GEL 324 Sedimentology

Particle Shape Analysis

Introduction

The shape of sedimentary particles is an important physical attribute that may provide information about the sedimentary history of a deposit or the hydrodynamic behavior of particles in a transporting medium. Particle shape, however, is a complex function of lithology, particle size, the mode and duration of transport, the energy of the transporting medium, the nature and extent of post-depositional weathering, and the history of sediment transport and deposition. In this exercise we shall examine and compare the shape of pebbles from different sedimentary environments in the region to evaluate which of these factors are most important for determining pebble shape.

Measuring Particle Shape

Standardized numerical shape indices have been developed to facilitate shape analyses by mathematical or graphical methods. Quantitative measures of shape can be made on two-dimensional images or projections of particles or on the three-dimensional shape of individual particles. Two-dimensional particle shape measurements are particularly applicable when individual particles cannot be extracted from the rock matrix. Three-dimensional analyses of individual irregularly shaped particles generally involve measuring the principal axes of a triaxial ellipsoid to approximate particle shape (Figure 1).

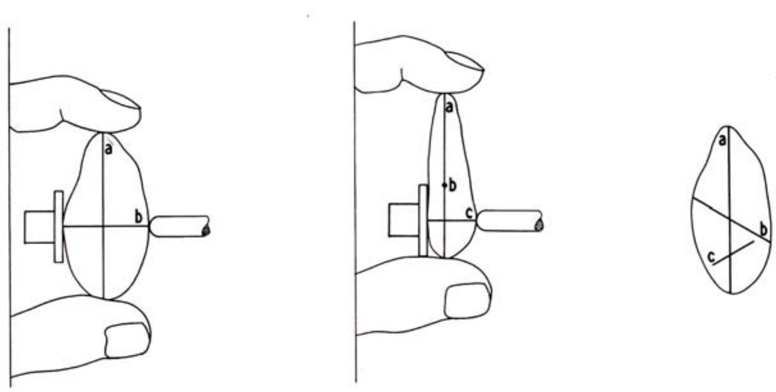

Figure 1. Concept and measurement of pebble diameter (Krumbein, 1941 in Pettijohn, 1975, Figure 3-1).

The two-dimensional particle shape is generally considered to be a function of attrition and weathering during transport whereas three-dimensional shape is more closely related to particle lithology.

Roundness and Sphericity

Roundness and sphericity are two of the most common shape indices. Roundness indices generally compare the outline of the two-dimensional projection of the particle to a circle Wentworth (1919) first defined roundness as;

$$Roundness = \frac{r_i}{R}$$

where r_i is the radius of curvature of the sharpest corner and R is the radius of the smallest circumscribing sphere. The Wadell Roundness (Wadell, 1932) index is given by:

$$Roundness = \frac{\sum_{i=1}^{n}\left(\frac{r_i}{R}\right)}{n}$$

where r_i is the radius of curvature of particle corners, R is the radius of the largest inscribed sphere, and n is the number of particle corners measured (Figure 2).

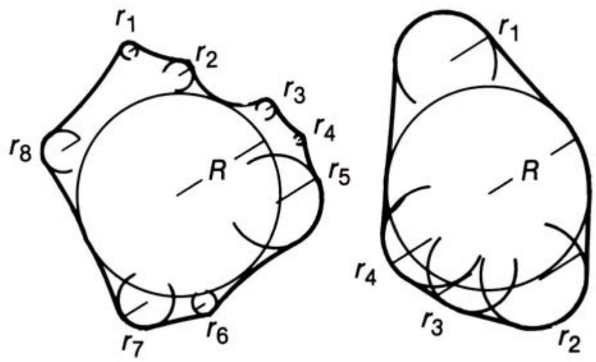

Figure 2. Two-dimensional particle images showing definitions for the radii of individual corners (r_1, r_2, and etc.) and the maximum inscribed circle (R) (Krumbein, 1940 in Friedman, *et al*., 1992).

The measurements are generally taken from two-dimensional images of the maximum projection area of the particle (i.e. the a-b plane).

Wadell (1932) defined true sphericity as the ratio of the particle surface area to the area of a sphere with the same volume. Unfortunately, this index proves to be difficult to measure. Operational Sphericity (Wadell, 1932) is given by;

$$\psi = \left(\frac{V_p}{V_{cs}}\right)^{1/3}$$

where V_p is the particle volume and V_{cs} is the volume of the smallest circumscribing sphere. This equation may be approximated by;

$$\psi = \frac{abc}{a^3} = \left(\frac{bc}{a^2}\right)^{1/3}$$

where a, b. and c are the long intermediate and short axis dimensions, respectively, of the particle (Krumbein, 1941). Sphericity values range from 0 (nonspherical) to 1 (perfect sphere) with most sedimentary particles falling in the range of 0.3 to 0.9..

Zingg Shape Classification

Zingg (1935) developed a more versatile shape classification scheme that uses the particle dimensions along the three principal axes. Particles are classified into four form categories; spheroids, discoids, rods, or blades based upon the b/a and c/b ratios as shown in Table 1. These classes are shown graphically in the Zingg diagram (Figure

3), which includes representative solids of equal roundness (roundness = 0). Lines of equal sphericity, based on the Wadell-Krumbein sphericity index are added to the Zingg diagram. It is important to note that the same value of sphericity may be applied to differently shaped particles, thus sphericity and geometric form are different measures of particle shape.

Table 1. Zingg shape classes (after Zingg, 1935 in Pettijohn, 1975)

Class	b/a	c/b	Shape
I	> 2/3	< 2/3	Oblate (discoidal, tabular)
II	> 2/3	> 2/3	Equiaxial (spherical, equant)
III	< 2/3	< 2/3	Triaxial (bladed)
IV	< 2/3	> 2/3	Prolate (rods)

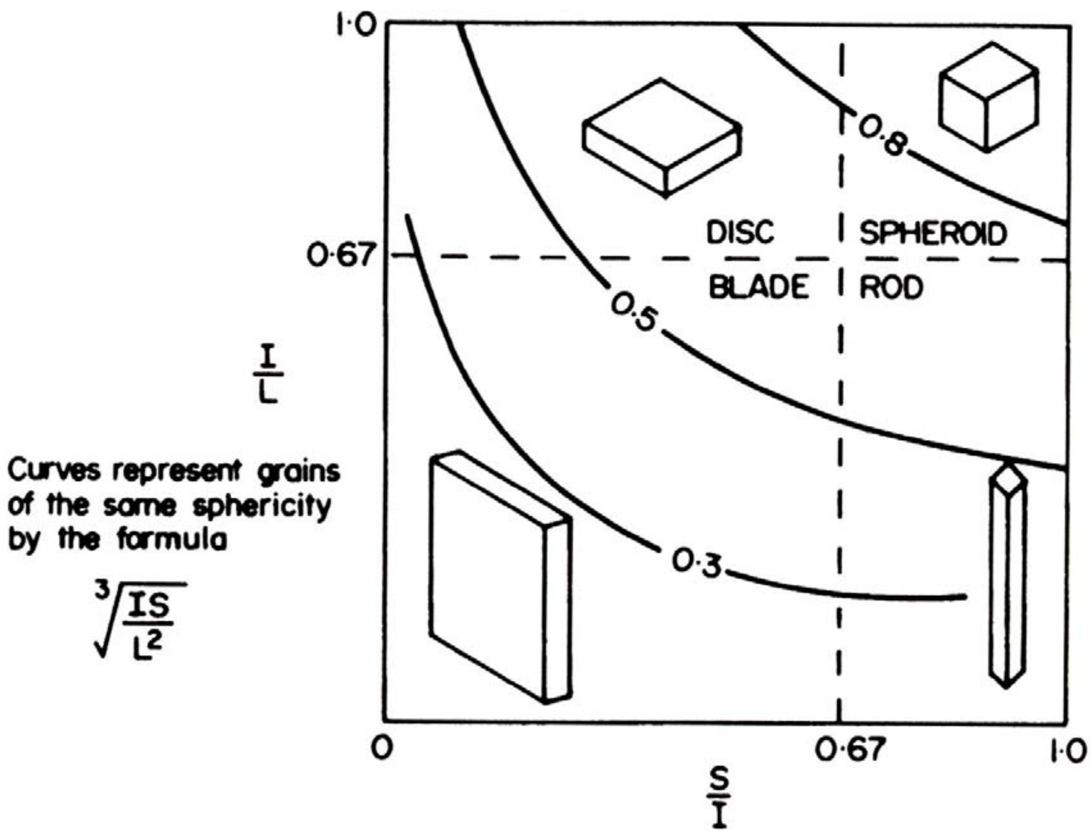

Figure 3. Zingg diagram showing lines of equal Wadell sphericity (from Lewis and McConchie, 1994, Figure 7-1A).

Sneed and Folk Sphericity-Form Diagram

Sneed and Folk (1958) developed a different sphericity index, the maximum projection sphericity, which they believed represented the hydrodynamic behavior of particles in a fluid. The maximum projection sphericity of a particle is given by the equation;

$$\psi_p = \left(\frac{c^2}{ab}\right)^{1/3}$$

The maximum projection sphericity is represented in the sphericity-form diagram of Sneed and Folk (1958) (Figure 4). As in the case of the Zingg diagram (Figure 3), lines of equal maximum projection sphericity span several form fields in the diagram.

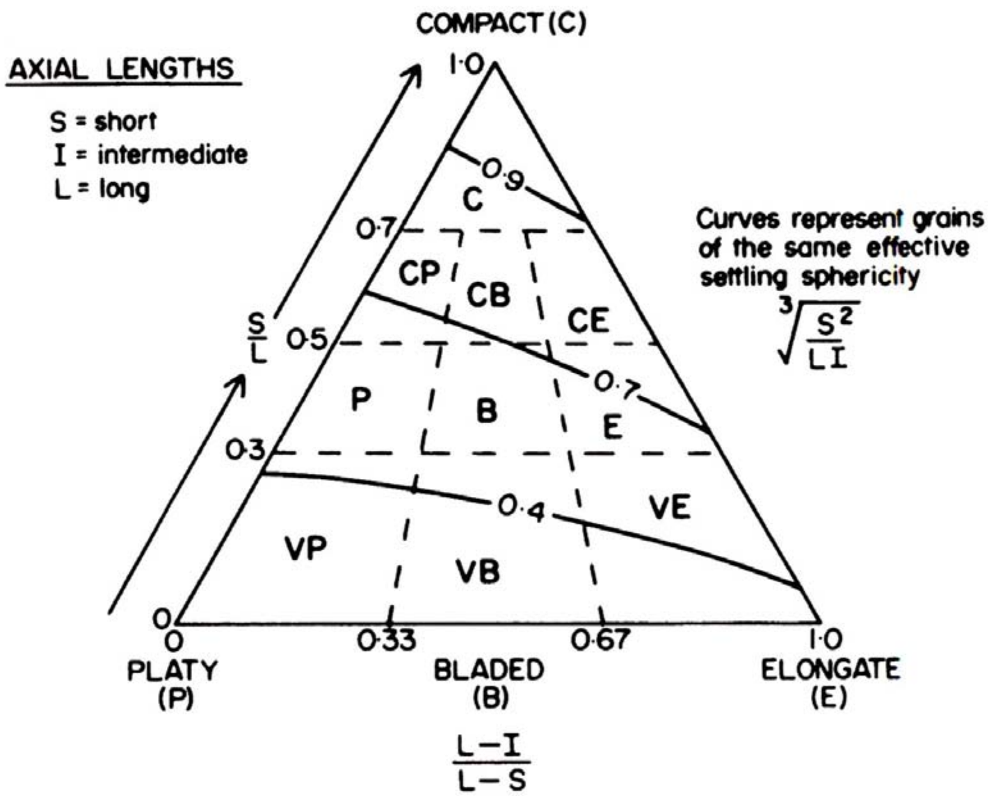

Figure 4. sphericity-form diagram of Sneed and Folk (1958) (from Lewis and McConchie, 1994).

Cailleux Flatness Index

Cailleux (1945) developed the flatness index based upon the relationship between the particle dimensions along the three principal axes. The index is given by;

$$F = \left(\frac{a+b}{2c}\right)$$

The index ranges from a minimum value of 1 for an equant particle and becomes progressively larger the flatter the particle. There is no maximum limit.

<u>Power's Scale of Roundness</u>

Powers (1953) developed visual comparison chart of reference particles of known sphericity and roundness (Figure 5). The chart offers a quick and easy way to estimate two-dimensional particle shape, although the comparisons can be subjective. The method is particularly useful in cases where the individual particles cannot be removed from the rock matrix.

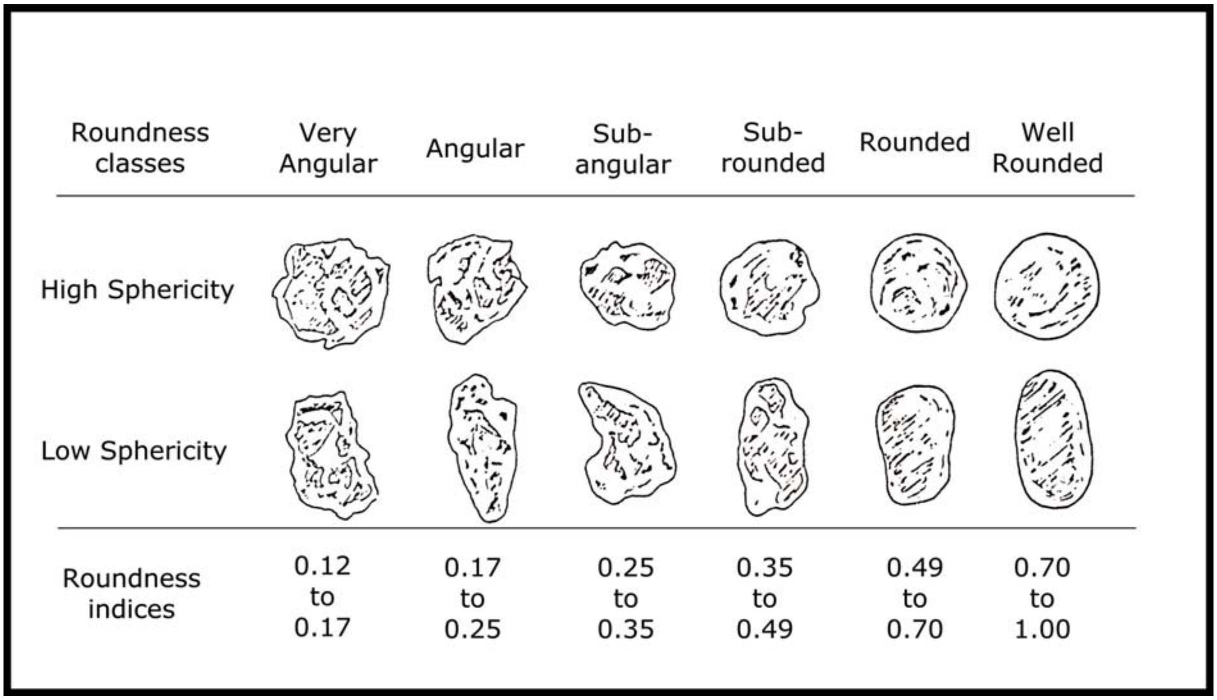

Figure 5. Chart for estimating the roundness and sphericity of sedimentary particles based upon comparisons with particles of known sphericity and roundness (based on Powers, 1953).

The roundness classes are based upon another Wadell roundness index given by;

$$\rho = \frac{r}{R}$$

where r is the radius of curvature of the largest inscribed circle and R is the radius of the smallest circumscribing circle. The index ranges from 0 to 1, with 1 indicating a perfect circle. The roundness classes are based upon a logarithmic scale because the distinction of differences at the high roundness end of the scale is more difficult than at the low roundness end of the scale. The class between 0.00 and 0.12 is excluded, because natural particles generally have roundness values greater than 0.12.

Exercise

Each laboratory group will be given a sample of pebbles collected from different sedimentary environments. A representative sub-sample consisting of 50 to 100 pebbles will be extracted for the analysis. Each pebble should be numbered and the lengths of the a, b and c axes and the pebble lithology should be measured and recorded in a spreadsheet.

1. Plot the pebble dimensional ratios on a Zingg diagram and determine and record the shape class for each. A different symbol should be used for each lithology.
2. Calculate the Krumbein sphericity, Wadell roundness, and Cailleux flatness indices for each pebble.
3. Calculate average values for each shape index according to particle lithology.
4. Group the shape data into two size classes; small pebbles (4mm to 32mm), medium pebbles (32mm to 64mm) using the average diameter or the b-axis dimension. Calculate average values for each shape index according to pebble size.

The results for individual laboratory groups will be combined during the second week of this exercise. These data should be sorted by particle size, lithology and environment.

5. The shape of particles in the same sedimentary environment may vary significantly with particle lithology (e.g. Cailleux 1945; Bluck, 1967) and for this reason, your assessment of particle shape as a function of environment should use be based upon individual rock types.

   Construct a Zingg diagram for each particle lithology using the average length ratios for each laboratory group. Each sedimentary environment should be given a different symbol.

6. Sneed and Folk (1958) found that shape was more closely related to particle size than to the distance of transport because particles of the same lithology but different size wear at different rates.

   Construct Zingg diagrams for each size category using the average length ratios for each group. Each sedimentary environment should be given a different symbol.

7. Write a report that addresses the significance of the various shapes and their relationship to the sedimentary environment from which they came. Include all relevant data.

References Cited

Bluck, B., 1967, Sedimentation of beach gravels: Examples from South Wales: Journal of Sedimentary Petrology, 37:128-158.

Friedman, G.M., Sanders, J.E., and Kopaska-Merkel, D.C., 1992, Principles of Sedimentary Deposits: Stratigraphy and Sedimentology: Macmillan Publishing Company, New York, 717p.

Krumbein, W. C., 1940, Flood gravels of San Gabriel Canyon, California: Geological Society of America Bulletin, 51:639-676.

--------, 1941, Measurement and geological significance of shape and roundness of sedimentary particles. Journal of Sedimentary Petrology 11:64-72.

Lewis, D.W., and McConchie, D.M., 1994, Analytical Sedimentology: Chapman and Hall, New York, 197p.

Pettijohn, F.J., 1975, Sedimentary Rocks 3rd Edition, Harper and Row, Publishers, New York, 628p.

Powers, M.C., 1953, A new roundness scale for sedimentary particles: Journal of Sedimentary Petrology, 23:117-119.

Sneed, E. D., and R. L. Folk, 1958, Pebbles in the lower Colorado River, Texas, a study in particle morphogenesis. Journal of Geology 66:114-50.

Wadell, H., 1932, Volume, shape, and roundness of rock particles. Journal of Geology 40:443-51.

Wentworth, 1919, C.K., 1919, A laboratory and field study of cobble abrasion: American Journal of Science, 27:507-521.

Zingg, Th., 1935, Beiträge zur Schotteranalyse: Min. Petrog. Mitt. Schweiz., 15:39-140.

Additional References

Barock, E. J., 1974, Coarse sediment morphometry: A comparative study. Journal of Sedimentary Petrology 44:663-72.

Barrett, P. J., 1980, The shape of rock particles, a critical review. Sedimentology 27:291-303.

Boggs, S., Jr., 1967, Measurement of roundness and sphericity parameters using an electronic particle size analyzer: Journal of Sedimentary Petrology 37:908-913.

--------, 1968, An experimental study of rock fragments: Journal of Sedimentary Petrology 38:548-555.

--------, 1969, Relationship of size and composition in pebble counts: Journal of Sedimentary Petrology 39:1243-1247.

Bretz, J. Harlen, 1929, Valley deposits immediately east of the channeled scablands of Washington II: Journal of Geology, 37:505-541.

Briggs, L.I., McCulloch, D.S., and Moser, F., 1962, The hydraulic shape of sand particles: Journal of Sedimentary Petrology 32:645-646.

Bryan, K., 1931, Wind-worn stones or ventifacts – a discussion and bibliography: Report of the Commission on Sedimentation, 1929-30, National Resources Council, reprint and circular series No. 98, p.29-50.

Cailleux, A., 1945, Distinction des galets marins et fluviatiles. Societe Geologique de France Bulletin 15:375-404.

Carver, R.E., ed., 1971, Procedures in sedimentary petrology: Wiley-Interscience, New York, 653p.

Catacosinos, P. A., 1965, Tables for the determination of sphericity and shape of rock particles. Journal of Sedimentary Petrology 35:354-65.

Crofts, R. S., 1974, A visual measure of shingle particle form for use in the field. Journal of Sedimentary Petrology 44:931-4.

Dobkins, J. E., Jr., and R. L. Folk, 1970, Shape development on Tahiti-Nui. Journal of Sedimentary Petrology 40:1167-1203.

Ehrlich, R., and B. Weinberg, 1970, An exact method for characterization of grain shape. Journal of Sedimentary Petrology 40:205-12.

Flemming, N. C., 1965, Form and function of sedimentary particles. Journal of Sedimentary Petrology 35:381-90.

Folk, R. L., 1955, Student operator error in determination of roundness, sphericity and grain size: Journal of Sedimentary Petrology, 25:297-301.

--------, 1972, Experimental error in pebble roundness determination by the modified Wentworth method. Journal of Sedimentary Petrology 42:973-4.

Gale, S. J., 1990, The shape of beach gravels. Journal of Sedimentary Petrology 60:787-9.

Grogan, R., 1945, Shape variation of some Lake Superior beach pebbles: Journal of Sedimentary Petrology 15:3-10.

Harrell, J., 1984, Roller micrometer analysis of grain shape. Journal of Sedimentary Petrology 54:643-5.

Holmes, C.D., 1960, Evolution of till-stone shapes in central New York: Geological Society of America Bulletin, 71:1645-1660.

Illenberger, W. K., 1991, Pebble shape (and size). Journal of Sedimentary Petrology 61:756-67.

King, C. A. M., and J. T. Buckley, 1968, The analysis of stone size and shape in Arctic environments. Journal of Sedimentary Petrology 38:200-14.

Landon, R.E., 1930, An analysis of beach pebble abrasion and transportation: Journal of Geology, 38:437-446.

Kuenen, Ph. H., 1955, Experimental abrasion of pebbles 1: Wet sand-blasting: Leidse Geol. Meded., 13:189-201.

--------, 1956, Experimental abrasion of pebbles 2: Rolling by current: Journal of Geology, 64:336-338.

--------, 1959, Experimental abrasion 3: Fluviatile action on sand: American Journal of Science, 257:190-192.

--------, 1960, Experimental abrasion 4: Eolian action: Journal of Geology, 68:427-449.

--------, 1964, Experimental abrasion 6: Surf action: Sedimentology: 3:29-43.

Kuenen, Ph., H., and Perdok, W.G., 1962, Experimental abrasion 5: Frosting and defrosting of quartz grains: Journal of Geology 70:648-658.

Li, Z., and P. D. Komar, 1986, Laboratory measurements of pivoting angles for applications to selective entrainment of gravel in a current. Sedimentology 33:413-23.

Landon, R.E., 1930, An analysis of beach pebble abrasion and transportation: Journal of Geology 38:437-446.

Moss, A. J., 1962, The physical nature of common sandy and pebbly deposits, Parts I & 2. American Journal of Science 260:337-73 and 261:297-343.

Moss, A. J., P. H. Walker, and I Hutka, 1973, Fragmentation of granitic quartz in water. Sedimentology 20:489-511.

Patro, B. C., and B. K. Sahu, 1974, Factor analysis of sphericity and roundness data of clastic quartz grains: Environmental significance. Sedimentary Geology 11:59-78.

Perez, F. L., 1987, A method for contouring triangular particle shape diagrams. Journal of Sedimentary Petrology 57:763-5.

Plumley, W., 1948, Black Hills terrace gravels: A study in sediment transport: Journal of Geology, 56:526-577.

Rittenhouse, G., 1943, A visual method for estimating two-dimensional sphericity. Journal of Sedimentary Petrology 13:79-81.

Rosenfeld, M. H., and I C. Griffiths, 1953, An experimental test of visual comparison techniques in estimating two-dimensional sphericity and roundness of quartz grains. American Journal of Science 251:553-85.

Sames, C. W., 1966, Morphometric data of some recent pebble associations and their application to ancient deposits. Journal of Sedimentary Petrology 36:126-42.

Shepard, F. P., and R. Young, 1961, Distinguishing between beach and dune sands. Journal of Sedimentary Petrology 31:196-214.

Spalletti, L. A., 1976, The axial ratio C/B as an indicator of shape selective transportation. Journal of Sedimentary Petrology 46:243-8.

Swan, B., 1974, Measures of particle roundness. Journal of Sedimentary Petrology 44:572-7.

van Genderen, J.L., 1977, Nomograms for morphometric gravel analysis. Sedimentary Geology 17:285-94.

Von Engelen, 1930, Type form of faceted and striated glacial pebbles: American Journal of Science, 19:9-16.

Wentworth, C.K., 1936, An analysis of the shapes of glacial cobbles: Journal of Sedimentary Petrology, 6:85-96.

Whitney, M.L., and Dietrich, R.V., 1973, Ventifact sculpture by windblown dust: Geological Society of America Bulletin, 84:2561-2581.

Winkelmolen, A. M., 1971, Rollability, a functional shape property of sand grains. Journal of Sedimentary Petrology 41:703-14.