

ABRASION BY GLACIERS, RIVERS, AND WAVES

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INTRODUCTION

Erosion¹ or land sculpture includes rock disintegration, where the rock is coherent, and transportation of the material disintegrated. Disintegration has been divided into weathering and corrasion. Stream- and wave-wear may be either chemical or mechanical, though in all ordinary circumstances the mechanical wear is so much greater than chemical solution that the latter may be neglected. Ice-wear is purely mechanical. Omitting chemical solution, which is an entirely distinct process, corrasion may be defined as the mechanical wear performed by wind, streams, waves or glaciers. Gilbert² uses the term "corrasion," excluding chemical corrasion, for the "mechanical wear . . . performed by the aid of hard mineral fragments which are carried along by the current." Chamberlin and Salisbury³ define stream-corrasion as "the wear effected by running water." This use of the term is wider than that of Gilbert, for it includes not only wear by tools, but also the process of sweeping away material which has always been incoherent and "material loosened in advance by the process of weathering." To distinguish these radically different processes of stream-action, in this paper the term "abrasion" will be used for the mechanical wear performed by tools, and "plucking" for the removal of rock fragments. "Corrasion," including all mechanical wear by streams, will include both abrasion and plucking. None of the terms are new; they have more or less overlapped in use, and it is believed that the meaning here assigned to them is that generally understood today. The terms can be applied to glacier- and wave-action with the same significance with which they are

¹ Gilbert, *Geology of the Henry Mountains*, pp. 99-102.

² *Ibid.*, p. 101.

³ Chamberlin and Salisbury, *Geology*, Vol. I, p. 113.

applied to stream-action. The analysis of erosion by waves, glaciers, and streams, would be arranged as follows:

$$\text{Erosion} \left\{ \begin{array}{l} \text{Rock-Disintegration} \\ \text{Transportation} \end{array} \right\} \left\{ \begin{array}{l} \text{Weathering} \\ \text{Corrasion} \\ \text{Solution} \end{array} \right\} \left\{ \begin{array}{l} \text{Abrasion} \\ \text{Plucking} \end{array} \right.$$

In geological literature abrasion is ordinarily considered an important factor in land sculpture. It is the purpose of this article to suggest that abrasion by glaciers, streams, and waves is in most cases a negligible factor in erosion, and to emphasize the importance of weathering in the work of erosion by streams and waves. Wind-erosion is not considered.

GLACIAL ABRASION

The common understanding of glacial erosion has been that it is accomplished by the wear of solid particles held in the bottom of the ice against the rock surface over which the ice moved. This process would be favored by the weight of the glacier and by the fact that particles so held are often in continuous contact with the bed-rock for long distances. If this process were the only or the chief factor involved in glacial erosion, the rasplike action of the broad glacier bottom should produce a smoothed, sub-even surface. Within the glaciated area of North America there are many nearly level, glacially smoothed surfaces, but these are in regions which were level in preglacial times, and are areas which there is reason to believe were not deeply eroded. In the hilly regions of glaciated North America and in glaciated alpine valleys the detail of such surfaces is controlled by rock jointing, and glacial abrasion is limited to smoothing the surfaces and rounding the corners of the joint blocks. This hackly character of the topographic detail of surfaces covered by the Pleistocene ice-sheet may be in part an inheritance from pre-Pleistocene time, but in glaciated alpine valleys (see Fig. 1), having lateral hanging valleys, the rounded-hackly surface of the lower part of the main valley has been produced by the normal action of glacial erosion in live rock, scores and perhaps hundreds of feet below the original surface. Here plucking, or the removal of large blocks bounded by joint planes, has been the important element in erosion.

Before glacial abrasion has been able to smooth away the inequalities produced by plucking, the process of plucking has produced new inequalities. The effect of abrasion in wearing down the valleys is neutralized by the removal of the joint blocks when only partly abraded. It has been a pluck-and-heal process, with plucking always ahead. It is not a question here whether the blocks plucked are removed mechanically by the ice, or are loosened by subglacial weathering; the point emphasized is that valley-deepening does not take place through scratching by material carried in the bottom of the ice.



FIG. 1.—Joint-controlled glacially eroded surface. Direction of ice-movement was to left. The view shows the inability of abrasion to obliterate the control, by jointing and plucking, of the surface form. Lake Creek, above Twin Lakes, Colo.

There is nothing new in this statement of the process of glacial erosion. Plucking is recognized more and more. The relative incompetency of glacial abrasion is mentioned here because it leads up to the consideration of the inadequacy of stream-abrasion. The same class of facts is appealed to for evidence in both cases, and these facts have been recognized much more widely in the case of glacial erosion than in that of stream erosion.

STREAM-ABRASION

Stream-abrasion has generally been considered an important element in valley-cutting. It was clearly distinguished by Gilbert¹ and recent texts usually consider it, though no attempt has ordinarily been made to indicate the relative importance of abrasion, plucking,

¹ Gilbert, *Geology of the Henry Mountains*, p. 101.

and weathering. Chamberlin and Salisbury¹ go as far as any recent text in emphasizing the importance of weathering and plucking, and so in limiting the relative importance of abrasion in valley-cutting. They say that in any valley cross-section the amount removed by corrasion may be measured by a rectangle the width of which is the width of the stream, and the height of which is the depth of the valley. It seems, however, that even this relatively small proportionate amount, while allowed to the stream, must be denied to stream-abrasion, and divided between plucking and weathering.

Theoretically stream-abrasion is less probable than abrasion by glaciers. The cutting particles are not held against the rock bottom by any overlying mass of ice; indeed, the weight of the particles is lessened by their immersion in water. The smaller particles are largely carried in suspension, striking the bottom only at intervals. Fragments too large for suspension move over the bottom with rolling and not with sliding friction.

The form usually shown by the rock-bed over which the stream flows bears evidence to the inadequacy of mechanical wear of detritus in shaping it and in lowering the bed. The Olentangy River below Delaware, O., for example, is flowing over nearly horizontal beds of Devonian limestone. The bed of the river, which has since glacial time been cut a dozen feet into the hard rock, consists of a succession of very broad, low steps, each step being a limestone stratum, its down-stream limit determined by vertical joint-faces. In some places the edges, and in a few places the surfaces, of these steps are slightly rounded, as if by mechanical wear; but this in no way affects the large fact that the rock in the stream-bed is bounded by stratification- and torsion-joint planes. The agency effective in removing the rock from the stream-bed has taken it away in large blocks; the rock has not been scratched away by the mechanical rubbing of fragments swept down by the stream. The ordinary processes of weathering are believed to have loosened the jointed limestone, and the blocks were later swept away by the stream. As in the case of glacial erosion, before abrasion could reduce a joint-block, weathering processes isolated the partly worn block, and delivered it to the

¹ Chamberlin and Salisbury, *Geology*, Vol. I, p. 108.

stream for removal. In each case the character of the bottom bears evidence to the ineffectiveness of abrasion.

This fact in regard to the form of the stream-bed has been noticed by the writer in the streams cutting the Ohio shale and Cincinnati limestone (see Fig. 2) in Ohio, in the sandy shales near Ithaca, in the Berea sandstone of Ohio, in the Triassic sandstone along the lower Westfield River and the Connecticut River, and in the crystalline rocks along the upper Westfield River. Views showing stream-beds, notably the collection in Tarr's *New Physical Geography*, give evidence in the same direction.



FIG. 2.—Stream in thin-bedded Cincinnati limestone, in which the characteristic irregular surface of the stream-bed, the result of plucking rather than abrasion, is shown. Near Camden, O.

In qualification of what has just been said in reference to stream-abrasion, two things may be mentioned. First, reference should be made to pothole action. It is abrasion, and where numerous potholes are forming and connect, they may decidedly aid downward erosion. This action, however, is believed to be exceptional; the great majority of streams are without it. Secondly, and forming a really important exception, in certain cases streams are flowing over rock-beds which are thoroughly smoothed, and appear to have been deepened by wear of stream-swept detritus. In these cases it is believed that it will be found that the rock is nearly jointless. This is especially the case with crystalline rocks, particularly the more massive granites. This process of wear by abrasion is most common in swift streams in mountainous areas, but even here it is exceptional, and in the consideration of stream-erosion generally it is insignificant.

In conclusion, the joint-controlled form of the rock sides and

bottoms of stream-beds shows that abrasion has not been a determining element in valley-deepening, and that the stream is a transporting and not an abrading agent, removing materials dislodged from its bed or swept into it from its valley sides.

WAVE-EROSION

As in river-erosion, so in wave-erosion, abrasion, or the wear by material thrown against the base of the cliff, has been generally emphasized in the texts. Chamberlin and Salisbury¹ make corrasion by the impact of detritus an important element in wave-erosion on hard rocks, at the same time emphasizing the co-operation of weathering along joint planes. Geikie² says: "The waves make use of loose detritus within their reach to break down cliffs exposed to



FIG. 3.—Shore on the east side of Easton's Point, Newport, R. I.

their fury. Probably by far the largest amount of erosion is thus accomplished." Le Conte³ says that "fragments hurled against the shore are the principal agent of wave-erosion." But if abrasion has been the determining factor in wave-cutting, the shore in the vertical zone of breakers

should bear evidence of this by its rounded and worn character. The only chance which the writer had to study rock shores with this consideration in mind was at Newport. In the hard conglomerate and sandstone at Easton's Point (see Fig. 3), on the south side of the island, no evidence of abrasion was found. To be sure, in some protected pockets, into which gravel had been swept

¹ Chamberlin and Salisbury, *Geology*, Vol. I, pp. 327-29.

² Geikie, *Text-Book of Geology*, Vol. I, p. 569.

³ Le Conte, *Elements of Geology*, 5th ed., p. 34.

by the waves, the roll of the gravel had smoothed the solid rock; but elsewhere the waves are breaking either on surfaces which have not been appreciably eroded, or on a rocky shore composed of angular masses of rock of all sizes, which have been loosened by weathering. Wherever the shore is being worn, it is by combined weathering and plucking, and not by abrasion. Easton's Point is not yet marked by a wave-cut cliff, and so is not the best place to show the process of erosion; but along the Cliff Walk, at the west end of Easton's Beach, where the rock is prevailingly Carboniferous schists, a distinct cliff faces the ocean; the base of the cliff, however, is not rounded and smoothed as would be the case were it being worn back by abrasion. A very suggestive photograph of a raised wave-cut bench on Prudence Island has been published,¹ in which both cliff and bench are rough and angular, the detail determined by the jointing of the shales.

It will be easy, of course, for anyone to test the matter for himself. Detritus protects rather than endangers the cliff. Except at times of high storm, the beach material protects the cliff and acts on itself. It does not seem probable that the bombardment of the cliff at times of heavy storm would seriously affect the cliff. Certainly there is little evidence of such action in the detail of the cliff base. Waves acting by hydrostatic pressure along joint planes may be effective; apart from that action their work would appear to consist in reducing and removing materials supplied them by the processes of weathering. They, like streams, are transporting and not abrading agents.

RELATIVE IMPORTANCE OF PLUCKING AND WEATHERING

The mechanical work of corrasion has been divided between abrasion and plucking. Abrasion does not appear to be an important factor. It is further a delicate question as to how far plucking can be considered a separate process, to be distinguished from weathering on the one hand and transportation on the other. In the case of glacial erosion it is easy to believe that the pressure of the ice may dislodge blocks from a jointed floor which has not been affected by weathering, though it would be difficult to show that frost-weathering had not had a share in loosening these blocks. It is possible that a

¹ *Geology of the Narragansett Basin*, Monograph 33, U. S. Geological Survey, Plate XXIII.

similar effect may be produced on the sea-cliff in time of heavy storms. But the impact of storm-waves even would seem to be less effective than the pressure of glacial ice, and the fact that the cliff base is exposed to the air, and is often, and in some cases always, water-soaked, indicates that the loosening of the rock fragments which are finally dislodged by the waves is in reality the result of weathering. In the case of streams flowing over jointed coherent rock, it is difficult to believe that even the swift currents of flood seasons are able to dislodge rocks from the stream-beds. The impact of the water is too slight, and is exerted on the nearly flat stream-bed at a great disadvantage. The stream is able to sweep away blocks, not too large, which have been loosened and partly dislodged by weathering; but it is not easy to believe that the stream is the dislodging agent.

If, as seems certain in the case of stream-erosion, and as seems probable in case of wave-erosion, the loosening of the rock fragments is the result of weathering, then plucking becomes merely the first step in the transportation of débris, and is reduced to a vanishing quantity between weathering and transportation. In that case the stream becomes a transporting and not a corradating agent; weathering becomes the important factor in valley-deepening as in valley-widening; while the stream acting as a transporting agent prevents the process from clogging. To the extent that weathering replaces plucking by wave-action, the same thing is true of shore erosion. In glacial erosion only is plucking left as a large factor, and even here it is not certain that it is the only factor in joint-block removal.