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SOME RARE VARIETIES OF STONE CIRCLES

Forms known as *stone polygons* or *stone circles* have already long ago attracted the attention of scientists. These forms belong to one of the major varieties of so-called patterned grounds, i.e. micropolygonal or cellular structures characterized by sorting of stones and fines within each individual cell (forms with sorted material according to Washburn, 1956, 1967).

Of the origin of stone polygons there is so far no satisfactory explanation that would be uniform and generally accepted. This may be to a certain extent attributable to the existence of several varieties of sorted forms, which may naturally suggest various origin. The present writer believes that most of these differences are due to the influence of local primarily edaphic factors as well as to different stages of development of certain processes, and holds that this interesting phenomenon might be explained by means of a few basic physical concepts (out of the great number of those competing with them on equal terms). At the same time some facts at our disposal seem once again to advise caution in solving this problem.

We deal here with forms which – though morphologically almost indistinguishable from structures of the common miniature type with clearly defined sorting of material which often occur in various Arctic, Polar, and Alpine regions – differ from them in origin. Although such forms are rather rare, a description of them appears justified on account of the utter absence in the literature of any discussion of their origin.

Stone circles were observed on a low near-bed bar of the right bank of the Yana, 0.3 km downstream from the locality of Nižniye Kresty. In this sector of the Yana the right-bank near-bed bar stretches along the river as a strip 15–20 to 30–40 m in width. It adjoins an undercut steep bank of the first supra-inundation terrace with large ice-wedge polygons. The bar is composed of smooth step-like surfaces slightly sloping towards the river-bed. The surface of the upper step is 0.6–0.8 m above low water, while that of the lower one is only 0.15–0.2 m high. In some places the surfaces are separated from one another by well-marked steps 0.05–0.15 m high which correspond to the levels of ephemeral flood waters, whereas in other, they slope gently.

The bar is rather uniform in composition. It consists of horizontally and diagonally stratified well-washed fine- and medium-grained sands, gravels and small pebbles. Sandy layers predominate, especially in cross-sections of the upper steps where they often contain a larger admixture of silts. On the surface of the steps, mainly of the lower ones, there is a thin cover of gravels and small pebbles. This deposit is characterized by medium degree of roundness and represented exclusively by rocks of local (Yana) origin, i.e. by Triassic sandstones and shales.

The near-bed bar is completely devoid of vegetation which testifies to an intensive operation of erosional and accumulational processes: the bar being flooded in spring, autumn and summer. It should be noted that the lower steps of the bar were cleared of water just before our arrival (the last decade of August, 1962). Scattered over the bar's stretch on its medium step rising 0.4–0.5 m above low water clearly defined sorted forms attracted attention (Pl. 1). They look like round saucer-shaped depressions of equal size (0.1–-0.15 m in diameter), separated by narrow (2–4 cm) borders composed of gravel including small pebbles. The borders are elevated ca. 1.5–2 cm above the central depression. Silty-sandy patches, smoothly concave in cross-section, are composed on the surface of dusty fine-grained yellowish-grey well-washed sand. This looks very much like fresh alluvium just deposited by the river. This sand sometimes partly covers some stones of the border as well as those of its parts that are free from gravels and pebbles and immediately border on the patch. Single gravels and less often small pebbles may be found inside the silty-sandy patches. All this suggests that the thin layer of sand, gravels and pebbles was deposited by recently receded flood water. In profile, the sorted material reaches down to a depth of only 1–1.5 cm from the surface of the borders. Moreover, stone borders disappear downward at a lesser depth than that corresponding to the level of a cell's centre. Stones are here underlain by sand, analogous to that found in the polygon centres. This indicates that the polygonal structure is essentially formed in the layer of dusty fine-grained sand while the gravel-pebbly borders are as it were, superimposed formations which only emphasize this structure.

At a depth of 3–4 cm from the surface the ground becomes complete uniform. It consists of fine-medium-grained sand with thin gravel pebbly intrusions, separated from the upper layer by erosion surface. The area covered by polygonal forms is quite insignificant (just about 1 square metre) and it passes into a stretch of the bar with no traces of sorted material at all. A few yards off there is another area covered by polygonal sorted forms of somewhat larger size (up to 0.2–0.25 m in diameter). Relatively bigger stones are found in the border zone which is on the whole built up of small pebbles. The structures are remarkable for their lesser concavity at the centre owing to the bordering pebbles that are half buried in sand.

Stone circles were also discovered on a low step of the near-bed bar which is only 0.15–0.2 m above low water. These differ somewhat from those described above. They present well-defined cells up to 0.15–0.2 m in diameter with a rather noticeable concavity in the centre (up to 3–4 cm). The spaces between them are occupied by truncated margin elevations, 3–5 cm wide, which are crowned with a stone border. The latter has a width of 1–3 cm and is composed of gravels with an admixture of small pebbles. Stone material occurs exclusively on the surface of the marginal elevations and does not penetrate into the underlying sand. In some places of the elevations stone material is missing altogether. In the vertical profile the undercut steep bank of the low step exhibits polygonal structure only in the layer of upper unstratified 4–5 cm thick dusty/fine-grained sand. This layer undergoes sagging and simultaneously a decrease in thickness in the centre of cells, this process being accompanied by a rise and an increase of thickness in the intervening sections. The underlying sands and gravels are horizontally stratified.

These peculiarities in the arrangement and structure of polygonal sorted forms visible in both the cross-section and the plane suggest the idea that their origin may be due to certain hydrodynamic processes developing on the near-bed bar during its inundation by flood waters. The validity of this assumption is confirmed by the fact that the occurrence of these structures is confined to the layer of sediments left by the latest flood. Evidently, their formation was caused by the development of so-called macroturbulence during recession of flood waters. Macroturbulence is a common hydrodynamic phenomenon developing in a comparatively shallow stream of running water. It is characterized by the creation of currents and whirls with a vertical axis. These acquire in certain places an orderly, as if cellular (or polygonal), arrangement in the plane. The cellular (polygonal) arrangement of river-bottom deposits in some sections of the river may be viewed as a natural consequence of this complex process. The regular deposition of the material becomes a factor directing the flow of water currents. This leads, under suitable conditions, to further development of cells, first of all to their deepening. With changing water flow the regularity of forms may become obliterated or completely effaced. Here perhaps lies the reason for the fragmentary occurrence of polygonal forms within the limits of the near-bed bar with its sharply changing hydrodynamic conditions. Experimental data show that the forms described may come into being under a stream of water which 2–3 times exceeds the average size of surface fragments, i.e. in the present instance 8–12 cm deep.

Macroturbulence is more or less inherent to near-bed bars of all water sources but is is especially characteristic of mountain and semi-mountain rivers. Among the microconditions contributing to its onset one should single out such sections of a river as adjoin zones of overfall which are created, for example, by an abrupt change in the height of various levels of the near--bed bar. As already pointed out, stone circles near such zones are always better outlined than those located farther.

The morphology of these structures testifies to the fact that water currents were most active in the cells' centres which served as zones of divergence or erosion. From there such material as sand, gravel and pebbles was carried off towards the cells' margins where, in zones of convergence, it accumulated in the shape of small oval elevations slightly raised above the centres of cells. Since such peculiar sorting proceeded under conditions of water current being strong enough to remove sand particles from the surface of the river bottom, the elevations were found to be composed mainly of gravel and pebbles. Only at some depth appears an admixture of sandy material. A sharp change in hydrodynamic conditions connected with a lowering of the water level led to the disappearance of macroturbulence and finally to the cessation of movement of river bottom deposits in the area. Gravels and pebbles soon came to rest while sands for some time still underwent shifting thus forming a sandy blanket over some fragments of the bordering areas.

It is noteworthy that a certain correlation between the size of bordering fragments and that of the cells also finds its explanation in the light of the hydrodynamic nature of the forms under review. Whirls of greater force create larger cells with correspondingly bigger fragments at the borders, and *vice versa*. Another example of patterned grounds, also bound with hydrodynamic factors, is presented by peculiar forms, made up of pebbles and boulders, surrounded by borders of vertically set and radially disposed flat fragments, commonly shales. Their outward appearance may be defined as that of *stone rosettes* (Fig. 2). Such forms have been found on the shores of lakes and seas below the maximum level of wavecut and in regions considerably below the climatic border-line for patterned grounds (such as Scotland, south-western Ireland, eastern Greenland, northern Norway, etc.). A detailed description of analogous forms is given by J. W. Gregory (1930) who came across them on a shore of fiord-lake Loch Lomond in Scotland. He insists on the radial arrangement of shale slabs set on edge around obstacles in the form of large stones. This arrangement is due to lateral pressure. Gregory explains it by alternate freezing and thawing in water-saturated rock debris. C. Troll (1944) regards these forms (*Steinpackungen* or *stone packings*) as a special type of azonal patterned grounds developing on rocky shores under conditions of repeated inundation. Although Troll does not definitely settle the question of their origin he is nevertheless inclined to attribute them to a frosty climate. Like J. W. Gregory he emphasizes the fact that stone material is disposed transversely to the operating pressure and parallel to the encountered obstacle. The correctness of this statement can hardly be denied.

The facts cited above are quite sufficient to solve in principle the problem of origin of the patterned forms in question. They are hydrodynamic formations in littoral areas, subject to periodic inundation due to strong bottom currents and wavecut.

Increased hydrodynamic activity promotes transfer of small particles to deeper sections of sea or lake bottom while the remaining larger fragments undergo various dislocations big stones or tree trunks naturally becoming local centres of intense circulation of water currents and of the bottom deposits drawn by them. In case these obstacles are of a more or less isometric form, circulation of water near them acquires a turbulent character. Numerous observations and laboratory experiments have shown that at the base of such stones appear funnel-like depressions resulting from erosion of grounds including cracked rocks by obstacle-oriented water currents. The dimensions of these depressions depend on the size of the obstacles. Around large stones and tree trunks they will be larger, around small ones – lesser. If the shore area is predominantly composed of shales which, affected by weathering, produce slab jointing, fragments of the latter will accumulate around stones or tree trunks in the funnel-shaped depressions and assume a coulisse-like subvertical arrangement. As a result forms reminiscent of rosettes come into being.

The present writer has frequently observed phenomena of that type in the beds of the Yana's left-bank tributaries (Suor-Wolaah stream and others) originating in the northern foothills of the Ulakhan-Sis Ridge. The foothills are composed of predominantly clayey and sandy-clayey shales and sandstones. The short length of streams and numerous outcrops in their bed account for the predominance of rather poorly-rounded alluvial material. The near-bed bars display a most varied arrangement of shale slabs and whole areas where they are set up almost vertically. Evidently the "on edge" position of a slab with its long axis in the direction of water flow ensures the greatest stability of a slab under a strong water current[1]. It is interesting to note that with the presence of sufficiently rounded pebbles, small boulders and sandstones in bed deposits over such stretches of a river shale fragments

[1] Similar phenomenon may occur under different conditions, for example, in the oriented motion of creep processes, etc.

tend to locate themselves in a coulisse-like manner around the above-mentioned material. Nowhere, however, has the writer seen any fully developed complete circle of shale slabs, i.e. rosettes proper as described by the above named workers. This is most probably due to the hydrodynamic conditions of a rather turbulent rigidly oriented water current. In other sites too such formations occur rather exceptionally.

A. G. Doskač (1962) has reported quite peculiar sorted forms, very common in the Kazakh hummocky topography and resembling those described above. They look like small sinks (up to 0.5 m in diameter and 0.1–0.2 m deep) at the end of tree trunks containing markedly sorted material. The lowest parts of the sinks have at the surface sand underlain by gravel and fine rock debris.

In all probability these formations should be attributed to aerodynamic processes operating in the near-surface stratum of air due to the presence of obstacles in the form of tree trunks which direct air currents and sharply increase the local corroding effect of these currents on the ground. In the immediate vicinity of trees a zone of strong circular air whirls is created which contribute to blowing out of material and the emergence of sinks around tree trunks. On the surface the sinks are covered by a layer of sand which accumulated owing to a notable decrease in the velocity of winds. Gravel and small stone fragments, material removed to the margins form an outer belt of patterned forms.

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