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Art. XVI.—*On the Formation of "Natural Quarries" in Sub-arid Western Australia.*[1]

By J. T. JUTSON

(Geological Survey of Western Australia).

(With Plates XXVIII., XXIX.).

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Introductory.

The sub-arid interior of Western Australia possesses many striking surface features, which are as yet but little known, and still less have been the subject of investigation. Amongst minor forms, the remarkable hollows, to which the writer has applied the name, "natural quarries," are worthy of record. They differ in origin from the natural quarries due to ice action; and in normally moist climates they have no definite parallel. Their nearest topographic forms in such climates are certain scars left in places on steep hillsides, owing to land-slips, but for reasons stated below such an origin cannot be postulated for any of the quarries described in this paper.

Summary.

"Natural quarries," in sub-arid Western Australia are of three kinds, circular, rectangular and triangular. They are distinct excavations (resembling artificial quarries) in the hillsides of various rocks; and are chiefly due to the mechanical gouging or undermining action of rain under certain special conditions.

Description.

There are three kinds, broadly speaking, of natural quarries. They may be described as the circular, the rectangular and the triangular types, such terms being based on the kind of plane figure formed by the outline of the quarry on the normal surface slope. There is, however, a certain amount of transition between the different forms.

The Circular Quarry.—This kind forms a more or less circular hole of varying diameter and depth, on a hillside; and in many

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places has a resemblance to an ordinary shallow artificial quarry excavated in a similar locality. The slope of the hillside is usually steep, or at a moderately high angle from the horizontal. Treating such slope as a plane, the outline of the quarry on such plane would approximate towards a circle, and taking a section down the slope through the quarry, the section line along the plane across the quarry would be the chord, and the outline of the quarry on the section would be the arc, of a vertical circle. In some cases, however, the lowest lip of the quarry may be removed by erosion, and the quarry then passes gradually into the lower slope of the hillside.

The rocks of the hillside are either decomposed igneous rocks, or normal sediments such as shales and grits. The igneous kinds predominate. The rocks must be soft and easily removed, and therefore circular quarries are not found in the unweathered granite and "greenstone." These soft rocks are frequently capped by distinct bands of ironstone, or the surface layers of the rocks may become indurated, without forming a distinct cap. The upper surfaces, therefore, become resistant to erosion. The hard-capped or surface-indurated hills form lines of cliffs, known as "breakaways," connecting a tableland with a lower plain. Small water channels, which are usually mere furrows, one or two feet wide and deep, may lead into the quarry at the top of it, or out of it at its base.

In surface dimensions the quarries range in diameter from a few feet to perhaps 40 or 50 feet, and in depth from perhaps a foot or two to five or six feet. They are generally shallow in proportion to their surface area.

The Rectangular Quarry.—This type is also found on hillsides. Its floor, however, is practically coincident with the floor at the base of, or with the floor of a bench on the hillside. It is different from the circular quarry in that it is bounded by approximately straight lines. Its "back" forms a steep usually vertical, or close to the vertical, plane, which intersects at an acute angle the plane of the hillside. Its floor forms a plane but little inclined from the horizontal, and practically coincident with and forming an extension of the floor at the base of, or of the floor of a bench on the hillside. Thus there is frequently but not always no "front" wall dividing, or partly dividing, the quarry from the adjacent floor; and where a wall does occur it is generally very low and is always broken to allow for the passage of water from the quarry.

The "back" and the floor of the quarry approximate in outline to rectangles, which are frequently at right angles to each other. The two sides of the quarry form triangles on vertical planes, or planes which approximate to the vertical, and which tend to be at right angles to the plane of the "back." The sides of the triangles are therefore formed by the planes of the hillside slope, the "back" and the floor. In the rounding off of corners there is a tendency to destroy the sharp rectilinear outlines, but such outlines are clearly recognisable.

A quarry may form on any hillside provided the rocks underlying the surface rocks are comparatively soft and easily removed. Thus this type of quarry is found on hillsides of soft schistose or stratified rocks, or of any decomposed rocks; and such hillsides may include "dry" lake cliffs. It is not found on slopes with hard granite boulders; but it does occur on slopes littered with small but tough greenstone fragments, for often beneath the surface litter the rock *in situ* may be much decomposed. Rain furrows and small channels may lead to and from the quarry and across its floor. Most quarries are of small dimensions, the average of which for many would be about eight to ten feet high, six to eight feet broad, and ten to twelve feet long. Some quarries greatly exceed these measurements. One on the western shore of Lake Goongarrie, at Comet Vale, is probably 30 to 40 feet high, 40 to 60 feet broad, and 60 to 70 feet long; but this is an exceptionally large one so far as the writer's observations have gone. The figures given are approximate only, as no actual measuring has been done.

The Triangular Quarry.—This type of quarry is more akin to gulches produced by normal erosion at the heads of gullies. On the plane of the slope which it dissects it is roughly triangular, and has the base of the triangle on the upslope and the vertex pointing downhill. It is usually V-shaped in a cross section parallel to the base of the triangle, the sides having but moderate slopes. The "back" however, is somewhat steeper, this feature being accentuated when, as often occurs, a rock cap which tends to be undermined forms the coping to the back. The quarry is mostly connected with a drainage line at the vertex of the triangle, the quarry representing the present but somewhat abnormal head of that line, as the steep slopes and gulches do in an area of normal erosion. Similarly, as in such a normal erosion area, the quarry tends to be at the top of the slope, with its "back" close to the crest line of

the ridge. There is thus a close resemblance between the two types—the quarry under arid, and the steep slopes and gulches under normal, erosion; but marked differences also exist. In normal areas, the lower drainage line or channel is wider and more strongly marked than the upper portion running up towards the crest line, and if the upper portion be branched, the branches are separated by a ridge. In the quarry, however, there is a wide scooping out with no distinct bisecting ridge.[1] Moreover, the quarry is the clearly marked feature, the lower drainage line often being insignificant and difficult to trace by reason of the tendency of the occasional water flows to spread themselves over a comparatively wide belt of the lower country.

The triangular quarries have a moderate range in size. They are from 10 to 15 feet in all dimensions, to a large quarry having a "back" perhaps 100 feet in length measured horizontally along the top. They probably approach equilateral triangles in shape, but the base (the "back") is, the writer believes, usually longer than the sides.

This type of quarry does not, as a rule, form in granite, Much weathered "greenstones" or greenstone schists, with a cap of hard ironstone, appear to be the most suitable rocks for their formation.

Mode of Formation.

The action of the rain in beating upon and undermining decomposed comparatively soft rocks, which are associated in definite ways (to be presently stated) with certain harder rocks, is apparently the main factor in producing the three types of natural quarries above described.

The circular quarry originates in most instances at least in the following way: On the face of a "breakaway," the detritus from the hard surface layers and from the rocks below slowly drift towards the bottom, and in doing so the whole face of the "breakaway" may at any particular period of time be covered with this detritus or talus to a thickness of about one foot or less.[2] Owing to the widespread tendency in sub-arid Western Australia to cement all loose surface deposits by mineralised water rising to the

1 It must be remembered that these remarks only apply to the triangular natural quarries here described, and that gullies with normal branches in every way similar to those formed in wetter climates are numerous in hilly country in the dry areas.

2 A greater thickness than one foot may occur, but under such conditions it is doubtful if a natural quarry would form.

surface by capillary attraction and by the evaporation of such water with deposition of mineral water, this detritus may be compacted and hardened by the introduction of (chiefly) iron oxide or travertine as a cement. The cemented detritus then forms a cover, fairly strongly resistant to erosion, over the underlying soft rocks. The latter are, therefore, so long as the cover lasts, protected from further erosion. The cover may, however, not be quite continuous everywhere, or it may be very thin and not completely cemented in certain places, or for some other reason a hole in such cover may exist or be made. Having such a hole, the rain may directly beat upon the soft underlying rocks, or may find its way between the cover and the softer rocks, with the result in either case of removing portions of such softer rocks and undermining the cover, which collapses and gradually disintegrates into fine enough material to be carried away by the rain. Once started this process may go on, the hole growing larger until one sufficiently large enough is produced to be called a circular natural quarry. This seems to be the chief method of formation, although some quarries occur which do not seem to have had a distinct cover; but here there is probably some surface hardening of the rocks, without, however, the formation of an appreciable cover. It is also conceivable that some parts of the soft rock are less resistant to erosion than others; that therefore where no cover exists, the beating action of the rain may gouge out the less resistant rocks; and that when once started the cavity so formed may grow in size.

The rectangular quarry in places resembles the scar left by a landslip, but as an accumulation of detritus, such as would result from a rock fall, is never found on the floor of the quarry, this mode of origin must be rejected. It is difficult to account for all quarries of this type, but the following conditions favour their formation :—(1) An abuttal along a vertical or nearly vertical plane of decomposed soft rocks against a band of hard erosion-resisting rocks. (2) Decomposed soft rocks capped by a practically continuous band of loose fragments of a hard erosion-resisting rock derived from an outcrop farther up the hillside. In both cases, if the soft rocks form vertical or nearly vertical schists, the formation of the type of quarry now discussed, is accelerated. The mode of origin is not easy to understand, but it seems that the action of rain beating on the soft rocks is mainly responsible for the wearing away, aided of course by the ordinary weathering agents; and that the resulting form is governed by the band of hard rock or by the surface cover of hard detrital rock mentioned

above, either of these two rock arrangements necessarily tending to produce a steep cliff. It is possible also that water finds its way down through the rocks and oozes out at the base of the cliff; and so may slightly remove, or at any rate weaken the soft rocks at the base of the cliff. When these quarries occur at the edge of "dry" lakes bounded by rocky cliffs, the crystallization of salt from water evaporating from the rocks at the base of the cliffs may also help this type of quarry formation, but further investigation is desirable on this point.

The triangular quarries are due to the gouging action of rain on soft rocks. Their form is guided by the hard rocks forming a cap to the "back," which cap resists erosion and brings about the steep "back." At the same time the check given to erosion by such cap causes the denuding agents to follow the line of least resistance, with the result that the quarry is widened between the sides of the triangle, thus causing a lengthening of the "back" along the base of the triangle.

EXPLANATION OF PLATES.

Plate XXVIII.

Fig. A.—Section through a circular quarry. The broken lines indicate the original surface, which has now been removed.

Fig. B.—Block diagram illustrating the formation of a triangular quarry with a hard cap to the "back."

Figs. C. and D.—Sections illustrating the formation of rectangular quarries, the broken lines being the original surfaces, now removed.

Plate XXIX.

Fig. E.—A circular quarry, Niagara.

Fig. F.—A rectangular quarry, western shore of Lake Goongarrie, Comet Vale.