A LABORATORY AND FIELD STUDY OF COBBLE ABRASION

Preliminary Report

CHESTER K. WENTWORTH
University of Chicago

INTRODUCTION AND OBJECT

In the course of field work at Baraboo, Wisconsin, in the summer of 1916, it occurred to me that by means of a suitably designed tumbling barrel an experimental study might be made of the abrasion of cobbles in stream transit. It was believed that by carefully controlling conditions, quantitative determination of change of shape and size as related to distance of travel could be made which, when later combined with field studies, would serve as a valuable criterion in the study of deposits of transported materials. Later in in the summer of 1917, during occasional examinations of gravel deposits, the idea was so cordially received by Mr. A. J. Collier, of the U.S. Geological Survey, that I undertook the study of cobble abrasion at the University of Chicago the following autumn and have continued it, with some interruptions, to the spring of 1919. The following is a brief statement of the principal phases of the problem, the methods used, the more significant results obtained to date, and the points which I hope to take up in the future. More complete description of the methods and more thorough discussion of various conditions and their significance will be reserved for a later paper.

OUTLINE OF STUDY

Aside from lithologic character, the distinguishing features of any cobble are its size, shape, and surface texture. These are subject to change and the change is frequently characteristic of the transporting agent.

In stream transportation the rate of change in size of a given piece depends on: (1) its own size; (2) the size of associated cobbles;

(3) the number of such associated cobbles; (4) its angularity; (5) the violence of the motion; (6) the kind of rock (this factor might be subdivided into *elasticity*, *hardness*, etc.). The change of shape depends on: (7) distance traveled; (8) kind of rock; (9) violence of motion; (10) kind of motion; (11) size of cobble; (12) size of associated cobbles. The change of surface texture depends on: (13) kind of rock; (14) violence of motion; (15) kind of motion; (16) size of cobble; (17) size of associated cobbles.

APPARATUS

The apparatus employed consists of two metal drums lined with soft wood, 25 inches in internal diameter and 13 inches long. These

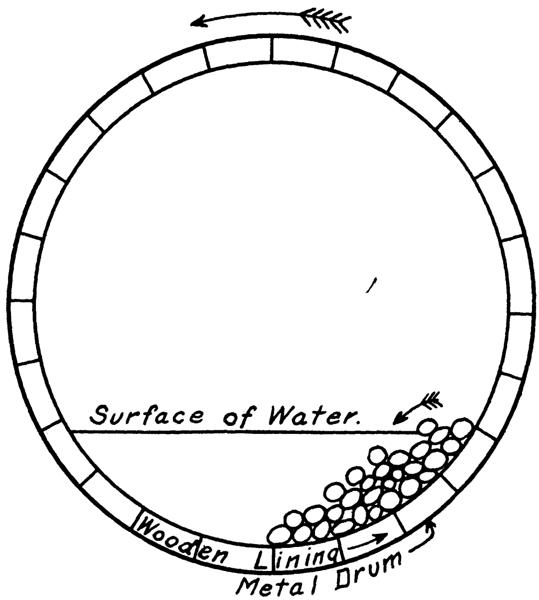

FIG. 1.—Diagram showing in cross-section relations of cobbles to water and to lining of drum while in motion.

are situated at the two ends of the supporting axis and, for all the work to date, have been driven at 27 revolutions per minute. The drums are kept flushed with water so that the finer detritus up to the size of coarse sand is carried out and collects in the settling tubs.

The cobbles in the drums roll continuously down the upgoing side of the barrel, practically under water, at its rate of peripheral travel (1.84 miles per hour or 44.16 miles per day).

The question of how closely the rolling of cobbles down this incline simulates the actual travel of similar materials in streams

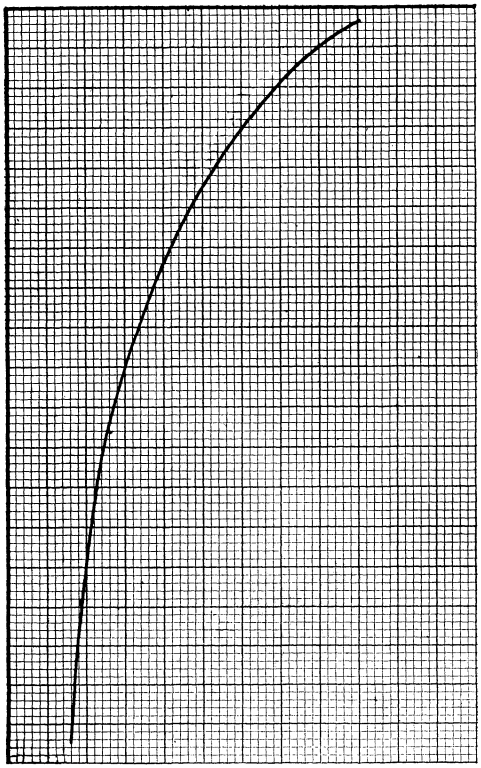

FIG. 2.—Relation of rate of wear to size of cobble

has not yet been carefully investigated. The chief difference, however, will be a constant difference in rate of wear, i.e., 1 mile in a drum equals more or less than 1 mile in the stream, and will not detract from its value in making comparative studies.

It is planned later to make experimental studies of wear during actual transit in streams under natural conditions and thus determine a factor of comparison to render applicable to field interpretation the comparative results obtained in the laboratory.

I hope also to experiment at length with different speeds and different kinds of motion both in the laboratory and in the field in the hope of throwing some light on the various shapes of cobbles

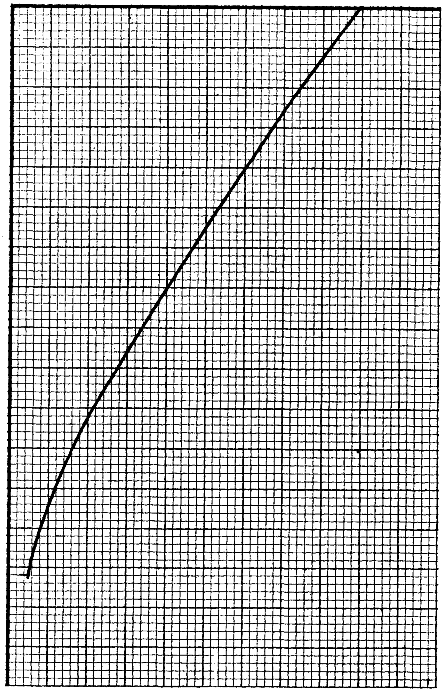

FIG. 3.—Relation of size to distance traveled. Ideal history of cobble starting at 178 grams weight.

thought by some to be characteristic of river deposits, shore deposits, etc. The following are data on some of the relations mentioned above.

RESULTS OBTAINED AND FUTURE WORK PLANNED

1. *Relation of rate of wear to size of cobble.*—I have taken the rate as $\frac{W-W'}{WD}$ where W = initial weight, W' = weight after test, and D = distance of travel, i.e., percentage loss per mile of travel.

Figure 2 shows the plotted average of 85 measurements of rate with cobbles ranging from less than 4 grams to 185 grams. The graph shows very plainly how much more severe the wear becomes as any given piece becomes smaller. This is probably in part due to the increasing ratio of surface to weight.

Figure 3 shows the size history of a cobble started at 180 grams. The rock used in this and all other determinations, unless

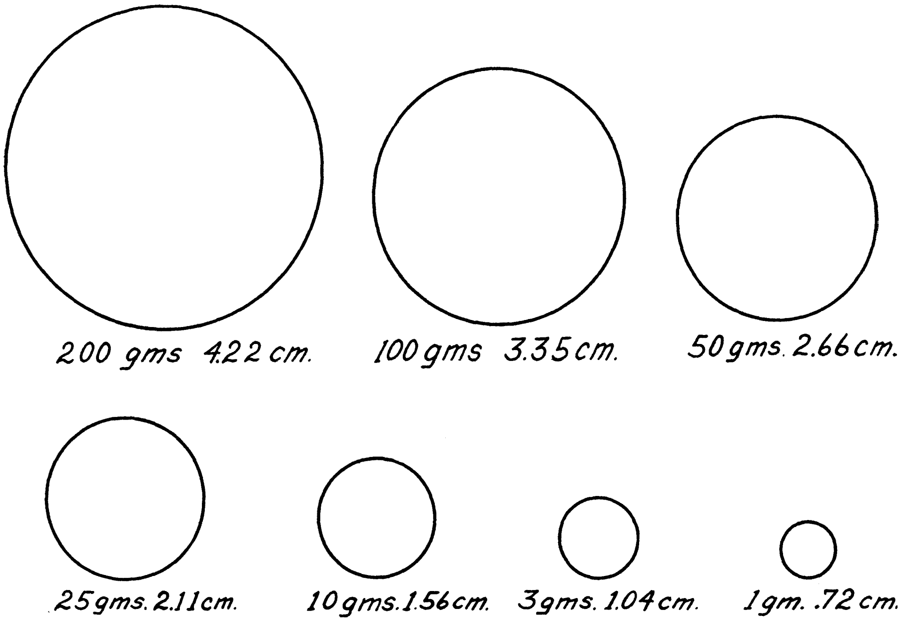

FIG. 4.—Showing sizes of spheres of limestone (density 2.65) of different weights. Weights in grams and diameters in centimeters.

otherwise noted, was Niagara limestone from the outwash gravel at Cary, Illinois. It will be noted that 700 miles of travel reduced the cobbles from 180 to about 10 grams. To aid in visualizing these sizes, Figure 4 may be consulted.

No extensive comparisons have yet been made between different kinds of rock, but measurements were made on one granite cobble which was more than ten times as resistant as the Niagara limestone, and some limestone has been used which was less than one-tenth as durable, so that there is known to be more than one hundred fold variation in rocks of different sorts. The curve of size history would therefore be notably different in the scale along the abscissa, though the form would be similar for different rocks.

2. *Relation of wear to size of associated cobbles.*—Not yet studied.

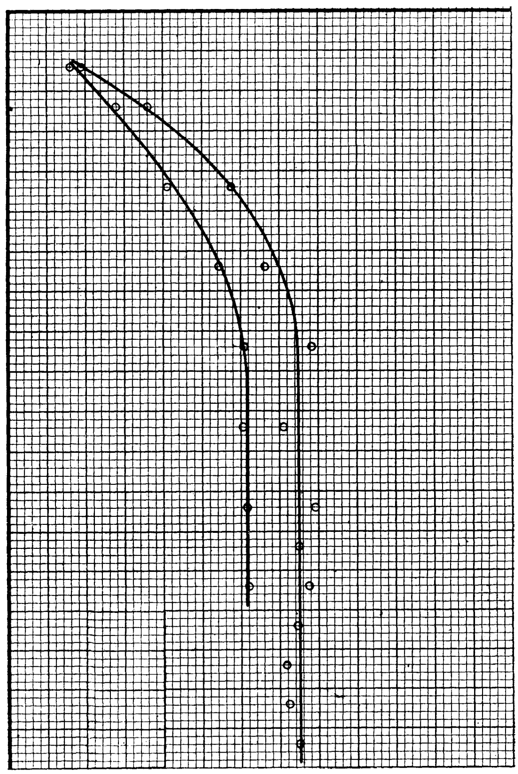

FIG. 5.—Effect of amount of mixture in compartment of drum

3. *Relation of wear to number of associated cobbles.*—That the total amount of material in a compartment of the drum was a very critical factor in the rate of wear was recognized from the first, and to aid in interpreting and correcting for unavoidable variations in the amount, series of runs were made with varying numbers of cobbles in the drum and measurements made on a number of test pieces. The results are shown in Figure 5.

It is to be noted that severity of wear is nearly proportional to the number of cobbles up to a certain point and then remains at an almost constant value. This point, beyond which further additions make little change in rate, is reached when the cobbles are rolling close-packed across the full width of the drum and additional cobbles roll down on top, forming a second layer. Future work will advantageously be done with a filling equal to or greater than 100×41.7 grams to eliminate to a large extent the critical effect of small changes in amount of mixture. The run shown in Figure 5 was started at 144 cobbles, reduced by stages to 14 cobbles, and then increased in an attempt to duplicate the curve. The form is nicely duplicated, while the change in absolute value is due to the diminution in the meantime of the test pieces and their consequent higher rate (see Figure 2); therefore the greater ordinates of the upper and later curve.

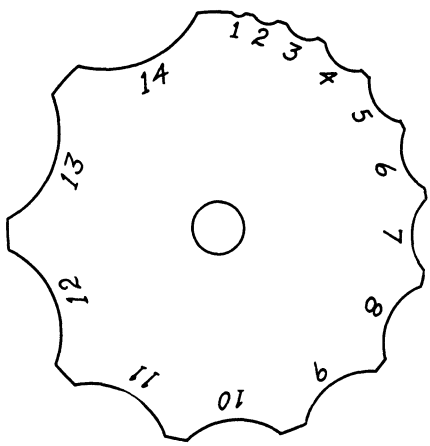

FIG. 6.—Gauge used in measuring curvature. Figures give radii in millimeters.

4. *Relation of wear to angularity.*—Not yet studied.

5. *Relation of wear to violence of motion.*—Not yet studied.

6. *Relation of wear to kind of rock.*—Not yet studied.

7. *Relation of change of shape to distance traveled.*—In stream-transported materials the change in shape, provided the rock is homogeneous, is an approach to sphericity. In studying this change in shape it is necessary to recognize varying degrees of roundness, in other words, to have a numerical answer to the question of how round a given piece is. At least three criteria of roundness readily occur to one in considering the question. These are (1) the ratio of surface area to volume, (2) the average deviation of diameters from a mean diameter, (3) the average

deviation of convexities from a mean convexity. Each of these values or coefficients of roundness reaches a minimum in the case of a sphere and has a maximum in the case of a line or a plane without volume.

Considerable computing and some experimenting was done to test out these methods for the definition of roundness. None was found entirely satisfactory, especially for field use. In order to

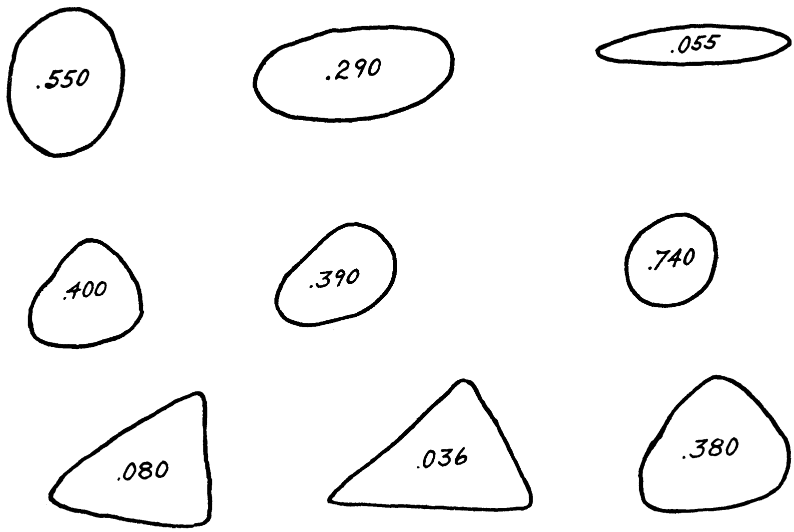

FIG. 7.—Profiles of cobbles showing differing degrees of roundness and giving values of *R*.

be of use in the field study of a deposit, the method of measurement should be simple and rapid enough to permit the calibration of one or two hundred cobbles in a day's time and to allow using the average of the results to characterize the deposit. In (1) the measurement of surface area with sufficient accuracy, while not impossible, was too laborious to use with more than one or two specimens. Likewise in (2) and (3) the need for many measurements of diameters and convexities rendered them liable to the same objection. The method of plotting different kinds of diameters used in the study of cube rounding reported below is of no value for various general shapes. As a practical solution of the

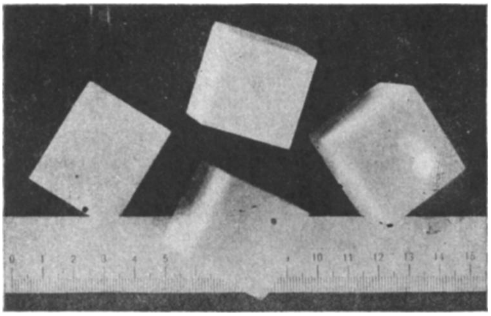

FIG. 8.—Stage 1, 0 miles, $R=0$

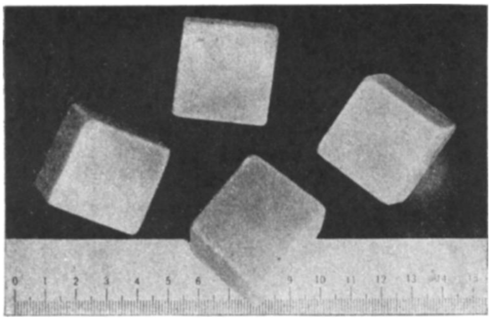

FIG. 9.—Stage 2, .31 miles, $R=.053$

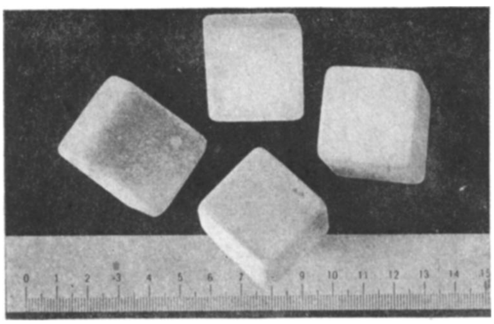

FIG. 10.—Stage 3, .91 miles, $R=.096$

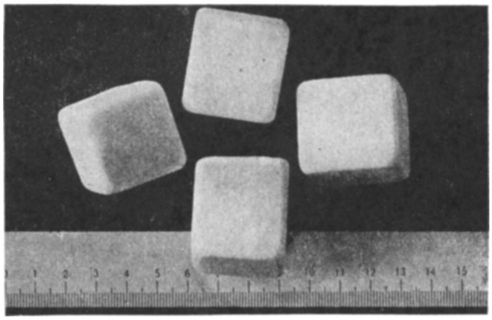

FIG. 11.—Stage 4, 2.18 miles, $R=.130$

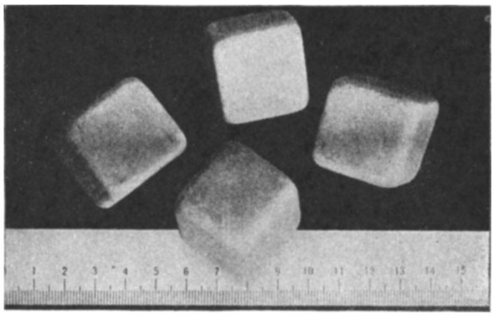

FIG. 12.—Stage 5, 5.12 miles, $R=.170$

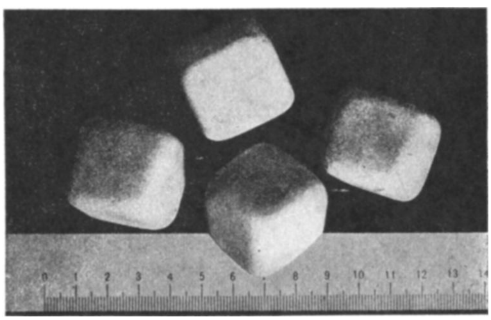

FIG. 13.—Stage 6, 14.1 miles, $R=.250$

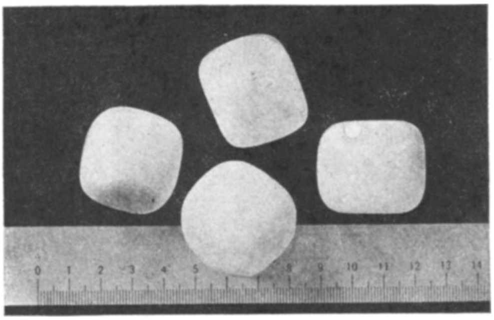

FIG. 14.—Stage 7, 31.5 miles, $R = .400$

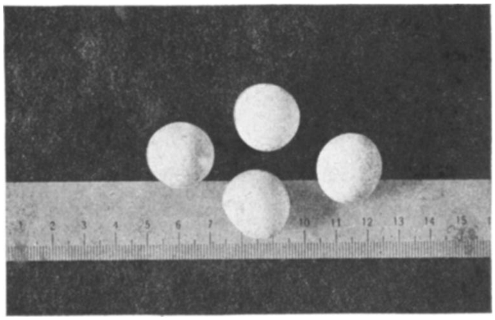

FIG. 17.—Stage 10, 134 miles, $R = .818$

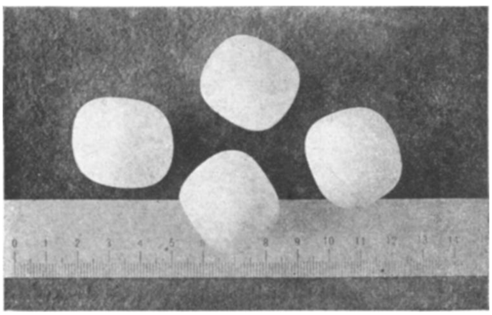

FIG. 15.—Stage 8, 54.5 miles, $R = .550$

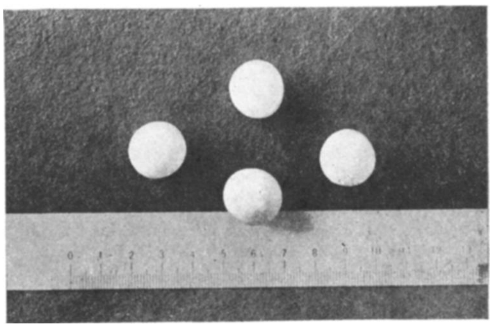

FIG. 18.—Stage 11, 159 miles, $R = .838$

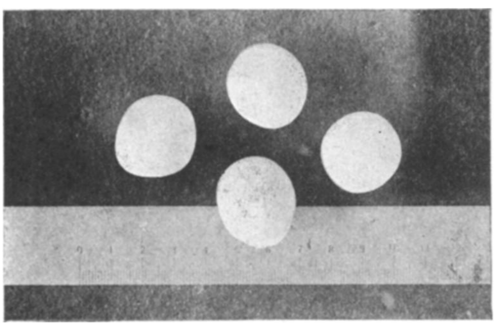

FIG. 16.—Stage 9, 94 miles, $R = .810$

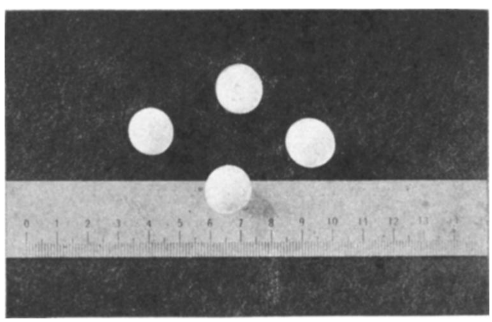

FIG. 19.—Stage 12, 189 miles, $R = .848$

problem, I have used the ratio of the radius of curvature of the most convex part of the surface to half of the longest diameter through that point. This radius is measured with a gauge such as shown in Figure 6 and the diameter with a caliber or usually with a scale with sufficient accuracy.

Figure 7 shows in profile various cobbles with their corresponding values of R.

Figures 8–25 show the history of four white marble cubes with the corresponding values of R. It will be noted that the four pieces reached a maximum roundness of .862 at an average weight of 3.29 grams and then systematically became somewhat less round as they decreased in size.

Figure 26 is a graph of the roundness as a function of the distance traveled. For this curious increase in angularity with travel I suggest the following interpretation: For any given rock there is

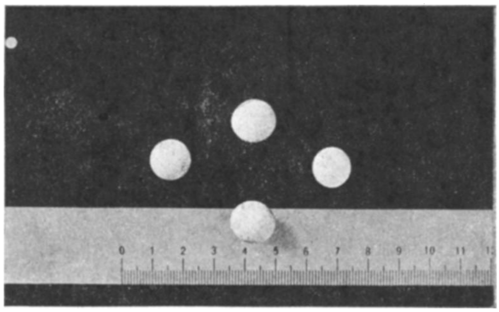

FIG. 20.—Stage 13, 209 miles, $R = .862$

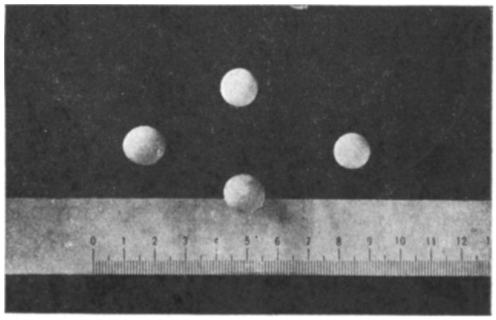

FIG. 21.—Stage 14, 223 miles, $R = .838$

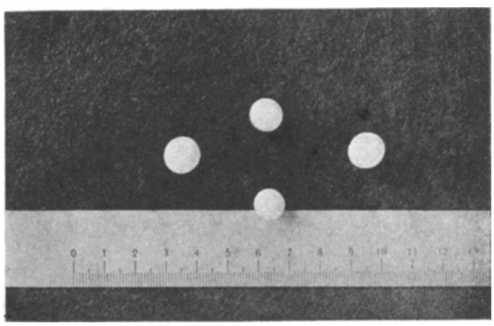

FIG. 22.—Stage 15, 244 miles, $R = .826$

an ellipsoid of equilibrium for wear by abrasion toward which the cobble approaches, which depends on the hardness, or more correctly, durability along various axes.

For a perfectly homogeneous rock this ellipsoid is a sphere; for a non-homogeneous rock it is an ellipsoid of greater or less eccentricity as the case may be and has a greater or less value for R in the notation here used. Further, and this is the essential point, this ellipsoid of equilibrium is of different eccentricity for different sizes, more eccentric for smaller sizes than for larger. Thus it is conceived that at 3.29 grams the marble cobbles had nearly or quite reached the ellipsoid of durability for that size and from then on were practically following the equilibrium figure in its decreasing values of R as the sizes grew less. This would mean that slight variations in durability between different directions come out more

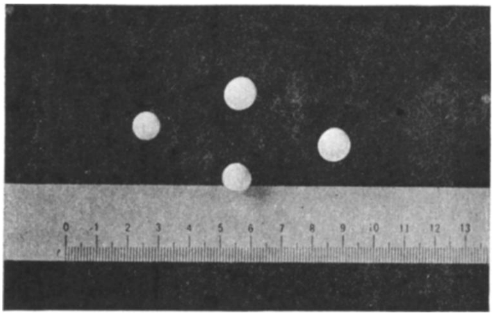

FIG. 23.—Stage 16, 263 miles, $R = .823$

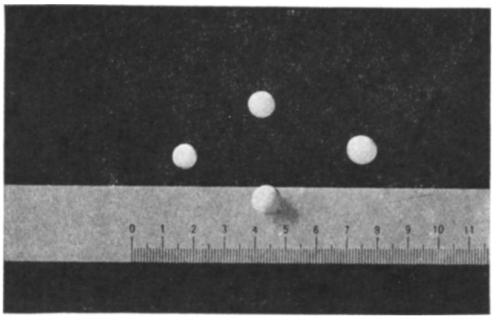

FIG. 24.—Stage 17, 286 miles, $R = .808$

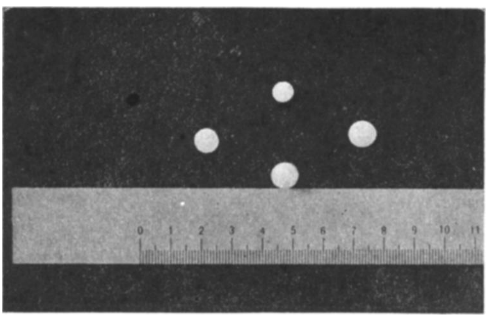

FIG. 25.—Stage 18, 307 miles, $R = .797$

notably in small pebbles than in large, which seems reasonable. This interpretation is put forward as a hypothesis which I hope later to test experimentally in considerable detail.

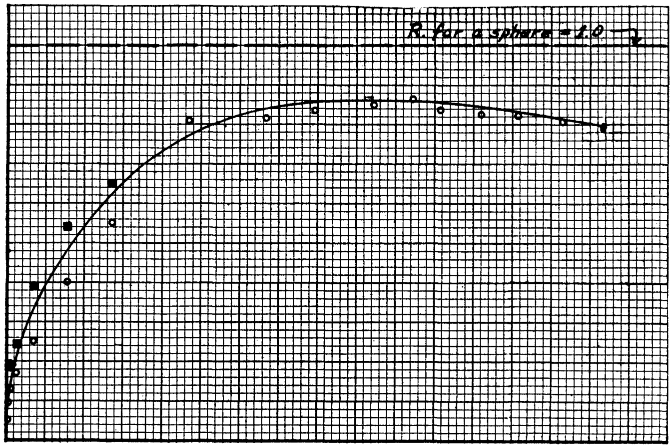

FIG. 26.—Graph of values of *R* plotted against distance for the series illustrated in Figures 8 to 25.

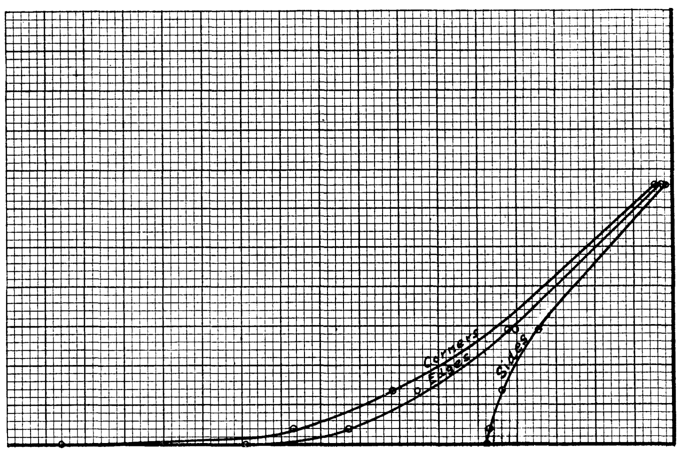

FIG. 27.—Showing convergence of diameters of cubes rounded by cobbles averaging 70 grams each.

8. *Effect of kind of rock on rounding.*—It is hoped later to make studies of the rounding of shaly or schistose rocks whose ellipsoids of

equilibrium would depart notably from spheres, but nothing has yet been done along this line.

9. *Effect of violence of motion on rounding.*—Not yet studied.

10. *Effect of kind of motion on rounding.*—Not yet studied.

11. *Effect of size of cobble on rounding.*—Not yet studied.

12. *Effect of size of associated cobbles on rounding.*—Figures 27 and 28 show the influence of this factor and indicate that large cobbles are much more effective rounding agents than those considerably smaller than the cobble rounded, as shown by the much

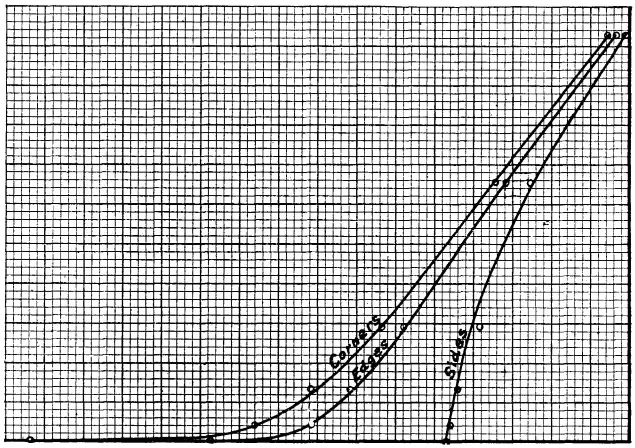

FIG. 28.—Showing convergence of diameters of cubes rounded by cobbles averaging 20 grams each.

slower convergence of the lines in the latter case. It will be noted that the corners and edges lose more rapidly at first (curves concave upward) while the sides lose more rapidly later when their areas are decreased by the wear of corners and edges (curve convex upward). Further studies of this factor are planned.

13. *Effect of kind of rock on surface texture.*—Not yet studied.

14. *Effect of violence of motion on surface texture.*—Not yet studied.

15. *Effect of kind of motion on surface texture.*—Not yet studied.

16. *Effect of size of cobble on surface texture.*—Not yet studied.

17. *Effect of size of associated cobbles on surface texture.*—Not yet studied.

It is hoped that by a study of the crescentic impact scars on some compact quartzites and other rocks an approximate quantitative measure may be made of conditions under which a given deposit was transported and its history thereby interpreted, but no detailed study has been made.

CONCLUSION

Experimental studies, physical or chemical, are of little value to the geologist until they have been applied to actual field conditions. In the studies described and planned above I have tried to keep in mind the possible field applications and hope, as time permits, to point out by field studies the value of each one of the foregoing relations in throwing further light on the past history of the earth. I am especially desirous of receiving opinions on the method of measuring and defining roundness described and used in (17) above, and will appreciate criticism and comment on any other points which have been overlooked or are subject to different interpretation.