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MICROSTRIATIONS ON POLISHED PEBBLES

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ABSTRACT. Very small striations, here called *microstriations*, occur on the smooth, polished surfaces of some pebbles. They average a millimeter or less long and are commonly less than 0.05 mm wide.

Microstriations of random direction occur on artificially polished pebbles, and also on pebbles from beach and fluviatile environments. Microstriations parallel to one another and oriented in sets occur on pebbles from various stratigraphic units including the Cloverly, Morrison, Wapiabi, and Windrow formations. These particular oriented microstriations are thought to be due to tectonic movement or compaction or both.

INTRODUCTION

Surface textures of pebbles are sometimes useful in the reconstruction of geologic history. Examples include the surfaces of glaciated pebbles and ventifacts as well as the shiny surfaces of stones coated with desert varnish. This paper reports on an additional characteristic of pebble surfaces that reflects geologic history, namely striations of very small size, here called *microstriations.*

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MICROSTRIATIONS

Description

Microstriations occur either as preferentially oriented scratches in one or more sets on a pebble surface or as random scratches. Their length ranges up to over 2 mm but averages between 0.25 and 1 mm. In width they are less than 0.1 mm and usually less than 0.05 mm. One can see the larger ones without magnification. In most instances, however, a hand lens or binocular microscope is needed to detect them, and in all cases some magnification enables easy observation. Most microstriations are sharp, well-defined continuous grooves. Some, however, are discontinuous, and a few consist of a series of linear chip-marks on the pebble surface.

Microstriations occur on smooth, usually polished surfaces. The higher the polish the more finely inscribed are the microstriations. Polished surfaces are usually confined to siliceous or fine-grained material. We have observed microstriations on pebbles from deposits ranging in age from Jurassic to the present. They are found on pebbles which have been both artificially or

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naturally shaped and polished. They are not restricted to a single environment or history.

Artificially produced microstriations.—Pebbles rounded and polished in tumbling machines for the jewelry trade carry microstriations. They are visible only with magnification. They are straight, narrow, and of uniform width throughout. They are randomly oriented and can occur any place on the pebble (pl. 1-A). Examination of a sample of 36 commercially polished pebbles showed that the microstriations were common on 12 and present but rare on the remaining 24. The sample included pebbles of quartz, chert and agate as well as a single pebble of granite.[1]

The general technique of shaping and polishing the pebbles is fairly standard, although each producer tends to introduce variations into the method. The basic procedure is given in Sheridan (1958, p. 56). All stages of the process are carried out in revolving drums or barrels, whose capacities range from eight or ten pounds of stones up to two or three tons. Water is essential in all stages, and progressively finer abrasives are used in each stage.

The scratches on the final polished surface seem to be acquired during the polishing stage. An examination of approximately 50 pebbles of clear quartz processed through the second stage of tumbling showed no striations. After the polishing or final stage of tumbling, minute, randomly oriented striations were present on the three pebbles of clear quartz available for examination.

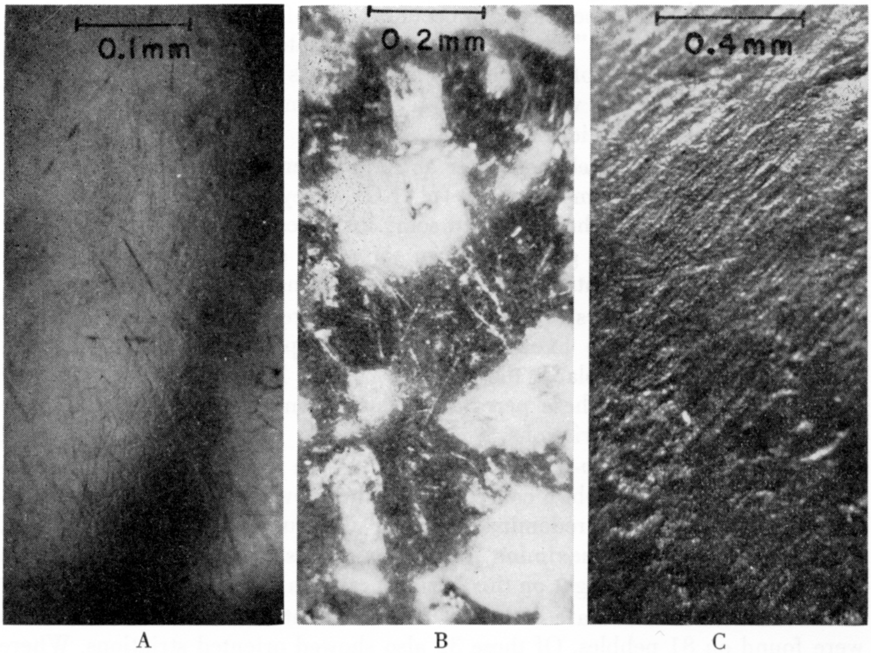
Microstriations on modern beach pebbles.—Polished pebbles occur on several beaches along the California coast south of San Francisco, particularly at Pebble Beach just north of Pescadero Point, and at Lobos State Park south of Carmel. Some of these pebbles exhibit microstriations, and these occur randomly as shown in plate 1-B. These striations are not as clearly inscribed as those on artificially polished pebbles, probably because the natural polish is not as well developed as the artificial polish. In addition to the microstriations, crescent-shaped scars of percussion or impact also occur. These are more common than the straight scratches, which we assign to abrasion as the pebble itself is moved either in the surf zone, or in the quieter swash zone of the beach, or in both.

Microstriations on stream gravels.—An examination of cassiterite pebbles from the placer deposits of Cornwall, England (Princeton University Mineralogical Collection, #5-248) has revealed a few randomly occurring microstriations. Similar striations are present on the semipolished surface of a pebble of magnetite taken from a creek bed at Gabb's, Newfoundland (Princeton University Mineralogical Collection, #79-237).

Small striations, but visible to the unaided eye and measuring up to 0.3 mm in width, occur on well-rounded but mat-surfaced, disk-shaped pebbles of Devonian red, sandy shale collected from the high water channel of Brodhead Creek, about two miles upstream from Stroudsburg, Pennsylvania. The striations are arranged in two or more sets, and within the sets the individual striations are parallel. The striations are generally broader at their centers

[1] The pebbles were supplied from stock by the International Gem Corporation, 15 Maiden Lane, New York City.

PLATE 1



A. Microstriations on surface of a pebble artificially polished in tumbling machine.

B. Microstriations on surface of a pebble from Pebble Beach near Pescadero Point, California.

C. Microstriations on surface of a pebble from the Wapiabi formation of Cretaceous age, Alberta, Canada.

than at their ends. The pebbles were found embedded in a sandy matrix with only their upper surface exposed. These pebbles are part of a recent fluviatile deposit and were probably exposed during the catastrophic flood of September 1955. Similar striations were found on pebbles just below Buck Hills falls, Pennsylvania, near the headwaters of Brodhead Creek. These pebbles lay in gravels moved during the same flood. We do not think that the striations are glacial, not only because the pebbles come from a stream deposit but also because the striations differ in their intensity and arrangement from those that can be definitely assigned to glacier action.

Similar but still larger striations are present on quartzite pebbles collected from deposits reflecting torrential stream conditions along Naked Creek four miles north of Elkton, Virginia on the eastern side of the Shenandoah Valley.

Microstriations on pebbles from the Wapiabi formation.—Pebbles from the Muskiki member of the folded and faulted Wapiabi formation of Cretaceous age in the Alberta foothills exhibit areas of well-oriented microstriations. The pebbles, collected by D. F. Stott, are considered by him (1958, p. 165) to represent the shoreline deposits of an advancing sea. The pebbles range in size from 5 to 75 mm in maximum dimensions, are well rounded, and many are disk-shaped. A dark gray chert is the dominant lithologic material but some quartzite and sandstone pebbles also occur. A few of the pebbles are pressure-pitted. A black, "varnish"-like veneer occurs in patches and has a very high luster. It chips or flakes off the pebbles and appears similar to desert varnish. It is on these patches of varnish and on areas immediately adjacent to them that we have found the microstriations.

The striations parallel each other and are generally less than 0.05 mm in width and less than 1 mm in length (pl. 1-C). They are straight and shallow and many taper toward their ends. In some instances, where the striations are abundant, they fall into a general pattern across the greater part of the pebble. Plate 2-A shows a concentric pattern of the striations on one such pebble.

Crescent-shaped scars of percussion are also present on the Wapiabi pebbles. In some places the finer parallel striations partly obscure the impact crescents, and in other places the percussion scars lie beneath the "varnish" veneer of the pebbles. These percussion scars, then, antedate both the "varnish" and the oriented striations.

Microstriations on so-called "gastroliths".—We have observed microstriations on 81 out of 91 pebbles collected from the Cloverly and Morrison formations. The pebbles are predominantly chert and quartz and are red, yellow, black, or white. Their maximum dimension ranges from 5 to 75 mm. Each pebble is polished and might on this basis be called a "gastrolith".

The microstriations are both random and oriented. The random striations were found on 81 pebbles. Of these 32 also showed oriented striations. Where a sequence can be determined, the oriented striations postdate the random scratches as well as crescent-shaped impact scars which are present on most pebbles.

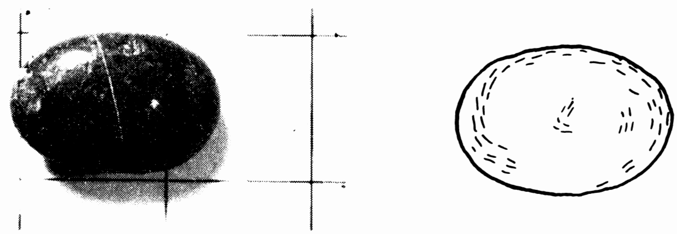
The oriented scratches ma ytake different patterns and forms. Thus the nonrandom microstriations may be oriented not only in respect to one another but also to the entire pebble, as shown in plate 2-B. In other pebbles two or more sets or patches of striations occur. Individual striations parallel each other within any given set but diverge from the direction of striations in neighboring patches.

The details of individual microstriations differ. Plate 3-A shows the most commonly seen types in which the microstriations are close, straight, sometimes deeper and wider at their centers, and sometimes of constant width throughout. Some microstriations are curved and some are short, with curved gouges deeper at one end as shown in plate 3-B. The oriented microstriations postdate the random, somewhat larger scratches.

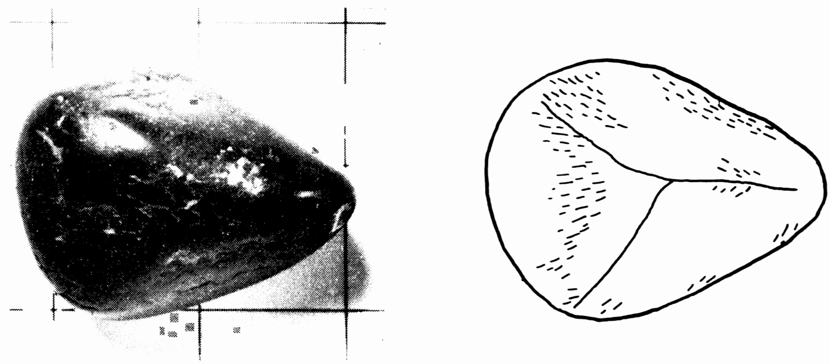
The striations are most common and best developed along the areas immediately adjoining the ridges that separate adjacent faces of the pebble.

The polished pebbles of the Windrow formation of Cretaceous (?) age have been referred to as gastroliths (Stauffer, 1945). A few microstriations were observed on small pebbles of quartz and chert collected from exposures of the Windrow formation near Tomah, Wisconsin. The pebbles are small, up to 10 mm in maximum size. The striations are both random and parallel. They are rare on the pebbles examined, and the parallel striations are very small.

PLATE 2



A. Orientation of microstriations on a pebble from the Wapiabi formation. Squares 25 mm (about 1 inch) on the side.



B. Orientation of microstriations on a pebble from the Cloverly formation, Wyoming. Scale as in A.

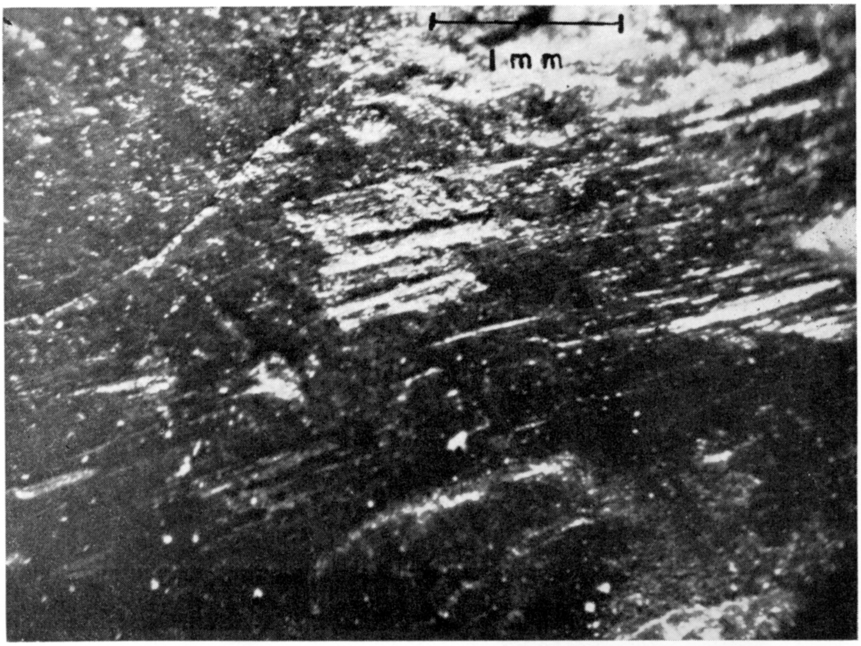
Origin

Bryan (1931) makes casual reference to "minute" parallel grooving observed on polished pebbles from the Morrison formation. We have found no other mention to features we call microstriations. Striations of megascopic size, however, are attributed to a wide variety of causes, and microstriations logically may be expected to result from one or more of these causes. What processes, then, produce striations?

Louis Agassiz' statement of the glacial theory in 1840 included a discussion of glacially striated rock. Since then a few studies of glacial striations (Chamberlin, 1888; von Engeln, 1930) have appeared. Unless proved otherwise, striations on bedrock and boulders have generally been assigned to glacial action.

Penck (1884) and Hughes (1895, p. 101) point out that pebbles may be striated by tectonic processes and that such striations may be mistaken for evidence of glacial action. Hughes (1898, p. 115) says that the scratches on a tectonically striated pebble "often appear pinched out and scored on both sides up to the edge" and that the "grooves follow the curvature of the stone". Subsequently several writers, including Freitag and Kästner (1909), Woodworth (1912) Götzinger (1914), Gregory (1915), Deeke (1920), Dunbar (1924), Voitesti (1925), and Krecji-Graf (1927), have referred to tectonically striated

PLATE 3



A. Straight parallel microstriations on surface of pebble from the Cloverly formation.

B. Crescent-shaped gauges on surface of pebble from the Cloverly formation.

stones. In 1906 McCollie observed that pebbles from a stretched pebble conglomerate showed striations parallel to their long axes. More recently Pettijohn (1956, p. 71) writes that "pebbles or cobbles in a rather fine-grained matrix may be striated or slickensided as a result of internal movement during deformation of the rock under pressure".

Hayden (1911, p. 40) reports pebbles with glacial-like striations from northern Afghanistan. These pebbles also bear the marks of wind pitting, and for this reason Hayden assigns the striations to wind action, a conclusion that appears otherwise unsupported. On the other hand Hovey (1909, p. 413) cites evidence that sand blast during the Mont Pelée eruptions in 1902-1903 produced striations on bed rock "similar to glacial" striations. They were 2 to 10 cm deep and 10 to 15 meters long. Hovey makes no reference to striations on individual pebbles or to small scale striations, but Cailleux (1942, p. 49) and Sharp (1949) describe fine fluting and grooving on ventifacts. Bryan (1931) suggests that the minute grooving on Morrison pebbles may be due to wind-driven material.

Mass movement of material has long been known as an effective process of striating rock. Penck (1883, p. 172; 1884) reports blocks striated by landslide movement. Wright (1892, p. 477) points to landsliding as a process producing pseudo-glaciated boulders and notes that small, artificially induced slides on slopes of slate spoil produce striations on some fragments. Meunier (1894) describes striations due to mass movement under experimental conditions. Hughes (1898, p. 116) records striations due to landslips, and Hovey (1909, p. 412) describes striations associated with avalanching during the Peléean eruptions. Breuil (1934, p. 270; pl. XXIV) reports and illustrates striations on pebbles and cobbles from the solifluction deposits of the Somme Valley, France. Similar striations are reported by Heim (1936, p. 452) from eastern Tibet and by Büdel (1936, p. 19) from unglaciated central Europe.

Krecji-Graf (1927) cites the mudflow as an agent that striates boulders, as do Pack (1923, p. 353), Scrivenor (1929), Blackwelder (1930), Sharpe (1938, p. 59), Sharp and Nobles (1953, p. 558) and Thornbury (1954, p. 92). Van Houten (1957) demonstrates that the Gunnison and Ridgeway conglomerates of Colorado, which carry abundant striated pebbles and cobbles, are most probably mudflow deposits rather than glacial deposits as originally interpreted by Atwood (1915).

Dyson (1937, 1938) and Imamura (1937, 1938) have simultaneously but independently reported on the effectiveness of snowslide avalanches as a process of striation.

Feilden and De Rance (1878) observed that sea ice driven ashore by high winds striates or "glaciates" stones. Dawson (1894, p. 105-110) repeats this observation and comments that the striation is confined to the exposed portion of the beach pebbles. Leffingwell (1919, p. 174) found a few stones on the Alaskan coastal plain that suggested striation by wind-driven sea ice, but he did not believe such stones could be mistaken for those transported by a glacier. Washburn (1947, p. 47), working on Victoria Island, found that not only did sea ice striate beach stones but that except for lack of faceting, such stones were difficult to distinguish from a stone carried by glacier ice.

Russell (1890, p. 117-120) reports that river ice of Alaskan rivers striate, facet, and polish stream gravels. The pebbles, embedded in clay matrix, are abraded by river ice, which scrapes across their exposed upper surface. Striations are generally parallel to the river flow, and the affected pebbles are similar to a pebble from a glacier except that the scratches are "less regular and less firmly drawn than the grooves and striations on typical glaciated pebbles". Wentworth (1928) invoked river ice to account for striated stream gravels found in terrace deposits along the rivers of the southern states. He found the striations on smooth-surfaced siliceous stones. He reports them to be clearly cut and uniform in width throughout. Their width ranges from 0.3 mm to 1 or 2 mm and their length 5 to 10 cm. They are most abundant on flat surfaces and over the edges from the flat areas. Some of the striations occur in strongly marked systems oriented in the same direction. More commonly two or three well-defined systems cross each other and are mingled with a few short, sometimes curved striations with no systematic arrangement. Later Wentworth (1932) studied the work of ice jams in arctic rivers and records striations similar to those found in the southern rivers, but gives no detailed description.

Du Pasquier (1897) invoked torrential stream flow without the intervention of ice to account for striations on blocks and cobbles in stream channels. Lugeon (1913) describes striated and polished bedrock in the Yadkin River, North Carolina, and (1921) in the Ardèche River of France. He postulates that the striations are cut by sand driven in jetlike flow and that the polishing is the result of a heavy silt load in the river.

The literature refers almost exclusively to large striations easily visible to the naked eye. On the other hand, the processes which produce these large striations could very conceivably produce the microstriations we have described. In considering the cause of microstriations it is apparent that we are dealing with two general types of microstriations, namely (1) single microstriations occurring randomly and (2) microstriations parallel to one another and arranged in one or more systems.

Microstriations of random occurrence.—Random striations demand that either the striating agent, or the pebble being scratched, or both, are free to move in many different directions. This situation occurs in the tumbling machine. and we have found that random microstriations are produced in the final or polishing stage of tumbling. A somewhat similar condition obtains in nature along the beach, either in the surf zone or in the quieter swash zone. We have found that polished pebbles on some present-day beaches in California bear small scratches with no preferred orientation. The turbulent action in a stream should also provide a certain freedom of motion, and smooth-surfaced pebbles from placer deposits are found to carry random, single striations.

Preferentially oriented microstriations.—To produce striations parallel to each other, the movements of the scratching agents in relation to the pebble must be unidirectional. The several processes discussed in the literature (tectonism, mass movement, wind, glacier, torrential stream flow, and ice jams on beaches or in streams) may satisfy these conditions to a greater or less degree. To this list we must add compaction as an additional process. Compaction is capable of moving matrix around large particles such as pebbles, particularly if the matrix contains an appreciable amount of fine-grained material. This movement, if the matrix carries adequate abrasive material, should striate pebbles.

In considering the causes of the oriented microstriations described in an earlier section, several potential processes can be discarded. Thus, for various reasons, glacier ice, sea and river ice, wind, and mass movement are inappropriate to the particular microstriations described.

We have enough observations to suggest that both random and oriented striations can be produced in a stream environment. We have found that the random striations can be very small, but we have found no examples of true microstriations with preferred orientation resulting from stream action. Furthermore, we would expect that if oriented microstriations do form in a stream environment they would be formed in no particular chronologic sequence when compared with random microstriations. On the sets we have described here we find that, when the relative age of the microstriations can be determined, the sets of oriented microstriations are younger than the random microstriations. These considerations point to the conclusion that the oriented microstriations described in this paper were not formed in a fluviatile environment but came into being subsequent to deposition.

We ascribe the systems of parallel microstriations described earlier either to tectonic movements or to compaction or to both. In the case of the pebbles from the Wapiabi formation other evidence points to tectonic activity, for some of the pebbles are pressure-pitted and all were collected from beds which have been folded and faulted. Compaction also may have played a role.

In considering the pebbles from the Cloverly, Morrison, and Windrow formations tectonic movements could also have been responsible, but there seems little to choose between this process and compaction. We are not able to explain the cause of the different sets of oriented striations on a single pebble, except to make the obvious comment that they show that the preferred direction of movement changed from set to set.

CONCLUSIONS

1. Microstriations, the largest of which are just visible to the naked eye, occur on some pebbles with smooth or polished surfaces.

2. Some striations are single scratches and occur randomly on the pebble. These can form in a tumbling machine, along a shoreline, and in a stream.

3. Other microstriations are arranged in parallel groupings. In some instances these microstriations define a coherent pattern over the entire pebble. In other cases they occur in two or more sets. Microstriations arranged parallel to one another on pebbles from the Wapiabi, Morrison, Cloverly, and Windrow formations are thought to be best explained by tectonism or compaction or both.

4. Microstriations may also be caused by ice jams in streams, by torrential stream flow, by wind-driven ice along a shoreline, by mudflows, or by glaciers.

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