MEASURING INTERCEPT SPHERICITY OF SAND GRAINS.

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ABSTRACT. A measuring wedge, by which three mutually perpendicular diameters of sand grains may be measured rapidly, accurately, and with a minimum of eye-strain, is described and figured. From these three diameters the intercept sphericity, the breadth/length ratio, and the flatness ratio may be determined. The applicability of intercept sphericities to particles having euhedral form, cleavage, or parting is discussed and the advantages of three-dimensional measurements of sphericity are outlined.

THE sphericity of large and small sediment particles is now determined by different methods. For pebbles and coarser fragments, the volume of the pebble is measured and compared to the volume of the smallest circumscribing sphere, the sphericity being defined by Wadell[1] as

$$\Psi = \sqrt[3]{\frac{\text{volume of the fragment}}{\text{volume of the smallest circumscribing sphere}}} \quad \ldots (1)$$

For sand and smaller particles that must be magnified, measurements are made only in the plane normal to the vertical axis of the microscope or projection apparatus. Various areas or diameters in this plane have been measured by different investigators, and consequently there are several definitions of "projection" or two-dimensional sphericity.

In projection methods, however, the third or "vertical" dimension is neglected. It is thus possible for a quartz sphere and a thin mica flake of circular cross-section to have the same projection sphericity. Although this is an extreme example, the deviation of projection sphericity from true sphericity is large for many grains. It is the purpose of this paper to show (1) that Krumbein's[2] intercept method of determining three-dimensional sphericity of pebbles is also applicable to smaller particles, and (2) that, with an apparatus designed by the writer, three-dimensional sphericity of medium and coarse sand grains may be obtained rapidly, accurately, and with a minimum of eye-strain.

[1] Wadell, Hakon: 1934, "Shape determinations of large sedimental rock-fragments," Pan-American Geologist, Vol. 61, pp. 187-220.

[2] Krumbein, W. C.: 1941, "Measurement and geologic significance of shape and roundness of sedimentary particles," Jour. Sed. Pet., Vol. 11, pp. 64-72.

Krumbein's intercept method uses the same basic definition of sphericity (equation 1) as Wadell's standard method, but the volume of the pebble, instead of being measured directly by displacement, is expressed in terms of a triaxial elipsoid having the three diameters a, b, and c equal respectively to the long, intermediate, and short diameters of the particle. Krumbein specifies that the three diameters must be mutually perpendicular but not necessarily intersecting. After a, b, and c, are measured, the ratios b/a and c/b are calculated, and the sphericity is read directly from a chart. For samples of 25 pebbles or more, the intercept method gives mean sphericities that closely approximate those obtained by the standard volume method of Wadell.

In applying the intercept method to smaller grains, a similar close approximation to results obtained by Wadell's standard volume method is to be expected, except as the shape of the smaller grains is affected by cleavage, parting, and original crystal form-properties not ordinarily possessed by pebbles or coarser fragments. Quartz, magnetite, ilmenite, garnet, and epidote, for example, have no good cleavage or parting, and grains that show original crystal form either are not common in sediments, or do not differ greatly in shape from elipsoids. For such minerals, the intercept method should give good three-dimensional sphericities. In contrast, zircon typically is euhedral in many sediments, and euhedral forms of apatite, hypersthene, tourmaline, diopside, and rutile are common. Good cleavage may be shown by the pyroxenes, amphiboles, feldspars, micas, and carbonates. Further tests are necessary to determine how accurately sphericities of such euhedral or cleavage grains can be obtained by the intercept method.

Fortunately, the more common shapes of grains with euhedral form or cleavage may be approximated by a relatively few geometric forms. By calculating the Wadell volume, the intercept, and Wadell projection spherities of these forms, a comparison of the three methods was made. The geometric forms compared were three prisms having lengths 1, 2, and 3 times the width (pyroxenes, amphiboles, feldspars, kyanite), a cylinder with hemispherical terminations (apatite, tourmaline, zircon), a tetragonal prism with pyramid terminations (zircon), and a cylinder lying on a .001 cleavage or parting (micas, apatite, tourmaline). The calculated sphericities of these forms are shown graphically in Fig. 1. For the tetragonal

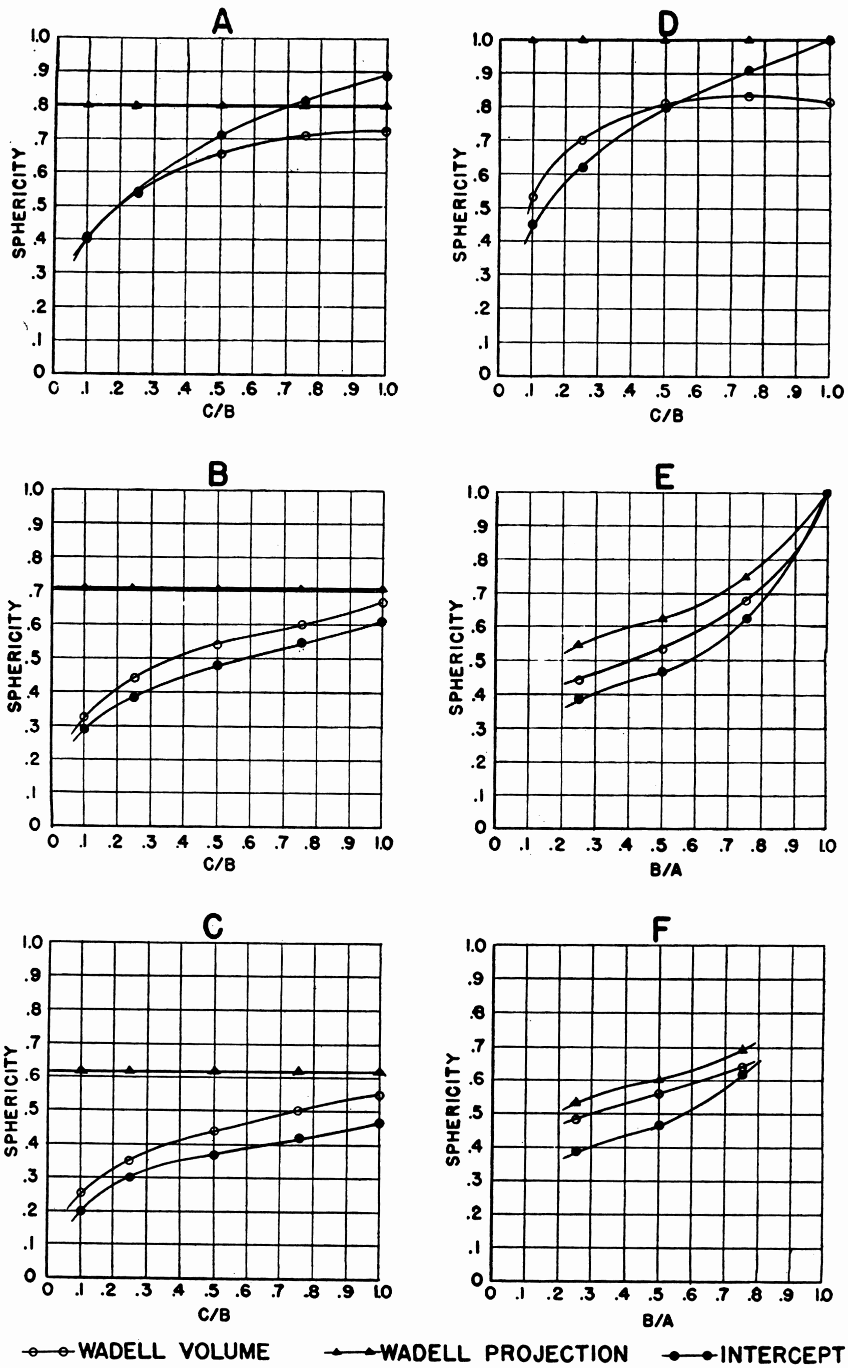

Fig. 1. Wedge used for measuring three mutually perpendicular diameters of sand grains or other particulate materials.

prism, and the cylinder with hemispherical terminations, sphericity has been plotted against length as measured by the ratio of intermediate to long diameters; for all other forms, sphericity is plotted against thickness as measured by the ratio of short to intermediate diameters.[3]

As shown in Fig. 1, the sphericity of most grains having cleavage, parting, or crystal form cannot be determined exactly by either projection or intercept methods. In general, sphericities obtained by the projection method are too large; those by the intercept method are too small. For all forms except the tetragonal prism and possibly the cylinder with hemisphere terminations, however, the intercept method is superior to the projection method in approximating Wadell volume sphericities. In general, the intercept sphericities become progressively better relative to projection sphericities as the elongation and/or flatness of the grains increase.

On a beach or in a stream, the corners of euhedral or cleavage grains will tend to be rounded. As this rounding occurs, sphericities obtained by the intercept method will approach closer and closer to Wadell volume sphericities. Sphericities obtained by the projection methods may also change, but will not necessarily approach the Wadell volume sphericities more closely. This is well illustrated by the change in sphericity resulting from the wear of a 1x1x.5 prism to a 1x1x.5 triaxial elipsoid. For these two forms the sphericities and their differences from Wadell volume sphericities are as follows:—

	Sphericity		Differences in Sphericity	
	Prism	Elipsoid	Prism	Elipsoid
Wadell volume sphericity	.67	.79	——	——
Wadell projection sphericity	.80	1.00	.13	.21
Intercept sphericity	.70	.79	.03	.00

For investigations in which sphericities are to be related to other properties of sediments, or to environments of transportation and deposition, the advantages of three-sphericities are too obvious to require further discussion. Two dimensional methods have been used because measurement of the third dimension or the volume of grains was difficult and inaccurate. Even when sphericity is used purely for description, as it might

[3] In prismatic and cylindrical forms, the long, intermediate, and short diameters used for sphericity measurements are not the crystallographic axes. For easier visualization of these forms, the ratios in Fig. 1 are for crystallographic axes.

be for correlating deposits, intercept sphericity has several advantages. First, the dispersion of sphericity values is greater for the intercept method than for the projection method. For example, average intercept sphericities for seven heavy minerals from a stream sand studied by the writer varied from .44 to .75, a range of .31, whereas the same grains had average projection sphericities of .72 to .81, a range of only .09. This greater dispersion is particularly valuable if differences in sphericity are to be tested for significance or non-significance by statistical methods. If the intercept method is used the existence of significant differences may be established by measuring fewer grains.

Second, the breadth/length ratio (b/a) and the flatness ratio (c/b), both of which are calculated in the intercept method before sphericities are determined, provide two additional criteria of similarity or difference in sedimentary deposits. Two sediments, or two minerals within the same sediment, may have the same sphericity, but the breadth/length and flatness ratio may reflect very real differences in shape. An intercept sphericity of .75, for example, may result either from breadth/length and flatness ratio of .90 and .52, or .70 and .87.[4] Such shape differences may also be extremely important in porosity, permeability, or sediment transportation studies.

The apparatus used by the writer to measure short or vertical diameters is inexpensive to construct and is simple in design. In its simplest form, the apparatus consists of two glass plates with their flat surfaces held in contact at one end and wedged a measurable distance apart at the other end, as shown in Fig. 2. Microscopic slides, 3″ x 1″ or 3″ x 2″, may be used for plates when the grains are less than 0.5 millimeters in diameter. For larger grains, the plates must be longer than three inches. Scotch drafting tape, or metal clamps may form the binding (B), that holds the plates together. The wedges are wire whose gage is varied for different widths of the opening T.

When the apparatus is tilted and tapped gently, grains placed at *P* slide down the lower plate until their tops make contact with the upper plate. The distance (T_1) between plates at the point of contact is the vertical diameter (c) of the grain

[4] The great difference in shape of grains of the same sphericity raises a serious question regarding the use of a single value to describe shape. Until the influence of shape is more clearly understood, the measurement and publication of breadth/length and flatness ratio seems desirable.

and, if the wedge is not deformed, may be calculated from the equation

$$T_1 = \frac{T}{L} \cdot L_1, \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

when T is the distance between plates at the open end, L is the total length of the measuring wedge, and L_1 is the distance between the grain and the point of contact between the upper and lower plates. Actually, the glass plates that form the wedge are usually bent slightly during their assembly or during the emplacement of the grains. Consequently, it is better to measure the distance between plates at six or seven places along the edges, plot these measurements against the distance from the end of the wedge, and determine the effective width (T_e), the

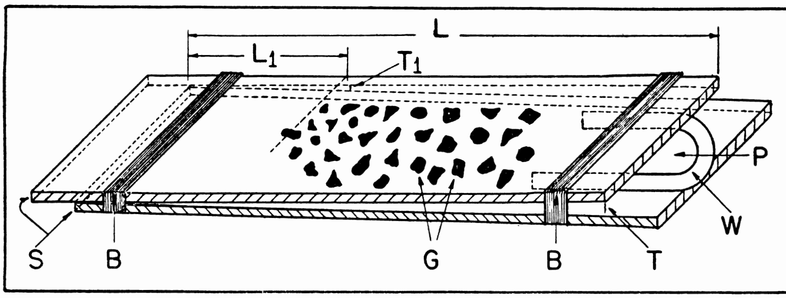

Fig. 2. Wadell volume, Wadell projection, and intercept sphericity of grain-like geometric forms. A, prism with $a = 1$, $b = 1$; B, prism with $a = 2$, $b = 1$; C, prism with $a = 3$, $b = 1$; D, Cylinder on .001 parting or cleavage; E, Cylinder with hemispherical terminations; and F, Tetragonal prism with pyramid terminations.

effective point of contact of the plates, and the effective length (L_e). These effective values are substituted in equation 2.

With the apparatus mounted on a microscope stage, the position of each grain is recorded by means of the mechanical stage scale and the long and intermediate diameters are measured with the micrometer occular. If desired, an oil of suitable index may be introduced in the wedge after the grains are emplaced, and the mineralogy of each grain determined at the same time as the measurements are made. Using the wedge, the intercept sphericity of grains is measured as follows:—

1) Clean and assemble the apparatus as shown in Fig. 2.
2) Place the apparatus on edge under a microscope and measure the width T with the micrometer occular. Reverse the appa-

ratus and measure T on the other edge. Adjust wedge until T is the same on both sides of the apparatus. (A paper binding clip may be used to hold the apparatus on edge under the microscope.)

3) Place the apparatus on a flat surface and transfer the sample to platform (P). Then tap the apparatus gently to make the grains assume their most stable position.

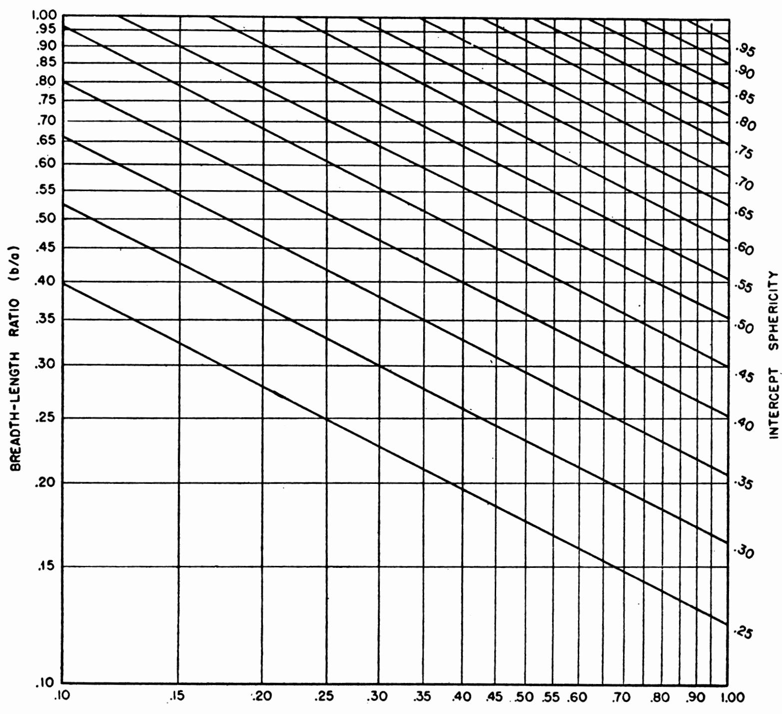

Fig. 3. Chart for obtaining intercept sphericities from the ratios b/a and c/b.

4) Tilt the apparatus about 10° from the horizontal and tap it gently with a pencil eraser. The grains will slide down the bottom plate until their tops touch the upper plate. A short period of tapping with the apparatus tilted at 45° or more may be necessary to insure that all grains reach their proper positions.

5) Insert a suitable index oil at the open end of the wedge.
6) Clamp the apparatus in the mechanical stage and for each grain measure the longest diameter (a) and intermediate diameter (b) normal to a with the micrometer occular, record the mechanical stage reading for the center of the grain, and identify the grain. (The intermediate diameter (b_s) that controls passage of grains through sieve openings can also be measured if desired.)
7) Remove the apparatus from the microscope and mark the edges and top at six or seven places with ink.
8) Replace the apparatus under the microscope and record the mechanical stage reading at each mark and at the open end of the wedge; turn the apparatus on edge and use the micrometer occular to measure the distance between plates at each mark.
9) On graph paper plot the mechnical stage readings against the micrometer occular readings; draw a straight line through the points, giving greatest weight to the points in the part of the wedge in which the grains are emplaced; and determine the effective width (T_e), the effective point of contact at the closed end of the wedge, and the effective length (L_e).
10) Subtract the mechanical stage reading for each grain (step 6) from the mechanical stage reading for the effective position of the closed end of the wedge to get the effective length (L_{le}) for each grain.
11) Compute the short diameter (c) of each grain, using the equation.

$$T_l = \frac{T_e}{L_e} \, . \, L_{le} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

12) Compute the ratios b/a and c/b.
13) Read sphericities from the intercept chart (Fig. 3).

Acknowledgments. The writer wishes to thank Dr. H. A. Einstein for suggestions relating to development of the apparatus and to Dr. E. M. Thorp for criticism of the manuscript.

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