEW,KURT,TOTG,TOTS,T
     *0
     1TM,TOTSI,TOTC
 1420 FORMAT(A5,A2,A1,4F8.3,5F6.2)
 1430 IF(NPIPE.NE.0) N=N-MZ
      N=N+1
      GO TO (10,1440,1440)NRET
 1440 JUMP=3
      IF(NRET.EQ.2) 30,120
 1450 END
      SUBROUTINE SPLIT(NAOS,NBOS,WTS,ORSS,FREQ,NSP)
C  THIS SUBROUTINE IS USED IF A FRACTION OF THE ORIGINAL SAMPLE IS SPLIT
C  BEFORE ANALYSES ARE DONE,OR IF PERCENTAGES OF SEPARATE SAMPLE
C  FRACTIONS ARE USED AND A SAMPLE OF EACH FRACTION ANALYSED SEPARATELY,
C  THE SUBROUTINE CONVERTS APPARENT WEIGHTS IN THE APPROPRIATE CLASS
C  INTERVALS, INTO WEIGHTS USED IN THE FINAL COMPUTATIONS.
      DIMENSION ORSS(100),FREQ(100)
      TOTAL=0.0
      DO 10  J=NAOS,NBOS
      TOTAL=TOTAL+ORSS(J)
   10 CONTINUE
      DO 20  J=NAOS,NBOS
      JNS=J+NSP
      FREQ(JNS)=ORSS(J)*WTS/TOTAL
   20 CONTINUE
      RETURN
      END
      SUBROUTINE EXTRAP(NSGM,SWT,FREQ,NEX)
C     THIS SUBROUTINE IS USED IF GRAVEL,SAND OR MUD FRACTIONS ARE PRESENT BUT
C  HAVE NOT BEEN ANALYSED EXPERIMENTALLY, IF REQUIRED THE AMOUNT IN SUCH
C  FRACTIONS IS EXTRAPOLATED USING THE SUM OF DIGITS METHOD.
C     INTERVAL MID-POINTS MUST BE SUPPLIED ON THE ORIGINAL DATA CARDS FOR THESE
C  EXTRAPOLATIONS
      DIMENSION FREQ(100),SINT(100)
      IF(SWT.EQ.0) GO TO 60
      JSUM=0
      NET=NEX+NSGM-1
      IF(NEX.EQ.1) GO TO 20
      NX=NSGM
      DO 10  J=NEX,NET
      JSUM=JSUM+NX
      SINT(J)=FLOAT(NX)
      NX=NX-1
   10 CONTINUE
      GO TO 40
   20 DO 30  J=1,NSGM
      JSUM=JSUM+J
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      SINT(J)=FLOAT(J)
   30 CONTINUE
   40 SSUM=FLOAT(JSUM)
      DO 50  J=NEX,NET
      FREQ(J)=SWT*SINT(J)/SSUM
   50 CONTINUE
   60 RETURN
      END
      SUBROUTINE PIPETTE (NBOA,MB,PTSA,FREQA,OBSA,NPIPA,NCA,WTA3,NSA,NGR
     1,NZ,NTYPA,BOUND)
C  THIS SUBROUTINE EXTRAPOLATES THE REMAINING SILT AND CLAY OF THE
C  PIPETTE OR HYDROMETER ANALYSIS DOWN TO ANY SELECTED GRAINSIZE(IN PHI UNITS).
C  USING THE SUM OF DIGITS METHOD, THE EXTRAPOLATION CAN ALSO BE DONE ON THE
C  TOTAL MUD FRACTION.
C     THE INTERVAL MID-POINTS OF THE EXTRAPOLATED WEIGHTS ARE AUTOMATICALLY
C  DETERMINED
      DIMENSION PTSA(100),RWTA(20),OBSA(100),RINT(20),FREQA(100),BOUND(1
     100)
      MA=IFIX(PTSA(NZ))
      IF(MA.EQ.NPIPA) GO TO 40
      MA=MA+1
      MB=NPIPA-MA
      RA=FLOAT(MA)
      RB=FLOAT(MB)
      ISUM=0
      INT=MB
      DO 10  J=1,MB
      ISUM=ISUM+INT
      RINT(J)=FLOAT(INT)
      INT=INT-1
   10 CONTINUE
      RSUM=FLOAT(ISUM)
      IF(NCA.EQ.0) OBSA(NBOA)=WTA3
      DO 20  J=1,MB
      RWTA(J)=OBSA(NBOA)*RINT(J)/RSUM
   20 CONTINUE
      NBP=NBOA+MB-1
      NAP=NBOA
      IF(NTYPA.EQ.2) NAP=NAP-1
      IF(NTYPA.EQ.2) NBP=NBP-1
      IF(NCA.EQ.0.AND.WTA3.NE.0) NAP=NAP+1
      IF(NCA.EQ.0.AND.WTA3.NE.0) NBP=NBP+1
      NP=1
      DO 30  J=NAP,NBP
      JNS=J+NSA+NGR
      FREQA(JNS)=RWTA(NP)
      NP=NP+1
      PTSA(JNS)=RA+0.5
      BOUND(JNS+1)=RA+1.0
      RA=RA+1.0
   30 CONTINUE
   40 RETURN
      END
      SUBROUTINE HYDROM(NHAQ,NHBQ,HWT3,HGRAV,NHYDR,NHYPE,MTOT,HHWT,MSAND
     1,HOBS,HREQU,MGRAV,MMUD)
C     THIS SUBROUTINE DETERMINES THE WEIGHT FREQUENCIES IN THE MUD SIZE
C  CLASS INTERVALS FROM HYDROMETER RESULTS.
      DIMENSION HOBS(100),HREQU(100)
      IF(NHYDR.EQ.2) GO TO 20
      DO 10  J=NHAQ,NHBQ
      HOBS(J)=HOBS(J)*0.623*HGRAV/(HGRAV-1.0)
   10 CONTINUE
      GO TO 40
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   20 DO 30  J=NHAQ,NHBQ
      HOBS(J)=(HOBS(J)-1.0)*1000*HGRAV/(HGRAV-1.0)
   30 CONTINUE
   40 IF(MTOT.EQ.1) GO TO 100
      NJNS=NHAQ+MSAND+MGRAV
      IF(NHYPE.EQ.2) NJNS=NJNS-1
      IF(HHWT.EQ.0.0) GO TO 50
      HREQU(NJNS)=HWT3-HOBS(NHAQ)*HWT3/HHWT
      IF(HREQU(NJNS).LT.0.0) HREQU(NJNS)=0.0
      GO TO 60
   50 HREQU(NJNS)=HWT3-HOBS(NHAQ)
   60 NHAQ=NHAQ+1
      IF(HHWT.EQ.0.0) GO TO 80
      DO 70  J=NHAQ,NHBQ
      NJNS=J+MSAND+MGRAV
      IF(NHYPE.EQ.2) NJNS=NJNS-1
      HREQU(NJNS)=(HOBS(J-1)-HOBS(J))*HWT3/HHWT
      IF(HREQU(NJNS).LT.0.0) HREQU(NJNS)=0.0
   70 CONTINUE
      GO TO 140
   80 DO 90  J=NHAQ,NHBQ
      NJNS=J+MSAND+MGRAV
      IF(NHYPE.EQ.2) NJNS=J-1
      HREQU(NJNS)=HOBS(J-1)-HOBS(J)
   90 CONTINUE
      GO TO 140
  100 NHAQ=NHAQ+1
      IF(HWT3.EQ.0.0) GO TO 120
      DO 110 J=NHAQ,NHBQ
      NJNS=J+MSAND
      IF(NHYPE.EQ.2) NJNS=NJNS-1
      HREQU(NJNS-1)=(HOBS(J-1)-HOBS(J))*HWT3/HOBS(NHAQ-1)
  110 CONTINUE
      GO TO 140
  120 DO 130 J=NHAQ,NHBQ
      NJNS=J+MSAND+MGRAV
      IF(NHYPE.EQ.2) NJNS=NJNS-1
      HREQU(NJNS-1)=HOBS(J-1)-HOBS(J)
  130 CONTINUE
  140 IF(HOBS(NHBQ).LT.1.0E-5.OR.MMUD.EQ.0) GO TO 170
      IF(HHWT.NE.0.0) GO TO 150
      HW=HOBS(NHBQ)
      GO TO 160
  150 HW=HOBS(NHBQ)*HWT3/HHWT
  160 NHEX=NHBQ+MGRAV
      IF(NHYPE.EQ.2) NHEX=NHEX-1
      IF(MTOT.EQ.0) NHEX=NHEX+1
      CALL EXTRAP(MMUD,HW,HREQU,NHEX)
  170 RETURN
      END
      SUBROUTINE GRPLOT(NUM,FREQU,BOUND,N,PTS,RSUM1,STDEV,SKEW,KURT,TOTG
     1,TOTS,TOTSI,TOTC,NGRAF,CLINT,NTYPE,LNG)
C     THIS SUBROUTINE DETERMINES THE CUMULATIVE FREQUENCIES AND MAKES CALLS TO
C  APPROPRIATE PLOTTING SUBROUTINE DEPENDING ON OPTIONS SELECTED
      DIMENSION NUM(4),FREQU(100),BOUND(100),PTS(100),FR(100,1),CUM(100,
     11),GREQU(100),NFR(3),NCUMFR(3)
      NFR(1)=8H*FREQUEN
      NFR(2)=8HCY PERCE
      NFR(3)=8HNT*
      NCUMFR(1)=8H*CUMULAT
      NCUMFR(2)=8HIVE FREQ
      NCUMFR(3)=8HUENCY*
      NUM(1)=8H*
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      NUM(4)=8H*
      IF(NGRAF.EQ.1.OR.NGRAF.EQ.3) GO TO 30
      CUMTOT=0.0
      DO 20 I=1,N
      IF(PTS(2).LT.PTS(1).AND.LNG.NE.1) GO TO 10
      CUMTOT=CUMTOT+FREQU(I)
      CUM(I,1)=CUMTOT
      GO TO 20
   10 J=N-I+1
      CUMTOT=CUMTOT+FREQU(J)
      CUM(J,1)=CUMTOT
   20 CONTINUE
   30 IF(CLINT.NE.0.0.OR.NTYPE.EQ.3) GO TO 70
      IF(LNG.NE.1) GO TO 50
      DO 40 I=1,N
   40 PTS(I)=-ALOG(PTS(I))
   50 CALL FRSCALE(FREQU,BOUND,N,GREQU)
      DO 60 I=1,N
   60 FR(I,1)=GREQU(I)
      GO TO 90
   70 DO 80 I=1,N
   80 FR(I,1)=FREQU(I)
   90 IF(NGRAF.EQ.3.OR.NGRAF.EQ.4) GO TO 150
      CALL QUIKPLOT(PTS,FR,-N,-1,8H*MID-PT*,NFR)
      IF(NTYPE.EQ.3.OR.NTYPE.EQ.4) GO TO 110
      WRITE(61,100) NUM(2),NUM(3),TOTG,TOTS,TOTSI,TOTC,RSUM1,STDEV,SKEW,
     *K
     1URT
  100 FORMAT(1X/8H SAMPLE ,A8,A2,4X,9HGRAVEL% =,F7.3,4X,7HSAND% =,F7.3,4
     1X,7HSILT% =,F7.3,4X,7HCLAY% =,F7.3//22X,6HMEAN =,F9.4,3X,9HSTD.DEV
     2.=,F9.4,3X,10HSKEWNESS =,F9.4,3X,10HKURTOSIS =,F9.4)
      GO TO 130
  110 WRITE(61,120) NUM(2),NUM(3),RSUM1,STDEV,SKEW,KURT
  120 FORMAT(1X/8H SAMPLE ,A8,A2,4X,6HMEAN =,F9.4,3X,9HSTD.DEV.=,F9.4,3X
     1,10HSKEWNESS =,F9.4,3X,10HKURTOSIS =,F9.4)
  130 IF(NGRAF.EQ.1.OR.NGRAF.EQ.2) GO TO 140
      CALL AUTOPLOT(PTS,FR,-N,-1,NUM,NFR)
  140 IF(NGRAF.NE.2.AND.NGRAF.NE.5) GO TO 160
      CALL QUIKPLOT(PTS,CUM,-N,-1,8H*MID-PT*,NCUMFR)
      WRITE(61,150)
  150 FORMAT(1X///)
  160 IF(NGRAF.NE.4.AND.NGRAF.NE.5) GO TO 170
      CALL AUTOPLOT(PTS,CUM,-N,-1,NUM,NCUMFR)
  170 IF(LNG.NE.1) GO TO 190
      DO 180 I=1,N
  180 PTS(I)=EXP(-PTS(I))
  190 RETURN
      END
      SUBROUTINE FRSCALE(FREQU,BOUND,N,GREQU)
C     THIS SUBROUTINE SCALES DOWN THE FREQUENCY VALUES CORRESPONDING TO CLASS
C   INTERVALS WHICH ARE LARGER THAN THE SMALLEST CLASS INTERVAL.FREQUENCIES SO
C   OBTAINED ESTIMATE THE FREQUENCIES WHICH WOULD HAVE BEEN OBTAINED IF ALL CLASS
C   INTERVALS HAD BEEN EQUAL TO THE SMALLEST INTERVAL USED.
C     THESE FREQUENCIES CAN BE THEN USED TO GIVE A TRUE REPRESENTATION OF THE
C   FREQUENCY DISTRIBUTION.
      DIMENSION FREQU(100),BOUND(100),GREQU(100)
      N=N+1
      DO 20 I=2,N
      IF(I.EQ.2) GO TO 10
      R=ABS(BOUND(I)-BOUND(I-1))
      IF(R.LT.RPT) RPT=R
      GO TO 20
   10 RPT=ABS(BOUND(2)-BOUND(1))
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   20 CONTINUE
      DO 30 I=2,N
      NX=IFIX(ABS(BOUND(I)-BOUND(I-1))/RPT+0.5)
      XX=FLOAT(NX)
      J=I-1
      QREQU(J)=FREQU(J)/XX
   30 CONTINUE
      N=N-1
      RETURN
      END
      SUBROUTINE TYPE3(PTS,N,CLINT,STDEV,NXX,FREQU)
C     THIS SUBROUTINE IS USED WITH SETS OF UNCLASSIFIED DATA VALUES IF
C  CUMULATIVE OR FREQUENCY PLOTS ARE REQUIRED. THE READINGS ARE CLASSIFIED INTO
C  EQUAL CLASS INTERVALS. THE CLASS INTERVAL SIZE IS GIVEN BY THE USER OR SET
C  AT 0.3 STANDARD DEVIATIONS IN DEFAULT.
      DIMENSION PTS(100),FREQU(100),VINT(100)
      NX=N-1
   10 NL=0
      DO 30 I=1,NX
      IF(PTS(I+1).LT.PTS(I)) 20,30
   20 X=PTS(I+1)
      Y=PTS(I)
      PTS(I)=X
      PTS(I+1)=Y
      NL=NL+1
   30 CONTINUE
      NX=NX-1
      IF(NL.EQ.0.OR.NX.EQ.1) 40,10
   40 IF(CLINT.EQ.0.0) CLINT=STDEV*0.3
      NINT=IFIX((PTS(N)-PTS(1))/CLINT)+1
      K=1
      DO 90 I=1,NINT
      VINT(1)=PTS(1)+CLINT
      IF(I.EQ.1) GO TO 50
      VINT(I)=VINT(I-1)+CLINT
   50 NN=0
      DO 70 J=K,N
      IF(PTS(J).LT.VINT(I)) 60,80
   60 NN=NN+1
   70 CONTINUE
   80 FREQU(I)=NN
      K=J
   90 CONTINUE
      PTS(1)=PTS(1)+CLINT/2.0
      DO 100 I=2,NINT
  100 PTS(I)=PTS(I-1)+CLINT
      NXX=N-NINT
      N=NINT
      RETURN
      END
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