SOME OBSERVATIONS ON THE DEVELOPMENT OF WEATHERING FORMS IN THE MILLSTONE GRIT OF THE BURBAGE BASIN, SOUTHERN PENNINES

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ABSTRACT

Weathering pits are formed when large quartz pebbles are removed from the surfaces of the grit blocks or tor tops. The cavities so produced are enlarged by solution, frost action and organic growth and decay. They were probably initiated in the Last Interglacial. Their development was interrupted by the onset of cold conditions in the Last Glacial. During this time, cracks were produced in some of the pits due to freeze-thaw action. They are currently developing on the surface of blocks, but are relict features when they occur on their sides.

Honeycomb weathering develops on the sloping surfaces of the grit free faces, tor plinths and blocks, where an iron deficient zone exists beneath a hard, iron-rich rock crust. The removal of quartz pebbles destroys the hard crust and exposes the inner decomposed rock, fretted with honeycomb weathering. It appears that the weathering was initiated after the detachment of blocks from the bed rock, probably microgelivation played an important part in its development.

The presence of an iron nodule is a pre-requisite for the development of the weathering circles. The iron-deficient zone peripheral to the iron nodule is etched out by chemical weathering and microgelivation to form circles. Their formation was contemporaneous with the Last Glaciation. As the active evolution of free faces stopped by the end of the Upper Dryas, circles on any free face cannot be older than about 10,000 years. Some of the weathering circles on blocks were produced on the free faces; others have been formed subsequent to the detachment of the blocks from the free faces.

INTRODUCTION

Throughout the Burbage area (800-1400 ft. O.D.) in the southern Pennines, bedrock exposures, tors, and blocks show a variety of weathering forms, some of which *viz.*, weathering pits, honeycomb weathering and weathering circles have been studied in detail. These features are developed on the Rivelin Grit zone of the Millstone Grit series, which consist of grit, sandstone and shales belonging to the Carboniferous period. The Grit contains pebbles of various sizes and of different rocks and minerals. It is massive bedded and shows a rectangular pattern of joints; for the most part gently dipping it forms mesas and cuestas.

WEATHERING PITS

General.

Weathering pits are defined as pits or hollows, developed on a level surface, regardless of their depth of development. Like free faces and tors the weathering pits have been explained in many different ways. Because of their chance occurrence near to the prehistoric sites they were considered by some of the early workers as having been formed by tools, (Rooke, 1785; de la Beche, 1839; Drake, 1859). There were others who favoured the idea of wind abrasion, (Ramsay, 1872; Ward, 1872; Green, 1887). In 1853 when Phillips put forward his marine theory for the formation of edges and tors many of the rock basins were explained in terms of sea action (Tute, 1868). Outside the Pennines these features have been studied on Dartmoor by Ormerod (1859) and Geikie (1882) who favour the elements of wind, rain, freeze/thaw, leaching and slopping water for their development. In the present century these forms have been studied by Radley (1958) in the Burbage area. He distinguishes two types of pits: (1) those due to lichen growth in crevices which are subsequently enlarged by wind and water attrition and thermal variation and (2) those formed due to the presence of an iron or clay nodule which is chemically reworked by carbonic acid and later modified by water.

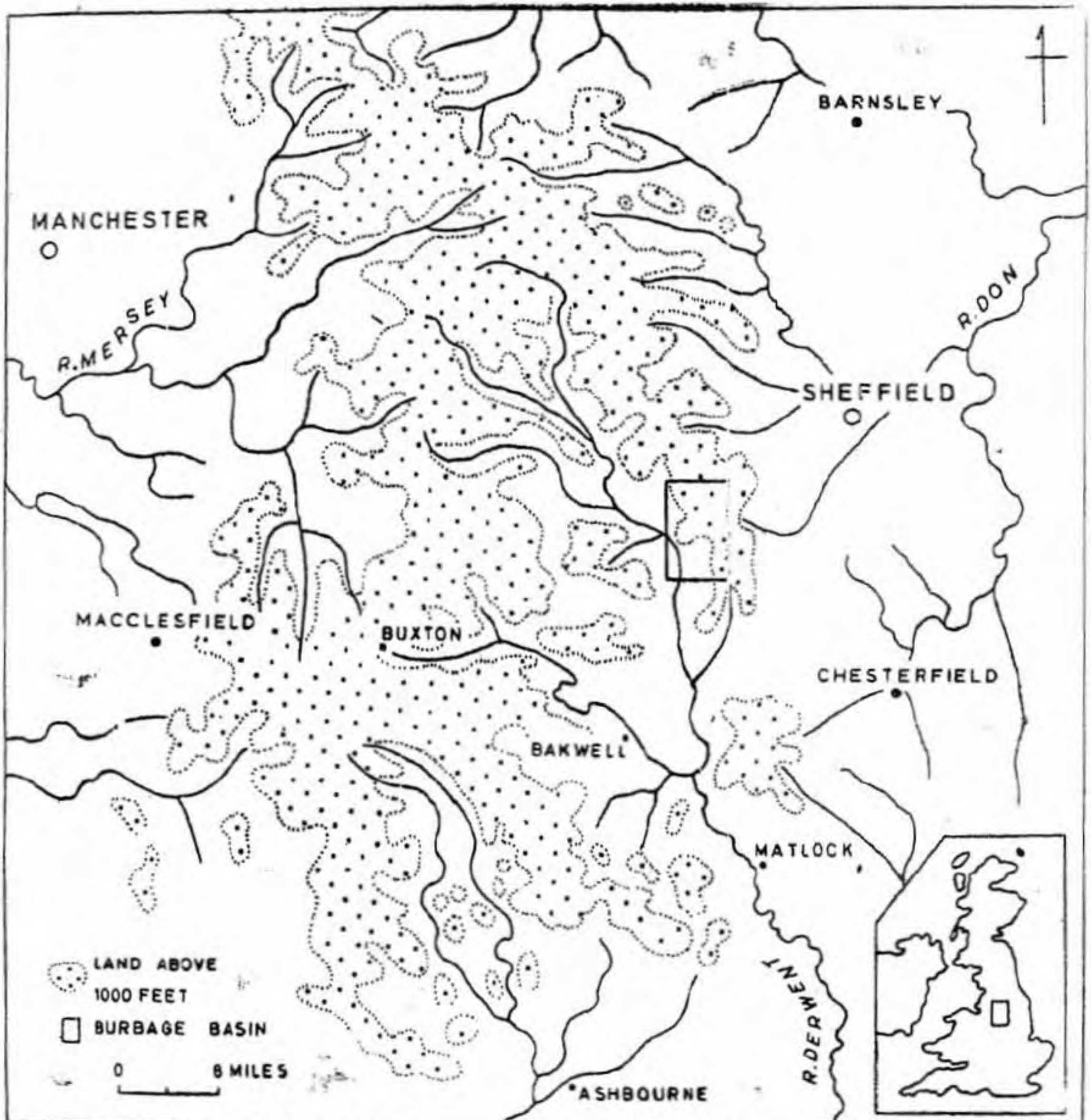

Fig. 1. Location.

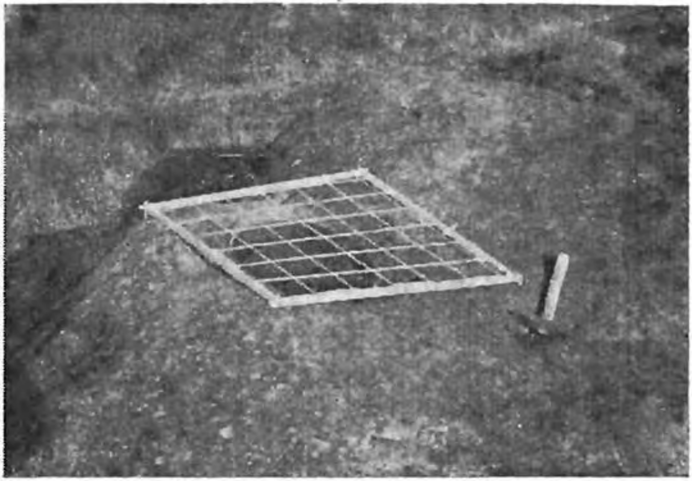

Plate 1. Grid used for mapping weathering pits,

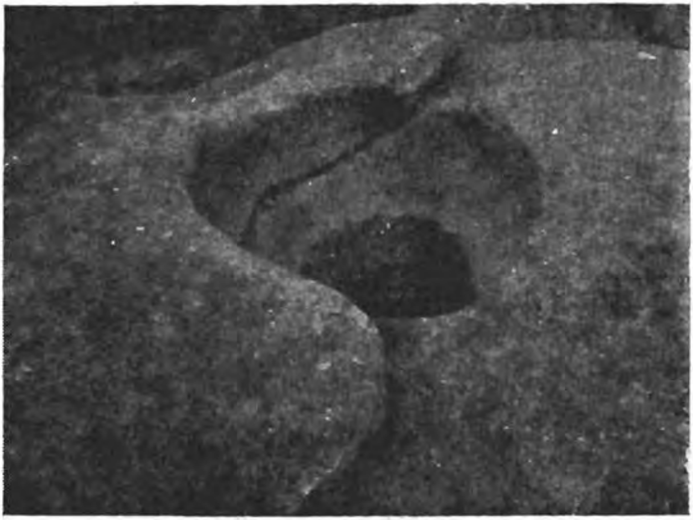

Plate 2. The development of a crack in a weathering pit due to frost action.

Weathering pits and similar feature have been described from different parts of the world. Bryan (1926) described the origin of desert niches to the loosening of grains of rock through the solution of cement by circulating water; Blackwelder (1929) emphasised the significance of dampness in the development of cavities that are sheltered and cannot be reached by rain. Smith (1941) regards alternate wetting and drying of rock as the main factor in the development of cavities in granites of the South Piedmont. Demik (1964) regards the pits in Bohemia as being due to the "agressive influence of water and the formation of salt crystals". Dahl (1966) favours microgelivation and chemical weathering as important in the development of pits in the Narvick Mts. Cavernous weathering has also been reported from Antarctica by Calkin and Cailleux (1962), and Mercer (1963). This has generally been attributed to frost action, insolation, dehydration and chemical action.

Size and Form.

Weathering pits vary in size from a few inches to 12 feet across, depending on their stage of development. Usually they are circular, very broad at the top and narrowing down-wards. They might occur singularly or in a group; in the later case they join together and as a result complex forms are produced. A well-developed pit exhibits, a convex lip, an inner wall and a floor. The floor of the pit is separated from the surface of bedrock or boulder by a convex lip. This is gentle in the initial stages but as the floor of the pit is lowered it becomes steeper. Where a relatively less resistant layer occurs in the floor, weathering is accelerated and a steep wall corresponding to the thickness of the weaker band is produced, which encroaches on the convex slope. In the advanced stages the lip is eliminated and the steep wall may directly join the surface of the bedrock or block. The lip is usually breached on one side by a mouth through which the pit drains. The wall between the lip and the floor is frequently covered with algae and/or lichen. Where soft bands occur they are etched out and weathering takes place. The wall may show micro-relief, such as large quartz pebbles, or shallow cavities left after their removal. Some pits also show cracks across the bedding planes.

The wall makes a concave break of slope with the floor which is very small in the initial stages of pit formation but which widens *pari passu* with the enlargement of the pit. There is usually a shallow hallow, (1 to 2 in. wide) in the floor where water stays. This constitutes the site of much active weathering. The floor is also characterized by micro-relief such as ridges, steps, and depressions formed by the removal of quartz pebbles or the spalling of scales. Like the wall the floor may also exhibit cracks.

Hydrological Conditions.

A weathering pit may be filled with water up to the level of its mouth (Pl. 3). During long spells of evaportion in dry weather, many pits dry out but the largest are seldom dry. Pits that contain sediments may hold much soil moisture long after rain water is evaporated. In the advanced stage of development when the mouth is at the level of the floor or the pit has developed cracks, it no longer retains water but remains permanently dry. During cold spells, from December to January the water in a pit may be completely frozen.

Deposits.

Weathering pits contain deposits of various types. In most cases they consist of coarse sand, pebbles and scales detached from the various parts of the basin. Incorporated in these sediments is wind-blown material e.g. fine sand, silt and fine-weathered peat. The later gives the deposit a very dark colour. In dry weather the fines are easily blown from the shallow pits by the wind, which leaves behind only the coarse fragments. The lip and that part of the pit above the normal water level are covered with algae and, in some instances lichen. Permanently dry basins are completely colonised by these organic growths. Where the basins are filled completely with sandy material they may be overgrown by clumps of calluna and deschampsia.

Distribution.

Weathering pits occur on the surfaces of the coarse grit that are usually devoid of soil and vegetation. They may occur on tors and detached blocks. With a few exceptions, weathering pits are found on the upper surfaces of all the tor tops. Some of the largest and deepest pits are found on them. On tor tops it is not uncommon to find several basins, some of which have coalesced to form an integrated drainage system. On the blocks they are found in two different positions, (a) on the top, whether the surface is developed parallel or acorss the bedding these are normally currently developing forms, and (b) on the side, which are relict features that developed originally on a level surface, usually a bedding plane.

Origin.

Weathering pits develop on the level surface of a horizontally-bedded or cross-bedded tor top or block of grit. As already noted, the Rivelin Grit contains large quartz pebbles, sometimes 2 inches across, that are cemented together by silica and clay minerals. When the cementing material is dissolved or weathered, the quartz pebbles are loosened and may be removed by rain or wind. A small, shallow cavity is thus created which is filled with water. A number of physical and chemical processes are involved in the subsequent enlargement of this initial cavity, e.g., those associated with wetting and drying, freezing and thawing and organic growth and decay.

In the initial stage the cavity is a smooth convex-concave depression with a shallow floor. Development appears to be very slow on resistant bands of rock but to be accelerated where a less resistant band is encountered. The enlargement of the pit along such a band may create an overhang. Where overflow occurs a mouth is created. Where several pits occur close together, the gradual removal of the intervening surface by the retreat of their walls and overflow of water from one basin to the next, results in the creation of an integrated drainage system. The height of the mouth, in relation to the floor, is an important factor in the development of a basin that is situated along the edges of the tor tops. The lowering of its mouth often keeps place with the enlargement of a basin. Where the floor encounters a more resistant band, deepening is arrested and the mouth is lowered to the level of floor. In such a case the basin cannot hold water, and its active evolution is stopped; but its floor is gradually weathered so that a funnel-shaped form is produced, which is progressively enlarged by running water during rain. It is thus, evident that these funnel-shaped forms mark the last stage of development of basins, along the edges of tor tops. They are not "half basins" produced by the splitting by frost action of tor tops or detached blocks as proposed by Radley (1958).

Dating of Weathering Pits.

Linton (1964) believes that the weathering pits have been formed in the Post-glacial. This view is also shared by Palmer & Radley (1961). During the course of this survey two different types of pit have been recognized: (1) weathering pits that are developed on the level surface of the block and (2) those which are developed on the sides of the blocks. It is also to be noted that some pits exhibit cracks. This evidence suggests that basin formation was interrupted by a cold phase during which some of the blocks were overturned while others were split. It is thus evident that not all pits were formed in the Post-glacial; some, at least, pre-date a cold phase.

Cunningham (1966) believes that since weathering pits are currently being formed in hot, wet climates, those in the Burbage area may be the survivals of the Tertiary weathering. It should be noted, however, that cavernous weathering has been reported from cold climates, where microgelivation is considered to be the dominant process, (Calkin & Cailleux, 1962; Mercer, 1963; Nicholas, 1953; Dahl, 1966). Thus basins are not characteristic of hot, wet climates only; nor can they be used as paleo-climatic indicators. Cunningham further suggests that the Post-glacial is too short for the development of these forms. As evidence he refers to the tops of the tor plinths that are devoid of any pits. He suggests that tors from these plinths were displaced by the moving ice and the plinth surfaces so exposed have remained unweathered throughout the Post-glacial.

It has been noted above that some pits on the detached blocks are developed across the bedding planes. This would suggest a period of basin formation subsequent to the displacement of blocks from tors and it is not unlikely that some of these pits developed during the Post-glacial. That such weathering can take place is evident form the extent to which the millstones have been modified during the last 200 to 300 years.

The development of the existing weathering pits was probably initiated under climatic conditions similar to those which prevail in the Burbage area at present. It is likely that they were initiated during the Last Interglacial. It seems that the tors on which pits developed were formed in the penultimate cold phase. Pit formation appears to have been interrupted by the onset of cold conditions in the Last Glacial, when some tor tops were displaced by frost action, and the basins developed on them ceased to evolve. This is evident from the presence of pits on the sides of detached blocks. In other basins large cracks were produced by freeze/thaw action. Those that survived this cold phase were considerably enlarged, particularly those situated in the centre of the tor tops. Those near the edge of the tor tops were also enlarged but ended up as long funnels. Basin formation appears to have been resumed on tor tops and blocks in the Post-glacial. It has been noted, that during the Post-glacial much of the Burbage area carried a vegetation cover and many of the low free faces and tor plinths were buried under soil and were not available for basin development (Said, 1969). It has been only after deforestation and burning of the moor in the Sub-atlantic that many of these feature have been exposed to the processes of weathering for short intervals. This probably explains the absence of weathering pits from many of the low tors and blocks.

HONEYCOMB WEATHERING

General Features.

Burbage Edge block field shows some very good examples of honeycomb weathering. These have been mapped in detail and some suggestions are made with regard to their development. Honeycomb weathering occurs on the grit block all over the area but it is particularly well-developed on the Burbage Edge block field. It is also found occasionally on the bedrock in the free, face along the Burbage Edge and on the tor plinths on Carl Wark. Like weathering pit,it is restricted to the coarse grit lithologies, butunlike them it is formed only on a sloping rock surface. On the blocks it is developed both on and across the bedding. In the Burbage block field which slopes south-east it is strongly developed on the southwestern (210-270°) sides of the blocks and weakly developed on their northeast - facing sides (30-90°). In places it also occurs inside some of the wide joints in the free faces in which position it shows no marked relationship to aspect.

In the intial stage the cells are 1 to 2 inches across, shallow (0.5 in), circular hollows with narrow, deeper cavities inside. They have an asymmetrical cross-profile. Generally they are circular in plan, but when they occur close together, they may coalesce to produce very complex forms. Their form also depends to a very large extent on whether they are developed on or across the bedding planes. In the former case, beds of varying resistance may be encountered by the weathering agents (Fig. Pl. 5). Thus the hollows are rapidly enlarged and extended laterally along soft bands, and diversified by ridges and overhangs, where resistant bands occur. On surfaces which are transverse to the bedding, the honeycomb weathering pattern is superimposed on the pattern produced by the deeply-etched bedding planes (Pl. 6). They are often covered with algae and in

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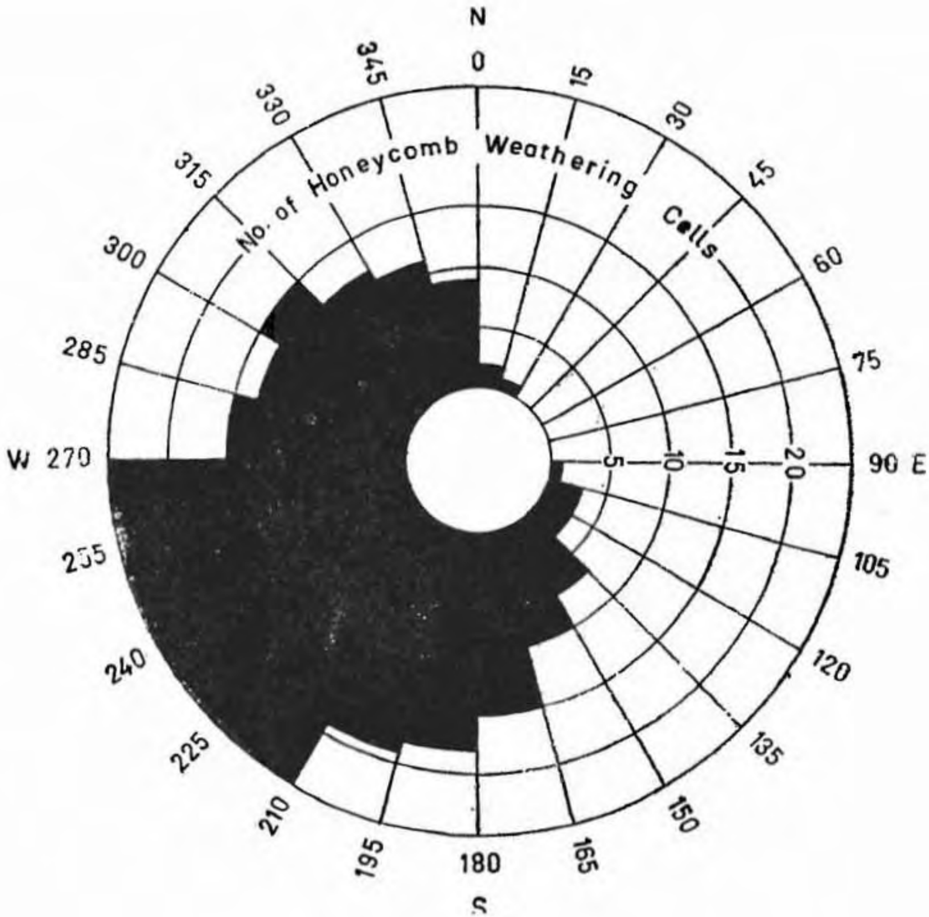

Fig. 2. Orientation of Honeycomb weathering.

some cases with lichen. As they are generally shallow and occur on the steeper sides of blocks and tors, they do not hold any water or sediment. It is also significant to note that the rock within and around the cavity is weathered and friable.

Origin.

It has been noted above that grit contains quartz pebbles ranging in size from 1 to 2 inches. The weakening of the cementing material very often results in the detachment of those quartz pebbles, leaving cavities of different sizes. It is likely that some of the small cells may have been produced in this manner. It is a relatively rapid process, as such cavities are frequently found on the quarried free faces. But the simple removal of the pebbles does not satisfactorily account for the highly developed weathering pattern or the decomposed rock within and around each cell.

Examination of the free face reveals the presence on joint-bounded surfaces of a thin crust formed by the deposition of iron, probably from solutions drawn up from inside the rock by capillary action. Immediately underlying the surface crust is relatively friable rock, deficient in iron. The iron-rich hard skin acts as a protecting cover. It may be broken up when a quartz pebble is removed and the cavity so-formed penetrates the hard layer and makes the underlying loose rock accessible to weathering by atmospheric agencies. As the weathering of the loose rock proceeds, the iron-rich crust is undermined and collapses. This process is accelerated as more pebbles are removed. Ultimately the entire crust is removed and the inner, decomposed rock is exposed, fretted with a honeycomb weathering pattern. The removal of quartz pebbles and weathering of the surrounding rock may be carried on, long after the removal of the iron-rich crust.

It appears that the honeycomb weathering might have been initiated at any time after the detachment of blocks from the bedrock. But it is conceivable that some pattern might have developed while the blocks were still part of the joint-bounded bedrock. As most of these blocks have been detached by frost action, it is possible that microgelivation played an important part in the development of their surficial honeycomb patterns. The processes of weathering appear to have been accelerated during the Post-glacial, when much of the fine material was removed and the blocks exposed. This probably explains the strong development of the honeycomb weathering patterns on the southwest-facing sides of the blocks.

WEATHERING CIRCLES

General Features.

In the free face along the Burbage Edge (SK/266825) and in the spreads of the grit blocks in front of it, there are found weathering forms which for want of any suitable terms are referred to, as weathering circles. Like the honeycomb weathering they have not been previously recorded or examined.

Weathering circles are generally circular, but complex patterns may arise where two or more of them intersect. In the initial stage the circle may be outlined by no more than a faint groove, but in more advanced stages a circular channel is developed, V-shaped in cross section and from 2 to 5 inches wide at the top. Depending on the stage of development, the channel may be shallow (0.5 in.) or as deep as 8 inches. Circles vary in diameter from 4 inches to 1.5 feet, but 8 inches is the average. The junction between the etched circle and the rock surface is very sharp. In the advanced stage it is marked by an almost vertical wall and in many cases an overhang. The centre of a circle is defined by a flat surface marked only by the weathering pattern of bedding planes; in the advanced stage it may stand out as a knob 4 to 5 inches above the rock surface.

In the Burbage area circular weathering is confined to one locality, where coarse, massive grit is exposed. Circles are developed across and on the bedding surfaces in both bedrock and blocks. On

Plate 7. Weathering circles developed on the bedding plones of a grit block.

Plate 8. Weathering circles developed across the bedding on a grit block.

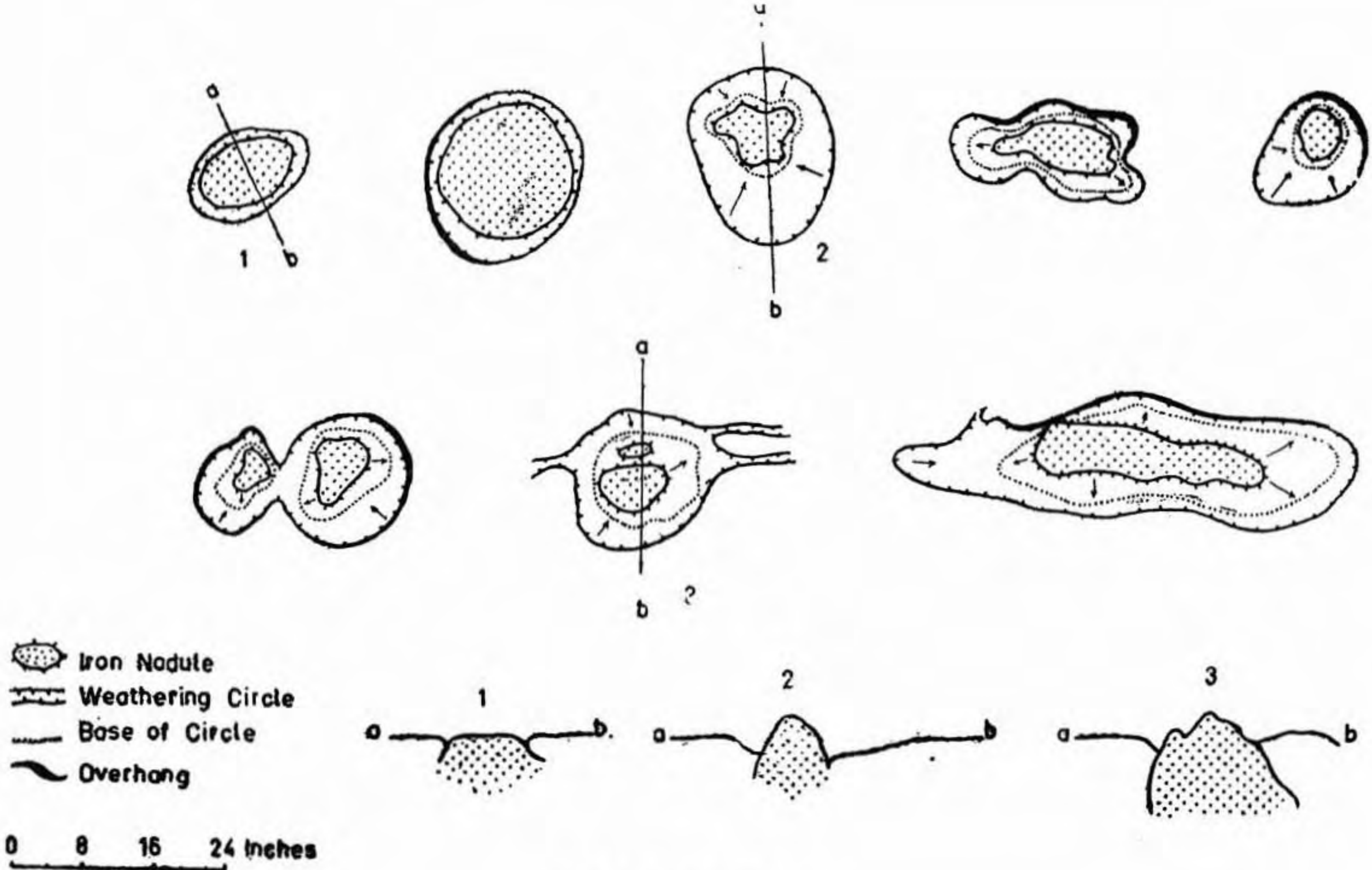

Fig. 3. Weathering Circles

the blocks they are found on all sides and bear no relationship to aspect. They are often defined by a light green circle of mosses and algae occupying the base of the etched circle. The mosses are best developed in the moister downslope part of the circle. Circles may also be overgrown by lichen. Some of the very large circles on the detached blocks are filled with wind-blown peat and sand, which carry stumps of calluna and deschampsia.

Origin and Age.

The following observations would seem to be particularly relevant to any considerations of the genesis of the circles.

(*i*) Their development is controlled by a narrow circular zone, relatively less resistant than the rock inside and outside the circle.

(*ii*) As the inner part of the circle stands higher than the surrounding rock, it would appear that it is more resistant than the surrounding rock.

(*iii*) Where fresh blocks have been detached from the free face, it is apparent that the inner part of the circle is a ball of relatively hard and resistant rock, rich in iron (iron nodule), surrounded by a less resistant zone from which iron has migrated inwards. As these iron nodules cut across joints and bedding planes it is most probably that they are diagenic features.

The presence of an iron nodule is a pre-requisite for the development of a weathering circle. The weathering of a free face may expose iron nodule-bearing beds to atmospheric weathering. The iron deficient zone, peripheral to the iron nodule, is etched out by chemical weathering and microgelivation. Initially isolated cavlties are developed along the weaker zone, As they are enlarged they are joined together and a continuous circle is formed. They are colonised by algae, mosses and lichen which appear to play an active part in their subsequent development. The etched circle so formed is deepened from all sides, ultimately resulting in the complete detachment of the iron nodule. On the free faces and steeper sides of the blocks, the iron nodule may be released leaving behind a depression. On the relatively level surface of the blocks the nodule may be present inside the hollow, though detached completely from the rock. Where the circles are close together, the weathering of the intervening walls may produce a complex form, containing several knobs.

As the weathering circles are developed on the bedrock, on the free faces and on the grit blocks, their development must post-date the initiation of free faces and the detachment of blocks from them. It has been suggested that the free faces in the Burbage area were produced during the Penultimate and Last Glacial phases (Said, 1969). Since most of the blocks with weathering circles are only 1000 feet from the free face, it is likely that most of them were produced by frost action in the Last Glacial. The initiation of the circles would thus be contemporaneous with the Last Glacial. It is probable that the distribution of these weathering forms is confined to a small patch of bedrock rich in iron nodules which was first exposed in the Last Glacial phase.

Because perigalcial conditions and the active evolution of free faces ceased by the end of Upper Dryas, it would appear that the weathering circles on any free face cannot be older than 10,000 years. Nevertheless the limited development of these features on free faces relative to that of weathering pits and honeycomb weathering suggest that the production of weathering circles is an extremely slow process. It is likely that some of these forms on the blocks, particularly those across the bedding planes, may have been produced originally on the free faces; but they might have been enlarged after their detchment in the Late-glacial and Post-glacial. It is also clear that during these times new circles were developed on the blocks.

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