SIZE DISTRIBUTIONS OF SOURCE ROCKS OF SEDIMENTS.

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ABSTRACT. Five samples of mechanically disintegrated igneous rocks, and two samples of chemically weathered igneous rock were collected in place and subjected to mechanical analysis. The size frequency distributions of the particles show a surprising similarity to the curves obtained from transported sedimentary material. Statistical analysis demonstrates that the "degree of sorting" is commensurate with that of sediments, but the skewness of the distributions is reversed as compared to coarse sediments. It was also found that the size distributions of the source rocks agree with Rosin's law of crushing, and the possible implications of this agreement are discussed.

INTRODUCTION.

CONSIDERABLE data have been collected on the size distributions of sediments, and the increased application of statistical devices within recent years has made possible the detailed description and comparison of many kinds of deposits. There is, however, a paucity of quantitative data on the size distributions and other physical properties of the source rocks from which the sediments are derived. It is the purpose of the present paper to examine several source rocks in terms of the statistical parameters of their size distributions, and to relate these parameters to those commonly found among coarse and medium-grained sediments.

The laboratory determinations and statistical computations are the work of the junior author; the senior author is responsible for the organization and mode of presentation of the data. Both writers wish to acknowledge the helpful suggestions of Dr. Carl Eckart of the Department of Physics, and Dr. F. J. Pettijohn of the Department of Geology of the University of Chicago.

COLLECTION AND ANALYSIS OF THE SAMPLES.

The prime requisite of the study was the collection of samples weathered strictly in place, and sufficiently disintegrated so that they could be analyzed without further preparation. Two situations were chosen. The first was a thoroughly chemically weathered igneous complex (the Carolina Gneiss) in western North Carolina, and the second was a series of physically disaggregated granite and gneiss boulders in the Wisconsin drift northwest of Chicago. These latter boulders are so disintegrated that they crumble when handled, and yet the mineral grains appear to be unaltered. It seems likely that hydration of the micas may produce a shattering or loosening of the crystal matrix. Seven samples were collected; their characteristics are indicated by the following data:

Sample 1. Gray, medium-grained granite, thoroughly disaggregated in place. Collected in gravel pit southeast of Fox River Grove, Illinois.

Sample 2. Gray, coarse-grained granite, thoroughly disaggregated in place. Collected in gravel pit southeast of Cary, Illinois.

Sample 3. Gray, coarse-grained granite, thoroughly disaggregated in place. Collected in same locality as sample 2.

Sample 4. Pink, medium-grained gneiss, fairly well disaggregated. Collected in same locality as sample 1.

Sample 5. Pink, medium-grained granite, fairly well disaggregated. Collected in same locality as sample 1.

Sample 6. Yellowish sandy clay, micaceous, thoroughly incoherent. Collected in clay pit just east of Sprucepine, North Carolina.

Sample 7. Yellowish sandy clay, micaceous, thoroughly incoherent. Collected from highway cut just east of Burnsville, North Carolina.

Samples 1 to 5 were treated in a standardized manner in the laboratory. The material of each sample was rubbed between the fingers, whereupon it crumbled to fragments and crystals ranging from about 8 mm. diameter to sand size. Examination with a binocular microscope showed that particles larger than 1 mm. were mainly clusters of feldspar and quartz grains, with adhering flakes of mica. Particles smaller than 1 mm. were almost entirely monomineralic. Thus the disintegration was not sufficient to separate all the individual crystals, and hence the analyses do not reflect the original size distribution of the granite crystals. Rather the fragments suggest a source rock for gravel and sand. The samples were sieved for ten minutes in a Ro-Tap, using sieves spaced at Wentworth intervals. A small amount of material remained in the pan below the 1/16 mm. sieve; this was arbitrarily assigned to the 1/16–1/32 mm. grade. The sieve residues were weighed and calculated as percentages, which are shown in Table 1.

TABLE 1.

SIZE COMPOSITION OF SOURCE ROCKS—WEIGHT PERCENTAGES.

Grade (mm.)	ø	1	2	3	4	5	6	7
8–4	–3––2	3.1	9.8	6.2	2.7	4.8	—	—
4–2	–2––1	36.0	32.2	35.2	10.7	42.3	2.6	8.8
2–1	–1–0	29.6	26.5	23.4	28.4	30.5	8.7	11.8
1–½	0–1	14.5	15.6	12.9	27.0	11.6	15.3	15.9
½–¼	1–2	9.0	8.2	9.3	16.7	5.8	16.8	16.4
¼–⅛	2–3	4.4	3.8	6.4	8.5	2.9	13.8	13.0
⅛–1/16	3–4	2.3	1.8	3.8	3.8	1.1	9.9	9.1
1/16–1/32	4–5	1.1	1.5	2.8	2.2	1.0	10.2	12.3
1/32–1/64	5–6	—	—	—	—	—	8.9	1.0
1/64–1/128	6–7	—	—	—	—	—	3.5	2.4

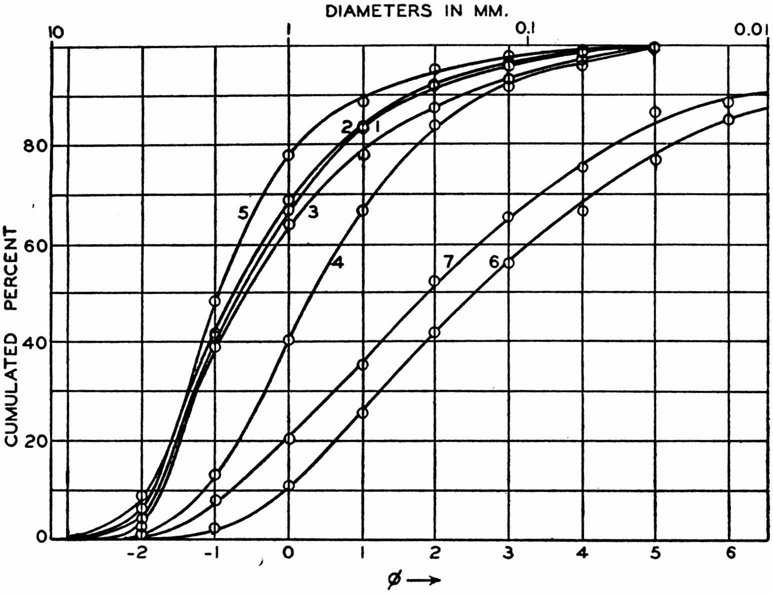

Fig. 1. Cumulative curves of weathered source rocks.

Samples 6 and 7 were chemically weathered and contained appreciable amounts of clayey material. These samples were accordingly dispersed with N/100 sodium oxalate solution and subjected to a composite sieve and pipette analysis (Krumbein and Pettijohn, 1938, pp. 166 ff.). The combined data are included in Table 1.

The cumulative curves of the seven samples are shown in Fig. 1. The four granites cluster about each other (samples 1, 2, 3, 5); the gneiss (sample 4) is similar to the granite curves but displaced toward larger phi values; the chemically weathered samples (6 and 7) show a gentler slope. It is to be noted that these curves do not differ markedly from cumulative curves of some sediments, and this similarity is even more striking when the statistical parameters of the samples are compared.

STATISTICAL ANALYSIS OF THE DATA.

The first three phi moments of the source rocks were computed by the standard "short method" (Krumbein and Pettijohn, 1938, pp. 251 ff.). The data are shown in Table 2. The

TABLE 2.

STATISTICAL DATA OF SOURCE ROCKS.

Sample	M_ϕ	Geometric mean (mm.)	σ_ϕ	$\alpha_{3\phi}$
1	−0.32	1.24	1.41	+1.14
2	−0.44	1.36	1.48	+0.87
3	−0.18	1.13	1.70	+1.00
4	+0.54	0.72	1.47	+0.37
5	−0.61	1.52	1.28	+1.40
6	+2.37	0.20	1.96	+0.23
7	+1.68	0.31	1.96	+0.31

range in value of the phi mean, M_ϕ, shows that the average size of the distributions lies mainly between 1 and 2 mm., except for the chemically weathered material, which is finer, and lies between ½ and ⅛ mm. The phi standard deviation, σ_ϕ, is fairly uniform for the physically weathered material, ranging about the value 1.4, whereas the chemically weathered distributions have values close to 2.0. The geometrical significance of these values is that the chemically weathered materials show a wider spread about their mean values, which may be seen from Fig. 1. The standard deviation and similar measures of spread are usually interpreted as measures of the "degree of sorting," and it is interesting to compare these measures with accepted values of sorted sediments. Trask (1932) divided sediments into three types on the basis of their *So* (sorting coefficient) values. Trask's coefficient is based on quartiles rather than on moments, but a direct comparison is possible by use of the phi quartile deviation (Krumbein and Pettijohn, 1938, pp. 234-235). From such a comparison it is found that samples 1 to 5 fall within the range of Trask's "well-sorted" sediments, and samples 6 and 7 are in the class of "normally sorted" sediments. *A priori* it would seem that the source rock should be less well sorted than any sediment derived from it, but it is obvious from these data that that concept must be qualified.

The degree of spread of the source rock distributions bears further on the term "sorting" as it is commonly used. It is clear that the mere existence of a low degree of spread is no indication that the material has been subjected to any sorting process whatever. Some degree of spread is, as a matter of fact, an attribute of any frequency distribution regardless of origin. For this reason Wadell, for example, suggested that the term "statistical sorting" be used for such measures, to indicate that a descriptive statistical device is being used, instead of a dynamical concept. It cannot be emphasized too strongly that an interpretation of the "degree of sorting" should be made with caution, because a number of factors may influence it. It is even conceivable that violent transportation may result in an increase of the spread away from the source, due to an increase of broken particles in the distribution en route.

The third moments of the distributions (α_3 in phi terms) vary about the value of $+1.0$ for the physically weathered granites, as shown in Table 2. The gneiss (sample 4) is appreciably different, and resembles the chemically weathered rocks, for which α_3 ranges from 0.2 to 0.3. Without exception the values are positive, and in this respect they differ from numerous coarse sediments. To check this point, the several hundred histograms published by Wentworth (1931) were examined by inspection, and the great majority of the coarser sediments showed a negative phi skewness. It is possible, therefore, that the positive skewness of the source rocks may have a genetic significance. If it is a tendency for coarser source materials to be skewed positively, selective transportation may result in the development of negatively skewed distributions in two ways at least. The coarser material may be left behind, or if transported, the coarser particles may wear down by abrasion more rapidly than small particles. The net effect may be an increase in the percentage of grains in the smaller sizes and a corresponding decrease in the coarser sizes, with corresponding changes in the shape of the distribution, until the skewness becomes actually negative. It is interesting to note in this connection that a change from positive to negative skewness presumably involves a stage with a zero third moment, inasmuch as the positive value must vanish before negative values appear.

A study of the progressive changes in the third moment along a stream would shed light on this question.

Fine-grained sediments appear to behave in a manner different from coarse sediments. Many silts and muds show a positive phi skewness—the sediments of Barataria Bay fall in this category (Krumbein and Aberdeen, 1937). Miss Gripenberg (1934) showed that an increased skewness was developed during transportation, and this skewness is increasingly positive in a phi sense. Miss Gripenberg's analysis applies to fine sediments carried by non-selective transportation, presumably by laminar flow. It appears from this that the full understanding of skewness as a function of distance from source must await much more quantitative data, both on coarse and fine sediments. There seems to be no *a priori* reason why coarse and fine sediments may not behave differently in transport.

A study of Table 1 shows that the largest percentage of material in the granites is contained in the 4−2 mm. grade. This also is in marked contrast to coarse sediments, in which that grade rarely appears as a maximum (Wentworth, 1931). The nature of the grains in the source rocks offers an explanation of this situation. The largest grade (8−4 mm.) consists entirely of rock fragments with the crystals tightly interlocked, and so are comparatively resistant to breakage during transport. The smaller grains in the distribution (under 1 mm.) consist almost entirely of single mineral grains. These also would tend to remain whole during transport. The particles in the 4−2 mm. grade, on the other hand, consist largely of two or three crystals locked together. It seems probable that the rigors of transportation could more readily break such grains between the crystal boundaries, than either the larger or smaller particles. On this assumption, particles in the 4−2 mm. grade would disappear comparatively rapidly, perhaps affording a natural discontinuity in the distributions of gravel on the one side and sand on the other, as the load is carried along the stream.

ROSIN'S LAW OF CRUSHING.

In an attempt to determine whether the size distributions of source rocks fit into any recognizable category, the data were tested by means of Rosin's law, which has found wide application in engineering practice, especially in the study of crushed coal. The law was introduced in 1934 by Rosin and Rammler as a function of the type

$$R = 100 \ e^{-bx^n}$$

where R is the weight per cent retained on a sieve of mesh x, e is the number 2.7188, and b and n are constants for any given material. More recently Bennett (1936) reviewed the basis for the law and showed that it could be obtained directly from probability considerations in the form

$$R = 100 \ e^{-(x/k)^n}$$

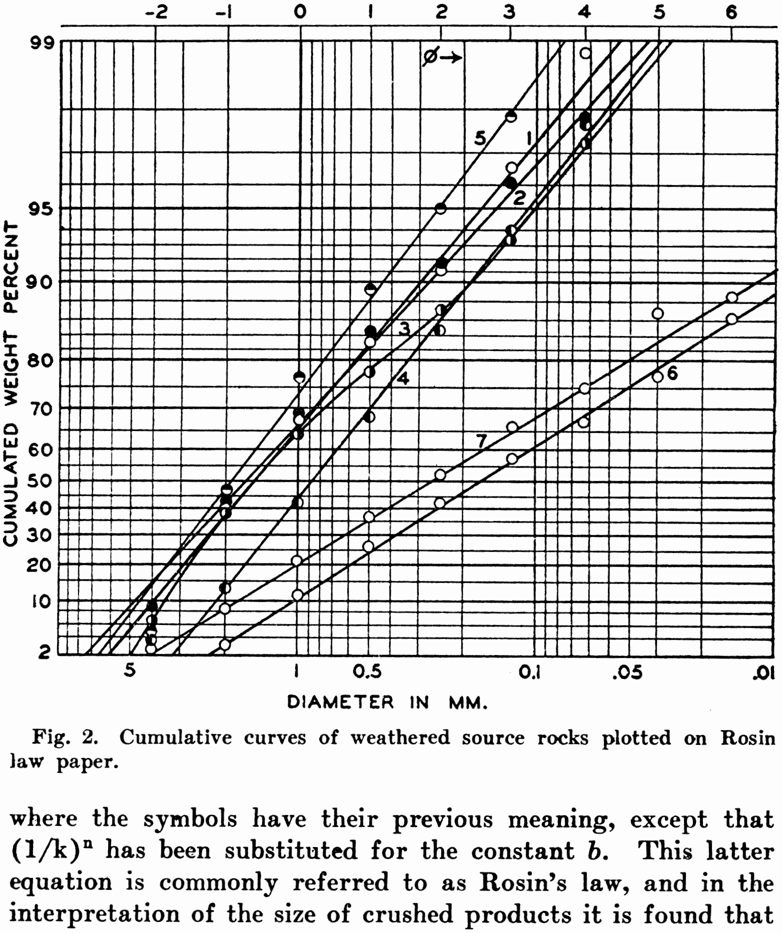

Fig. 2. Cumulative curves of weathered source rocks plotted on Rosin law paper.

where the symbols have their previous meaning, except that $(1/k)^n$ has been substituted for the constant b. This latter equation is commonly referred to as Rosin's law, and in the interpretation of the size of crushed products it is found that k represents an average size, and n represents a reciprocal of the spread of the curve, a concept similar to the "sorting value" of sediments, except that it decreases as the spread increases.

In 1938 Geer and Yancey developed a simple method of determining k and n by means of special graph paper. The frequency scale is so constructed that if an ordinary logarithmic cumulative curve be plotted, the distribution is a straight line if it follows Rosin's law. Moreover, the scale factors are so adjusted that n is read directly from the slope of the line, and k is read directly from an intercept. Thus it becomes merely mechanical to test whether Rosin's law applies in a given case.

Fig. 2 is a graph of the source rocks on Geer and Yancey's special paper. The straight line relations are satisfactory in all cases except that of sample 3, one of the physically weathered

TABLE 3.

ROSIN LAW PARAMETERS OF SOURCE ROCKS.

Sample	k (mm.)	n
1	1.95	1.19
2	2.05	1.04
3	—	—
4	1.12	1.19
5	2.40	1.28
6	0.28	0.63
7	0.48	0.62

granites. From the graph it is found that n and k have the values shown in Table 3. The value of k is merely an average size (it is found by reading the mm. value corresponding to the point of intersection of the straight line and the 36.8 per cent line of the vertical scale). The values of n (the tangent of the angle of slope) cluster about the value 1.2 for the first five samples, and are approximately half that large for the chemically weathered material. This is in contrast to the values of σ_ϕ from Table 2, an indication of the approximately reciprocal nature of n and σ_ϕ.

Rosin's law has been found to fit artificially crushed products of many kinds and sizes, although most data are available on coal. This would suggest that data which fit Rosin's law bear evidence of crushing phenomena, but such a conclusion may not be justifiable. In his development of the theory, Bennett showed that the law arose from the random breakage of the material, and to that extent it seems likely that the process of physical weathering may follow the law. The values of n for crushed coal lie between 0.5 and 1.5, which covers the range of n for the seven samples considered here. The interpretation is not so direct for the chemically weathered samples.

It seemed to the writers that in addition to physically weathered rocks, certain sedimentary materials may follow Rosin's law, especially glacial tills, where presumably the ice crushes its load with no selective effect. Surprisingly enough, of some 50 tills tested, about ten showed good agreement with straight lines on Geer and Yancey's paper. The best agreement was found among tills of Early Wisconsin age (samples A to E in Krumbein, 1933), all of which yielded excellent lines. Among samples which did not plot as straight lines, some could be explained on the basis of the incorporation of well-sorted sand into the till near its outer border.

It was also found that some pyroclastic materials of the type described by Moore (1934) yielded good straight lines. Moore's samples represented *nuee ardente* deposits from the Crater Lake region. On the other hand, no typical coarse, well-sorted stream or beach sediments yielded straight lines on the paper, although some fine-grained sediments of the Barataria Bay type gave approximate straight lines, similar to curve 3 of Fig. 2. This latter effect may be due, however, to breakage of fine particles during dispersion for mechanical analysis.

From such data it is tentatively concluded that Rosin's law may prove useful to geologists in the study of sedimentary source materials and sediments belonging to categories involving random breakage rather than high degrees of selection. In addition, it appears that coarse materials are more sensitive to this analysis than fine; this may be due to differences in the laws controlling the transportation and deposition of coarse and fine sediments.

GENERAL SUMMARY.

The present paper represents an approach to a fuller understanding of source rocks of sediments, and the relation between their characteristics and the characteristics of the sediments derived from them. If disintegrated source rocks in general tend to follow Rosin's law, it should be possible to investigate the implications of this agreement in terms of the processes of random breakage which may occur during decay. Moreover, by studying the progressive changes in the Rosin parameters as the sediment is followed along a stream course, it should be possible to determine the distance required to cause significant departures from Rosin's law. By correlating such data with other statistical parameters of the sediment, in terms of possible changes from positive to negative skewness, light may be shed on the selective processes involved in transportation.

It also appears probable, from this study, that coarse and fine sediments may disclose significant differences in their response to transporting media. Whether these differences are due entirely to segregation into traction and suspension loads the writers are not prepared to state.

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