DEEP WEATHERING, GLACIATION AND TOR FORMATION IN CHARNWOOD FOREST, LEICESTERSHIRE

by

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Summary

The significance of the deeply weathered zones in the Leicestershire igneous rocks, briefly noted long ago by Bosworth, is discussed in the light of new exposures in working quarries. The deep-weathering is shown to ante-date the Chalky Boulder Clay and is thought to be Tertiary in age. It is shown to have operated only where the impermeable seal of Keuper Marl was broken by erosion; much of the rotted material has been removed by glaciation. Evidence is presented that ice completely over-rode Charnwood Forest and considerably modified the exhumed Triassic mountain tops. Glacial scouring, followed by periglacial mass-movement, has sculptured some of the Charnian crags into tors.

Introduction

"It may confidently be asserted that the landscape of those parts of the Forest founded upon ancient rocks, the characteristic Upland landscape, is one of Triassic date and character, emerging practically uninjured from its burial (in Keuper Marl)". So said Watts in his classic book on Charnwood Forest in 1947. Here, as elsewhere, Watts made out a case for the landscape of Charnwood Forest being essentially an exhumed Triassic landscape. In so doing, he overlooked the significance of his own record of Boulder Clay to a height of 750 feet O. D. on Bardon Hill. He also ignored the evidence offered by deeply weathered zones in a number of the Charnian outcrops. These had been noted by Bosworth (1912, pp. 37-39), who commented briefly "it is probable that there was intense weathering among these rocks before the glacial period, and that during the glaciation of Charnwood a great deal of the rotten stone was swept away". Bosworth went on to comment "comparison between parts of the rock covered by drift and parts now bare, shows that the decay has gone much deeper since the glacial period." Bosworth briefly described and figured some quarry faces with spheroidal core-stones in matrices of varying degrees of rottenness, but, as he was concerned with the Triassic rocks, he did not discuss the matter further.

Both Watts and Bosworth drew attention to what they called wind-eroded surfaces on the Mountsorrel granite and the South Leicestershire diorites, beneath the unconformable cover of Keuper Marl. Harrison had previously referred to these etched and terraced rocks at Sapcote as part of an ancient sea-beach, apparently of pre-glacial age (1877; photographs opposite pages 44 and 46). In 1884, Harrison (p. 10) noted sand and boulders of unspecified age overlying the sand-polished surface. Fox-Strangways (1903, plate 1 and p. 10) clearly stated that surfaces at Mountsorrel were wind-blasted terraces, and that they were buried in Keuper Marl. Raw (1934), in contrast, maintained that the surfaces at Mountsorrel were the result of erosion by icy winds sweeping across the Pleistocene tundra around the ice sheets, and that they were subsequently buried in boulder clay full of material derived from the Keuper Marl. Wills (1950, p. 120) supported Raw's claim of Pleistocene wind erosion in spite of Watts' (1945) assertion to the contrary, though it must be admitted that Watts was relying on the evidence of the quarry manager some 50 years earlier. Wills also (1950, p. 109) included a map showing the wide trail of erratic boulders derived from Charnwood Forest and carried as far as the Chalky Boulder Clay spread on the Cotswolds. Watts (1947, p. 115) claimed that "foreign" boulder clay with erratics from the north and north-east was to be found only on the flanks of Charnwood, and that ice from outside had not overridden either the central valleys or the heights, in spite of Lucy (1870) having noted a widespread distribution of flints over much of Charnwood.

There are obvious conflicts in the above statements:-

1. Either Charnwood was deeply eroded by ice or it was not.

2. The ice cover of Charnwood was either purely local or came from outside.

3. The wind-eroded surfaces are either buried in Triassic deposits or not.

4. The deep weathering in pre-glacial, or post-glacial, or both.

The implications for the Pleistocene history of Leicestershire carried in the answers to these questions are many, and to this end a resurvey of the nature of all available sections has been undertaken; the results are given below. Most of the original sections were described inadequately and have now been quarried away, but new sections are being provided by continued quarrying, and some of these are described herein.

For the purposes of this study, the region of Charnwood Forest is taken to include the Mountsorrel granite and the South Leicestershire diorite and microdiorite masses.

Present Sections and Exposures

(a) Croft

The large quarry in the Lower Palaeozoic microdiorite intrusion cuts into the south-eastern flank of Croft Hill (National Grid Reference SP/510967) which rises to an altitude of 420 feet O.D. The igneous rock is overlain unconformably by Triassic Keuper Marl, with the thicknesses up to about 50 feet in places. The top of the hill is formed entirely in the microdiorite, which thus rises above the Keuper Marl by about 100 feet. At the highest point of the quarry face, the microdiorite is deeply weathered and is in a rotten crumbly condition, to a depth of at least 40 feet in places. In places, the rotted zone passes into less rotten coherent rock forming spheroids, but elsewhere there is a sharp boundary along the prominent inclined joints. In the lower parts of the face, hydrothermal alteration of the igneous rock follows these joints; the most rotten material can be seen to pass downwards into the hydrothermally altered (pinked) rock, which is still hard. The rotted zone is now seen only where there is no cover of either Keuper Marl or glacial deposits. Beneath the cover of Keuper Marl the microdiorite is not rotted, though there are

N. Europe	Alps	Zeuner	Charnwood
Weichsel	Würm	Last glaciation	Frost action and removal of waste leaving tors
	Interglacial		weathering
Saale	Riss	Penultimate	Chalky Boulder clay. Lake Harrison clays etc.
	Interglacial		weathering
Elster	Mindel	Antepenultimate	(Bubbenhall Till of Warwickshire) ?
	Interglacial		weathering
Preteglen	Gunz	Early	? deep weathering
	Pliocene		?

Text-fig. 1 Correlation table to show the approximate time-scale of the events in Charnwood Forest in relation to the sub-divisions of the Pleistocene used elsewhere.

hydrothermal alteration zones.

The deeply weathered and rotted zone is at present seen on the south-western side of a sharp knob of microdiorite. On the other side of this knob, hard fresh microdiorite has a striated surface with the striations trending from north-east to south-west, in agreement with the trend of later ice movement in the area. The striated surface is covered with about 20 feet of bluish Chalky Boulder Clay.

The deduction to be made from this section is that the knob if igneous rock is effectively a buried roche moutonnee; that ice scoured the upstream (north-east) face and plucked both blocks of hard microdiorite and rotted material from the south-west (downstream) face, before both were buried in till, which has itself subsequently been partly eroded away. The rotting is thus older than the Chalky Boulder Clay, and it is possible to infer that the knob, indeed the whole hill, was once covered in a rotted mantle. A small section of rotted material, with core-stones, is visible in an overgrown quarry on the west face of the hill (SP/509968), underneath a hard rock layer.

In the disused Huncote Quarry (SP 512969) on the north-east side (upstream) of Croft Hill, a few feet of Chalky Boulder Clay are seen to overlie a foot or so of Keuper Marl, covering the igneous rock. In a few places, where the Keuper Marl was breached by pre-Chalky Boulder Clay erosion, there is a limited amount of rotting, penetrating to a depth of 6 feet or so. Thus, here, the inference is of ice from the north-east riding up the hill-face largely on the relatively plastic Keuper Marl, leaving a veneer of marl on the microdiorite.

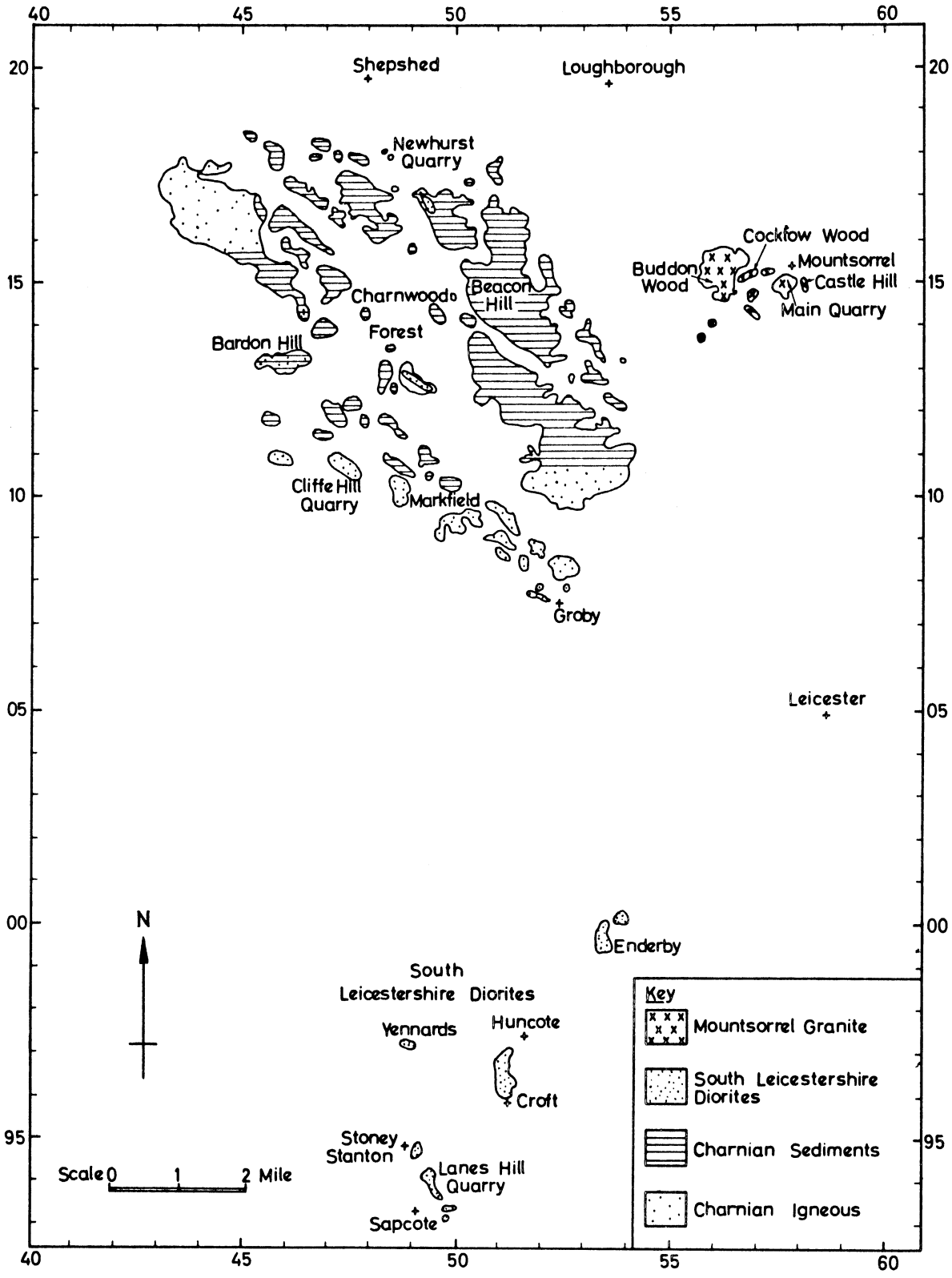
Taken together, these exposures suggest that the whole of Croft Hill acted as a large roche moutonnee, or crag-and-tail feature, from which the post-glacial River Soar has removed the tail.

(b) Sapcote

At the disused Calver Hill Quarry (SP/497932) some 8 to 10 feet of Chalky Boulder Clay is seen to rest on a striated surface of microdiorite. The striations trend N.W. to S.E. Windmill Hill Quarry (SP/497935), ¼ mile to the north, is now flooded and the tops of the faces overgrown, but a section near the top of the north face shows gravelly till overlying a few feet of Keuper Marl. Eastwood et al. (1923) recorded striations trending N.W. to S.E. on a "moutonnee" surface. Granitethorpe Quarry, a little further north, is also flooded but the north face is more accessible and shows an interesting section (SP/493942). The top of the microdiorite is fretted and grooved in a manner very like the photograph opposite page 44 of Harrison's book (1877). His photograph does not show the nature of the filling of the grooves in the fretted surface, but here they are clearly seen to be filled with basal Keuper Breccia, dolomite-cemented, with a few inches of Keuper Marl above. This is, in turn, overlain by gravelly till with flints. A few yards away to the west, the microdiorite has a deeply rotted zone, which clearly follows a hydrothermal vein system downwards between two walls of unaltered rock. The rotted zone appears to have been covered with the gravelly till at one time, and deep-weathering in pre-Chalky Boulder Clay times is again indicated. If Harrison's "Old Sea-Cliff" could be identified today, it might well turn out to be a Triassic wind-eroded surface!

(c) Enderby

A section high on the north-east side of the large Enderby Warren Quarry (SK/540001) shows the microdiorite to have two contrasted surfaces within a few yards of each other. One is a striated surface overlain directly by reddish boulder clay without flints, but containing Bunter pebbles passing up into Chalky Boulder Clay; and the other surface is still covered by about a foot thickness of basal Keuper Marl, with a thin breccia bed at the base showing dolomite cement. Both the sub-Triassic surface and the fragments in the basal breccia show the wind etching noted by Bosworth (1912, fig. 25). No deep-weathering was observed in the Warren Quarry, but in the adjacent disused village quarries spheroidal weathering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Shepshed
Loughborough
Newhurst Quarry
Cockfow Wood
Buddon Wood
Mountsorrel
Castle Hill
Main Quarry
Charnwood
Forest
Beacon Hill
Bardon Hill
Cliffe Hill Quarry
Markfield
Groby
Leicester
Enderby
South Leicestershire Diorites
Yennards
Huncote
Croft
Stoney Stanton
Lanes Hill Quarry
Sapcote
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Key
Mountsorrel Granite
South Leicestershire Diorites
Charnian Sediments
Charnian Igneous

can be seen to penetrate down the hydrothermally altered (pinked) zones in several places - indeed the upper parts of such zones are sometimes almost entirely rotted material with few core-stones. This rotted materal is, however, overlain by angular boulders of relatively fresh rock apparently transported as a solifluxion scree from slightly higher parts of the hill. These sections permit only two conclusions; one, that ice over-rode the hill with sufficient power to scour and striate the microdiorite in places, but also left a veneer of basal Keuper in hollows; and the other, that deep weathering pre-dates the solifluxion scree. The relative dating of the two phenomena is not possible at Enderby alone at present.

(d) Stoney Stanton

The north-east face of the large flooded Lane Hills Quarry (SP/493941) which is now a Lido, shows an important section of microdiorite, Trias and Pleistocene deposits as well as deep-weathering. A reddish Chalky Boulder Clay with very large flints caps most of the accessible face to a depth of 10 feet or so, but none of the surface has been bared to show striations. Beneath the Boulder Clay is a patchy and variable thickness of Keuper Marl, covering basal boulder beds up to 20 feet thick. These boulder beds consist of subangular boulders of fresh microdiorite, patchily cemented with dolomite, which locally penetrates down into joints in the igneous rock beneath.

Most of the igneous rock is fresh, but one section, behind the club house, shows a completely rotted zone following the line of some small hydrothermal mineral veins and an associated hydrothermally altered rock zone downwards. This rotted zone is up to 6 feet wide, with nearly vertical boundaries against fresh rock - and it is overlain by a boulder bed with fresh rock boulders. The conclusion to be drawn here is that this zone was hydrothermally altered in pre-Triassic times, but was sufficiently coherent then to withstand scouring out by Triassic wadi streams. After burial in Triassic deposits it was selectively deep-weathered, the boulders above being both unaffected by hydrothermal action and protected by a skin of dolomite. Since the section was then over-ridden by ice, the deep-weathering must have been pre-Chalky Boulder Clay in age. This is confirmed by a section, near the entrance of the same quarry, which shows incipient spheroidal weathering in a pinked zone, truncated by the boulder clay base, with a few rotted boulders in the base of the latter.

Eastwood et al. (1923, pp. 112-113) recorded a section, now very inaccessible owing to flooding and also very overgrown, in what was then Top Quarry (SP/492942) and is now the north-west corner of Lanes Hill Quarry. In it, several layers of glacial deposits rested on a microdiorite surface with striations trending N.W. to S.E. The lowest till was reddish, without flints, and passed up into blue Chalky Boulder Clay containing sand-lenticles, apparently disturbed by cryoturbation (= disturbance of stratification by frost - heaving).

(e) Cliffe Hill Quarry, Markfield

This is one of the few quarries in Charnwood where the contact between the Charnian (Precambrian) diorite and the metamorphosed mudstones can be seen. The latter, now known as hornstones, tend to have a blocky fracture and slaty texture. Both of these contribute to the filling of Triassic wadis (= gullies eroded by torrential run-off after rare desert storms), which are unusual in two ways. One is the almost complete absence of dolomite cement, normally a characteristic means of identifying Triassic deposits; and the other is that the fills are overlain by some 4 feet of quartz sandstone, with rounded wind-blown millet-seed grains, at the bottom of the Keuper Marls (here only a few feet thick). The Keuper Marl is in turn overlain by some 8 feet of Chalky Boulder Clay. These various deposits are excellently exposed on the eastern side of the quarry where baring operations have taken place (SK/477106).

The most remarkable point of these sections is the presence of completely rotted diorite boulders in the wadi fills and in the quartz sandstone. At times these are enclosed in a fine gravel of rotted diorite fragments. The conclusion here is that the boulders were transported in Triassic times, for no great

distance from the adjacent higher outcrops, in an unrotted condition, and that they have since rotted in situ through the unimpeded penetration of ground-waters in a period of deep weathering, before the Chalky Boulder Clay. The fine diorite gravel similarly was transported in a fresh state and has rotted in situ since.

About 100 yards further north along the quarry face, a small section of incipient spheroidal weathering is visible in the diorite.

(f) Bardon Hill Quarry

This large quarry rises from about 650 feet O.D. at the lower rim nearly to the highest summit in Leicestershire on Bardon Hill (912 feet O.D.). The highest rim is at about 850 feet O.D. (SK/458132). The igneous rock is a variety of Charnian "porphyroid" lavas, similar in composition to the diorites but of much finer grain. A little patchy deep-weathering is seen in a zone of structural disturbance on the highest quarry face, but the relationship to the surface is not visible. At the lower parts of the south-eastern face, however, there is an instructive section. The igneous rock is overlain by some 6 to 8 feet of Keuper Marl with a basal breccia, part of which passes into a thin sandstone with millet-seed sand-grains indicating aeolian transport. These Triassic deposits fill a wide shallow "wadi" between two higher rounded knobs of the igneous rock, and several other similar wadis are visible elsewhere in the quarry. This one is, however, overlain by some 10 feet of Chalky Boulder Clay, with lenses of water-laid (englacial?) sand. This in turn is covered with a solifluxion scree, up to 8 feet thick, of sub-angular boulders in a reddish clay matrix containing small Bunter pebbles and flints. The solifluxion scree can be traced uphill along the quarry rim to well over 800 feet O.D., the flints and pebbles derived from Chalky Boulder Clay becoming less common. The solifluxion scree is last seen close to the lower limit of the clitter of large boulders mantling the summit of the hill.

The conclusions from this section are that Chalky Boulder Clay once extended much higher up the hill than the 750 feet O.D. noted by Watts (1947, p. 21) and that subsequent solifluxion has carried both relics of this boulder clay cover and a large quantity of frost debris downwards from the original summit.

(g) Mountsorrel

Much of the Raw-Watts controversy about wind-eroded surfaces was concerned with exposures no longer available owing to quarrying; the record here is of sections currently visible. Cocklow Wood Quarry (SK/569151) has removed most of the former Hawcliff Hill and shows two interesting sections. Immediately behind the lip of the south side of the quarry, a trench shows some 6 to 8 feet of deeply-weathered and rotten granite with occasional spheroidal core-stones, noted as long ago as 1870 by Lucy (p. 498). The overlying podzol soil has scattered flints and Bunter pebbles, suggesting a former cover of Chalky Boulder Clay or gravel derived from it. The existence of such a cover is further supported by temporary excavations in the field 100 feet to the south, which show Chalky Boulder Clay with a high proportion of Keuper Marl fragments.

The northern face of the same quarry shows some 15 feet of Keuper Marl overlying unweathered, but smoothed, granite. The basal beds of the Keuper Marl enclose numerous rounded and etched boulders of granite, with a surface texture very like that of the wind-fretted boulders noted at Enderby and elsewhere by Bosworth (1912). One such boulder, lying some 6 feet above the base of the Marl, is wind-fretted and is about 3 feet long by a foot thick; it is thus very reminiscent of Fox-Strangways' sketch (1903, fig. 2). A small wadi is filled with boulders, rounded in a manner suggestive of a wadi-bottom rock mill but showing fretted surfaces. In the entrance cutting to the quarry, immediately behind the face just described, the Keuper Marl is seen to be overlain by a rotted granite wash some 6 feet thick, with cryoturbation, and this in turn is covered by reddish Chalky Boulder Clay. Another section in the same quarry shows a scree of angular boulders overlying the rotted granite.

Mountsorrel main quarry (strictly Broad Hill Quarry but almost always known as Castle Hill Quarry) has the upper parts of its faces now rather inaccessible and overgrown, but sections at the south rim show Chalky Boulder Clay overlying both Keuper Marl and transgressing on to the granite. No rotted granite and no "wind-terraced" surfaces are visible, but the wind-fretted sub-Keuper surface was observed to be covered directly with boulder clay at one point.

The presence of rotted granite in the quarry faces is very suggestive of the conditions necessary for tor-formation, as outlined by Linton (1955); and the various naturally outcropping crags of the Mountsorrel granite mass were re-examined with this in mind. Crags above the old Nunckley Quarry (SK/569142) show slight rounding, with a thin rotted zone down joints. Castle Hill itself (SK/580150) has slightly rounded granite boulders at the top of the east face; an old quarry on the south side shows spheroidal weathering. A crag on the north-west slopes of Buddon Wood (SK/558154) shows more tor-like characteristics in that slightly rounded blocks of granite form the crest of a ridge, with evidence of spheroidal weathering and rotted material in joints lower down. The evidence is thus that poorly developed tors do exist at Mountsorrel; others may of course have been quarried away in the past, with no record left.

The precipitous contacts of Keuper Marl and granite at Hawcliff Quarry, described by Fox-Strangways (1903, p. 9-10), are either quarried away or buried in debris. The highest vertical face noted was only 20 feet, and present sections show similar occasional vertical steps in the sides of wadis.

Boulder Clay in the Charnwood Forest Area

The cuttings in the recently constructed motorway through Charnwood Forest have served to show that Chalky Boulder Clay is much more widespread and thicker than had ever been supposed. Watts' contention that ice went round, rather than over, Charnwood can no longer be supported. Boulder Clay, to a thickness of 30 to 40 feet, was found at altitudes of over 700 feet around Copt Oak. It has long been known that Chalky Boulder Clay occurs at altitudes up to 800 feet O.D. to the east of Leicester, and to the north of the Trent, and it is thus difficult to escape the conclusion that the Chalky Boulder Clay glacier completely over-rode Charnwood Forest, with its highest point at 912 feet O.D. Most of its summits rise no more than 50 feet above nearby boulder clay, and it is difficult to envisage ice less than 50 feet thick depositing a similar thickness of boulder clay; the ice surface must thus have been well above 800 feet O.D. and most probably over 1,000 feet O.D.

The spread of erratics in the south Midlands, noted by Wills (1950, p. 109), indicates that a considerable amount of Charnwood weathered rock waste was transported out of the area; this would have to be restored, at least in volume, in any attempt to reconstruct the pre-glacial Charnwood Forest topography. The contrasted layers of boulder clay noted at Sapcote and Stoney Stanton are associated with striation trending N.W. to S.E., in contrast with the N.E. to S.W. trend under Chalky Boulder Clay elsewhere. These two trends confirm the observations of West and Donner (1956), but still provide no evidence as to whether or not two separate glaciations are represented.

Much still remains to be done in detailed mapping of boulder clay in Charnwood. Outwash sands and gravels and solifluxion screes are known to occur, but no sections with undoubted interglacial deposits have been recorded.

The Cliffe Hill "Rounded Boulders"

About 1937, quarrying on the south-western side of the Cliffe Hill Quarry broke into a fissure and over 50 large, almost spherical boulders rolled out and fell to the quarry floor. A few of these are preserved in the collections of the University of Leicester Geology Department. Almost all are diorite identical to that of Cliffe Hill, but one is a ganister-like sandstone with rootlet markings, almost certainly

from the Coal Measures. The boulders are ovoid to spherical and commonly a foot in length; since the fissure in which they were found was near the highest point of outcrop of the diorite, it is clear that they have not been transported any distance, but have been rounded more or less in situ. No details of the fissure fill other than the boulders are known, but verbal information from R. J. King (then a schoolboy) is that the fissure was some 30 feet deep; the interpretation given to him by H. Gregory was that it represented some form of "glacier mill" (i.e. a pothole scoured out by boulders rotating under the force of water falling in a glacial mill water stream). This seems to be the most probable interpretation - milling and rounding of boulders by glacier melt-water near the summit of Cliffe Hill.

The presence of the rounded ganister precludes the possibility of the "rounded boulders" being core-stones from deep-weathering, without further erosion, although some such weathering may have freed the boulders in the first place. It is a pity that the relationship of the boulders to other Pleistocene deposits is unknown. It is just possible that these boulders represented a Triassic wadi rock mill, as in Cocklow Wood Quarry, but the boulder of ganister would be difficult to explain in such a deposit and the surface texture of the Cliffe Hill boulders is unlike the wind-blasted boulders at Cocklow Wood.

The Sub-Triassic Surface

To quote Watts again (1947, p. 118) "... the upland landscape is one of Triassic date and character emerging practically uninjured from its burial ..." No one will deny that the Charnian peaks, as seen today, represent exhumed Triassic mountain tops, but are they "uninjured", in view of what has been recorded above? Taken literally, Watts' statement infers that the vertical-sided or overhanging crags, such as those on High Sharpley, Altar Stones, Beacon Hill, Hangingstones, Windmill Hill etc., are exhumed crags which had the same shape in Triassic times, possibly originally sculptured in Old Red Sandstone times (Watts 1903, p. 628). But the present sections through the Charnian-Triassic contact provided by quarrying show no such crags, nor were any recorded in any of Bosworth's detailed contour maps of the quarry edges in the early years of this century. Steep faces there may be, but they are the wadi margins, and the areas of inter-wadi Charnian are gently rounded hills, much wider than any of the present day crags. The conclusion becomes inescapable that the present day Charnian peaks are the highly modified remnants of much more gently rounded Triassic hills, and that the modification (injury!) is the result of the combined effects of deep-weathering, glacial scouring, and peri-glacial solifluxion.

The discovery of millet-seed sand-grains forming sandstones in the basal Keuper raises afresh the question of the wind-eroded surfaces at Mountsorrel and elsewhere. Originally ascribed to Triassic sandstorms by Watts (1903, p. 632 and fig. 12), these surfaces were claimed to have originated in Pleistocene times by Raw (1934), who postulated winds blowing across the unvegetated flats immediately after early ice melted, the flats being later covered in the till of a subsequent ice advance.

Watts (1945, pp. 34-36) restated his case that the wind-eroded surfaces were found embedded in Keuper Marl by a quarry manager. Bosworth also recorded numerous cases of wind-fretted boulders and surfaces underneath Keuper Marl. Now, the finding of millet-seed sandstones at Bardon Hill and Cliffe Hill, Markfield, appears to confirm the original opinion of Watts, though it is not impossible that some wind-erosion also took place in the Pleistocene and is no longer visible. As the wind-blasted surfaces were at an altitude of about 320 feet O.D. they would have been about 150 feet up the side of the proto-Soar valley before it was drowned by the pro-glacial Lake Harrison (Shotton, 1953); it is difficult to envisage the wind being able to blow consistently in the direction required by Raw's hypothesis.

The Charnwood Crags as Tors

Linton (1952) briefly referred to the possibility of the crags of Charnwood having originated as tors like those on Dartmoor, the Cairngorms of Scotland, or the Millstone Grit scarps of the Pennines, i.e. by peri-glacial removal of rotted material resulting from weathering during the previous interglacial.

The present investigation of the Charnwood crags supports Linton's hypothesis. If the solifluxion be accepted as Last Glaciation in age, it is clear that the deep weathering now visible is older than the Last Interglacial, and older than the preceding Chalky Boulder Clay.

The Charnwood crags are in a heterogeneous assemblage of rock types, with the further complication of an exhumed Triassic landscape, where the periglacial removal of loosened and rotted material could take place whatever the date of that loosening and rotting. The Charnwood crags are not all composed of igneous rocks capable of being deeply-weathered as are the granites of Dartmoor and the Cairngorms; some are cleaved and jointed hornstones. Since both of these partings are more or less vertical, and more strongly developed than bedding in many cases, it seems possible that the early plucking by ice could have been developed later by frost action; solifluxion of the resultant loose blocks could leave the tor-like residuals seen today.

Pleistocene Chronology

It now becomes possible to draw some overall conclusions and to make some suggestions about the more recent phases of landscape evolution in the Charnwood region.

Deep-weathering is clearly more ancient than the onset of the ice which deposited the Chalky Boulder Clay (i.e. Penultimate or Saale Glaciation) but is younger than the Triassic formations. Indeed it has only been found in positions where the Trias is missing or where it is sufficiently porous to have admitted freely moving groundwater (e.g. Cliffe Hill Quarry). In general, the Keuper Marl formed a seal which prevented deep-weathering by virtue of impermeability. Since deep-weathering is generally associated with a warm moist climate, the period of such weathering could be either the Interglacial previous to the Chalky Boulder Clay or any earlier period. It is debatable whether the climate of the Great Interglacial was warm enough for long enough to allow weathering to have penetrated 40 feet at least, as at Croft. Thus it seems reasonable to postulate that the deep-weathering took place in the Tertiary, as has been suggested for comparable occurrences in north-east Scotland by Fitzpatrick (1963). He suggested that the Cairngorm Tors may have resulted from Pliocene deep-weathering.

The Croft and Mountsorrel occurrences would then lie well below the altitude of some of the Pliocene erosion surfaces (cf. Rice, 1965, p. 109). The Chalky Boulder Clay at Sapcote and Enderby passes down into a red till without flints, covering a surface with N.W. - S.E. striations. This may either represent the Bubbenhall Till of Shotton (1953) and thus the Elster Glaciation, or it may simply be an early phase of the Saale Glaciation (cf. West and Donner, 1956). Clearly more study of this problem is required.

It is notable that the present examples of deep-weathering are confined to the coarser-grained granitic or dioritic rocks, and that no examples have been seen in hornstones or lavas. It is important, however, to realise that the examples seen are the few which survived glacial erosion, and that a much more general spread of rotted material probably once covered the igneous rocks.

Whatever the date of the deep-weathering, the next phase in the modification of the Triassic hilltops was clearly glaciation. The ice which deposited the Chalky Boulder Clay over-rode Charnwood, striated rock surfaces here and there or left a veneer of Keuper Marl, and spread erratic boulders far and wide over the south Midlands. In so doing, there is little doubt that it removed both some of the Keuper Marl cover and most of the rotted material, as Bosworth suggested, also accomplishing some degree of plucking to form roches moutonnées. Since ice-flow would tend to concentrate in the valleys of Charnwood, both at the onset and during the waning of the glaciers, it follows that the flanks of the exhumed Triassic peaks would have been scoured, plucked and thus steepened by ice erosion. The ice-dammed Lake Harrison (Shotton 1953) must have lapped at the southern flanks of Charnwood Forest, but no evidence of its effects or deposits is yet forthcoming, though stoneless clays have been noted in unpublished work by J.F.D. Bridger.

In the Last Interglacial, the present River Soar became established and the deposits of the previous glaciation were gradually removed. This removal probably includes the formation of the stream-captures ond gorges in Charnwood, and these also require further investigation in detail. The Last Glaciation (Würm) saw no ice in Leicestershire, but it was a phase of cold periglacial conditions. The exposed peaks of Charnian were subject to frost action; solifluxion carried detached blocks away from the steep flanks (with their strong jointing and cleavage), finally leaving the cores of both the ancient hornstone hills and the igneous intrusions standing up as near-vertical crags or tors. Little alteration of these has taken place since.

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