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HUMMOCKY MICRORELIEF IN THE MOOR HOUSE AREA OF THE NORTHERN PENNINES, ENGLAND

Abstract

There are very few references to thufurs in Britain. Evidence suggests this is due mainly to their infrequent occurrence. Because of this situation it was decided to examine a type of hummocky microrelief found above 670 m on the Moor House Reserve (northern Pennines, England). Following a general survey of the problem, detailed work was carried out on the distribution, size morphology and vegetation of hummocks at two contrasting sites on the Reserve. An assessment of possible origins led to the conclusion that these hummocks are periglacial features of the thufur variety.

SOME GENERAL PROBLEMS

While studying altiplanation terraces in south-west England, TE PUNGA (1956) and WATERS (1962) discovered features to which they gave the term 'mounds'. These were later noted by BRUNSDEN (1964) who attributed them to frost heaving. This interpretation was given further precision by DEMEK (1965, 1968, 1969) when he concluded that these mounds are thufurs of recent origin. The existence of similar features in other parts of Britain was first established by the present writer who recorded them above 670 m on the Moor House National Nature Reserve (north--east Westmorland), but gave only a few details (TUFNELL 1965, 1966, 1969). At about the same time D. E. COTTON was writing a thesis (completed 1968) in which he presented a long account of thufurs at six localities in the central and southern Pennines: these he compared with similar forms in Iceland. More recently, a few thufurs have been identified in Scotland (BALL and GOODIER 1970; GOODIER — personal communication; KELLETAT — personal communication) and in north Wales (BALL and GOODIER 1970). As indicated by the above remarks, present knowledge concerning the thufurs of Britain is sketchy. It was therefore deemed worthwhile to expand previous comments about the Moor House thufurs — especially as COTTON's detailed work was in areas of less severe climate at much lower altitudes (viz. 150—500 m) and concerned features whose dimensions and age differ from those of the Moor House examples.

The reasons for this scarcity of data on British thufurs are obscure. It may sim-

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ply be that thufurs are uncommon in Britain: alternatively, they may be widespread but have failed to attract the interest of British scientists. Present evidence inclines towards the first of these explanations. This is partly because phenomena normally associated with thufurs (gelifluction terraces, ploughing blocks, etc.) have been recorded much more frequently in Britishliterature and during the author's widespread investigations in northern England. There are also the experiences of GALLOWAY (1958) and KELLETAT (1970; personal communication) who, despite extensive studies of periglacial phenomena, recorded hardly any thufurs in Scotland. Likewise, CAINE'S (1961) widespread survey of frost features in the Lake District makes no mention of these hummocks. Finally, although thufurs have been discovered in north Wales, they have yet to be seen in well-developed fields (BALL and GOODIER 1970). Naturally, these indications that thufurs are somewhat rare in Britain must be treated with caution, for available data are sparse and resultant deductions correspondingly tentative.

If thufurs are uncommon in Britain, it would hardly be surprising as numerous factors can prohibit their development. Thus, in many uplands climate is unsuitable. On the other hand, this does not exclude the possibility that some areas might contain thufurs dating from the Little Ice Age (cf. COTTON 1968) or earlier. Again, there are places where rock type and the nature of unconsolidated deposits or soils must prevent thufur development. Unfortunately, little general work has been done on this problem and that which does exist may be confusing. For example, JAHN (1958) noted that in the Tatras areas of sedimentary formations are more likely to possess thufurs than are localities with crystalline bedrock. TROLL (1944) however remarks that in the Alps thufurs occur plentifully where bedrock is crystalline. Relevant to this problem is the fact that the thufurs described by COTTON (1968) and those of the Moor House Reserve have developed over sedimentary rocks, but that crystalline formations are widespread in upland Britain. At many localities steepness of the terrain prohibits thufur development because such features rarely form on slopes of more than 20°. Nature of the ground is also influential: thus, where vegetation is sparse or absent and where rock outcrops or coarse debris form the surface, thufurs will be missing. Again, slope moisture is important for if the ground is either very dry or excessively wet thufurs are unlikely to develop. The repeated formation of persistent snow patches at a locality is another factor militating against thufur development. Lastly, the activities of man or animals could prevent thufurs forming (eg. witness the effects of overgrazing by sheep.)

It therefore appears that unsuitable conditions prohibit thufur formation at many localities in upland Britain. Even so, there must be places within this region where thufurs have still to be found. Research must then be directed towards ascertaining the number of these localities and the reasons for their existence. When this has been done, it will be possible to say if the current periglacial environment of upland Britain differs from the corresponding zone (ie. the zone of bound gelifluction) in other European mountains, for there thufurs are often well developed.

HUMMOCKY MICRORELIEF ON THE MOOR HOUSE RESERVE

INTRODUCTION

Bedrock in the Moor House area consists principally of sandstones, limestones and shales dating from the Carboniferous. In many places these are overlain by gelifluction deposits and peat. According to MANLEY (1936), the northern Pennines are the coldest parts of England and have a climate like that of southern Iceland. Mean temperatures on the summit of Great Dun Fell (the highest part of the Reserve) are in fact usually lower than those at Reykjavik (Fig. 1).

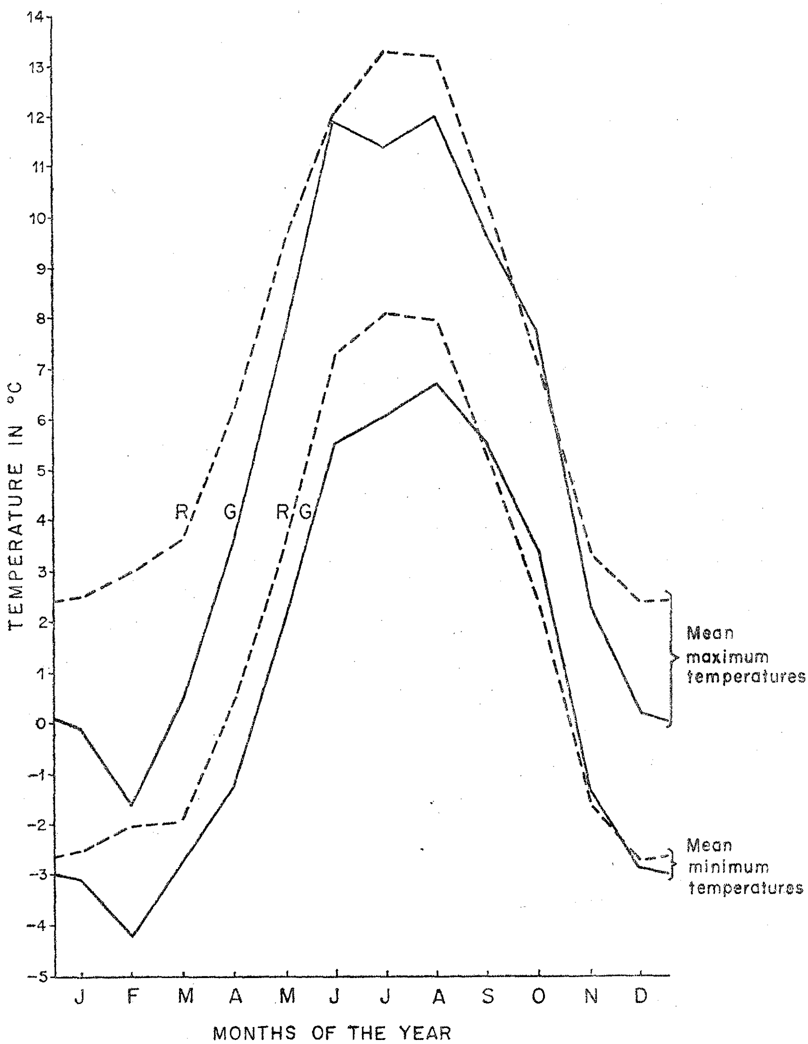

Fig. 1. Mean temperatures at Great Dun Fell (G) and Reykjavik (R), 1963—70 inclusive

HUMMOCK DISTRIBUTION

Thufur fields have been identified in two main areas of the Moor House Reserve. One is on the upper slopes of Great Dun Fell and includes some of the highest and coldest parts of the Pennines. The field at this locality which was selected for detailed examination occurs on the mountain's western slopes and is just below its flat summit at an altitude of c. 825 m O.D. (Field 1) (Grid ref. 709322). It has developed on gradients of 14—17° and lies immediately downslope of the Great Dun Fell radio station: undoubtedly, it represents one of the driest thufur sites on the Reserve (illustrated in TUFNELL 1969, Pl. 6). The other main area of thufur fields on the Reserve is at altitudes of c. 680—750 m in the upper Knock Ore Gill valley (Grid refs: several places within square 7130). Here fields tend to be associated with sets of damp flushes which emerge from the upper valley slopes on their eastern side. Consequently, they occupy much damper sites than does the field examined on Great Dun Fell. Indeed, one example has an associated stream which flows beneath about three-quarters of its length and then emerges in a small, though deep pool at its lower edge before running away downhill over the ground surface. A representative member of the thufur fields in this area was chosen for detailed study: it is on 3—9° slopes and lies above the junction of the roads from the Silverband mine and the Great Dun Fell radio station (Field 2) (Grid ref. 716309). Being near the foot of limestone cliffs, it is associated with a calcareous flush (Pl. 1).

Both of the fields chosen for detailed study have an irregular form in plan (Fig. 2) which can be explained largely in terms of soil moisture variations and changes in slope angle. The former influence thufur development in two ways. First, where the ground is excessively wet thufurs will either be missing or the density of their packing will be very low. This is clearly illustrated by field 2 one of whose boundaries adjoins a damp flush: examination of an area next to this boundary (D on Fig. 2) indicated a thufur density well below that for drier ground (D on Fig. 3). Secondly, thufurs tend to get smaller and may eventually disappear as the ground becomes increasingly better drained. Thus, the largest thufurs in field 1 are near its downslope border which is relatively damp: further upslope, as conditions become drier, thufurs get smaller and finally disappear (cf. JAHN 1958). Hence, the optimum environment for thufur development will among other things be in a finely-balanced hydrological state between the excessively wet and the over dry. This is why most thufurs in the upper Knock Ore Gill valley occur towards the edges rather than in the centres of flushes or on the drier ground beyond. Variations in slope angle can also limit the extent of thufur fields, as is clearly shown by example 2. The western limits of this field are the result of a sharp downslope increase in gradient from around 5° to just under 20°: its southern border is also marked by an abrupt steepening of the ground, but this time in an upslope direction the increase being from about 4° to 25°. More gradual slope increases would have led to the progressive deformation and exclusion of thufurs by gelifluction. Breaks of slope can also limit the extent of

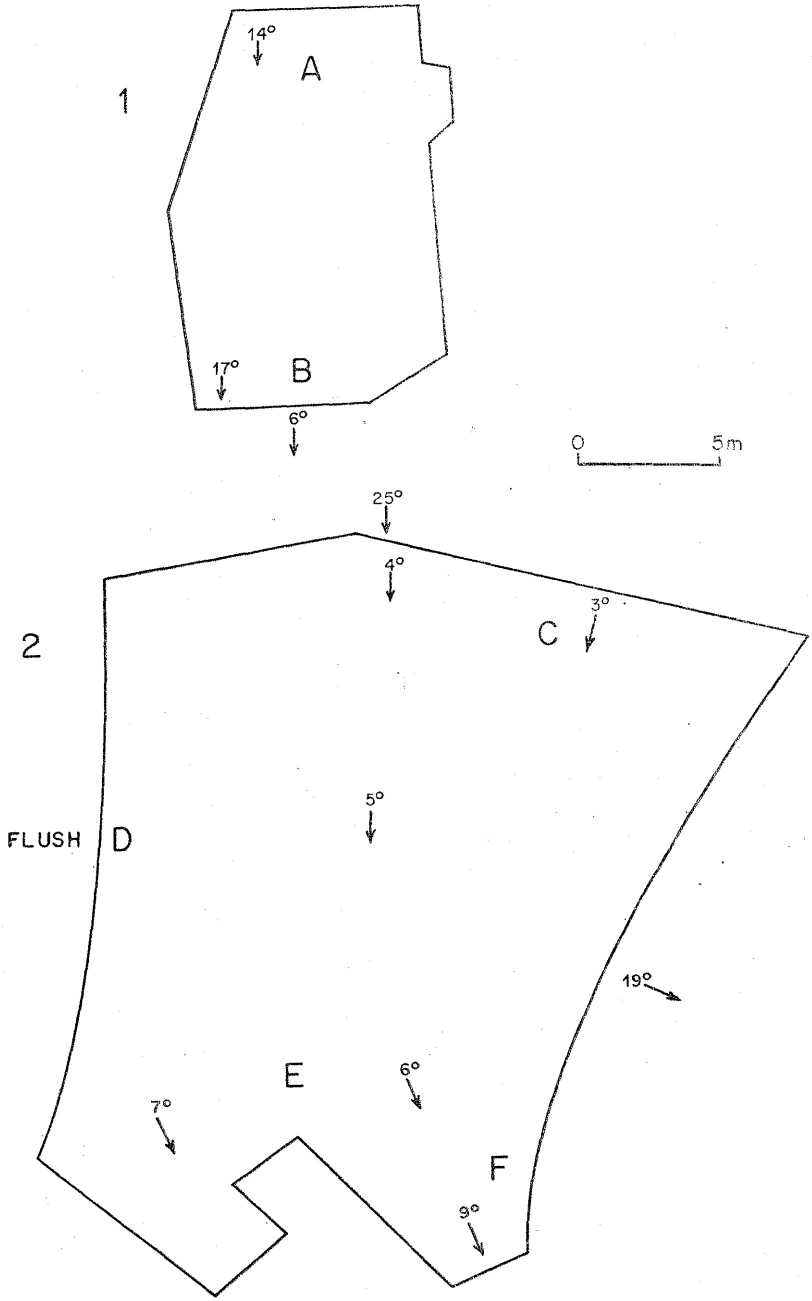

Fig. 2. The shape in plan of thufur fields 1 and 2

Arrows point downslope: their associated gradients are shown. Letters indicate the position of areas where thufur density was established thufur fields by producing unfavourable changes in the ground's moisture balance.

Although the individual thufurs within most fields are essentially juxtaposed, they sometimes exhibit interesting variations in the density of their packing. Because of this, several methods were considered for expressing these variations quantitatively. It was finally decided to use a technique which involves first selecting the areas to be examined: this was done bearing in mind two things. First, that all areas chosen should preferably be of equal size: it was fortunately possible to observe this requirement during the present work, but had it not been so, comparability would have been achieved by proportionate scaling of the parameters involved. Secondly, it was decided that, as far as visual inspection could determine, any area selected should contain within itself a fairly uniform spread of thufurs. The next step was to count the number of thufurs within each area. Following this, an assessment was made of the geometric form to which the plan of each hummock approximates, in order to determine how much of an area was covered by thufurs. At Moor House this stage of investigations was comparatively easy because the plan of most thufurs examined was roughly that of a circle, ellipse, or rectangle: difficulties arose only in the rare case of a thufur having a markedly irregular plan. Finally, collection of these data allowed one to plot the number of thufurs in an area against the percentage of that area which they cover. This technique gives a quantitative expression of the general thufur density within an area and as such is adequate for most purposes. Only on rare occasions will it be desirable to go further and examine the minor subtilties of thufur distribution which are not catered for by this technique. When this is necessary it may be best to construct a detailed plan indicating the position of every thufur in the area being examined.

Using the above technique hummock densities were established at six areas within the two fields (Fig. 2 and 3). Results show these densities to vary quite markedly, though in no case do the hummocks investigated occupy more than half of a given area (Fig. 3). The lowest density values were recorded at D and these can be attributed to the effects of an adjacent damp flush. Values are significantly higher for areas A,B,C,E and show fairly consistent relationships between increasing hummock numbers and the percentage of an area which they cover. However, these same relationships do not extend to area F, since its hummocks are relatively large and therefore occupy a proportionately greater area.

HUMMOCK DIMENSIONS AND MORPHOLOGY

While all thufurs are basically microfeatures, their dimensions can be quite variable. This is well illustrated by comparing the average size of hummocks examined in field 2 with those of field 1: taken as a whole, thufurs are lower and broader in the former case than they are in the latter (Table I). Measurements also indicate that thufur dimensions are smaller in the Moor House area than at many other localities. Thus, CAILLEUX and TAYLOR (1954,) TRICART (1970), and others give

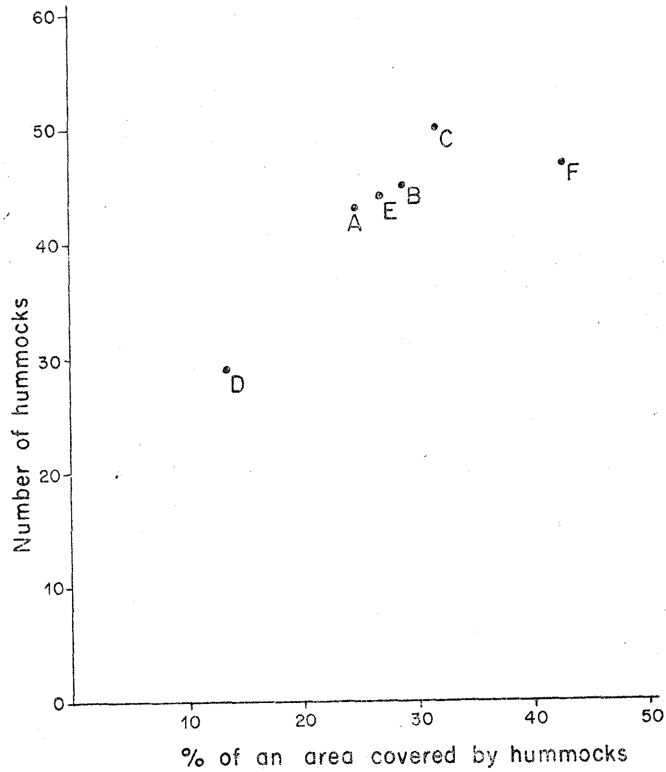

Fig. 3. Thufur density at six places within fields 1 and 2
The letters correspond to those on Fig. 2 which indicate the location of the areas selected. Each area measured 20 ft. (6 m) by 10 ft. (3 m)

20—50 cm as the usual height for thufurs and 0,5—1,0 m as their typical diameter[1]. Corresponding figures for the 254 hummocks surveyed in detail at Moor House are 17.3 cm (average maximum height) and 36.0 cm (average maximum diameter) (Table I).

The characteristic shape for an undeformed, well-developed thufur approximates that of an inverted bowl and may therefore be described as hemispherical (Fig. 4A). This is the commonest variety on the Moor House Reserve as it probably accounts for at least half the area's thufurs. Consequently, in this respect field 2 provides a more typical sample than field 1 (Table I)[2]. However, this is to be expected, since most of the Reserve's thufurs are on gentle slopes (like those of field 2) and have therefore not been significantly affected by gelifluction (unlike many hummocks in field 1 where gradients are steeper). Among the products of gelifluctional deformation is the elon-

[1] However, some authors (eg. Ball and Goodier, 1970) propose smaller average dimensions for thufurs, but even these indicate that most examples are larger than those on the Moor House Reserve.

[2] These points were verified by examining two fields on gentle slopes near the top of Great Dun Fell. Of the 200 hummocks included in this sample, 53% were of the hemispherical type.

Table I

The characteristics of 254 thufurs on the Moor House Reserve

	Field 1. Great Dun Fell. Grid ref.: 709322. N = 88	Field 2. Upper Knock Ore Gill valley. Grid ref.: 716309 N = 166	Average for the two fields
Mean maximum height (in cm)	19.8	14.7	17.3
Mean maximum diameter (in cm)	34.8	37.1	36.0
% hemispherical thufurs	25.6	49.6	37.6
% elongated thufurs	17.6	24.8	21.2
% ridged thufurs	24.8	6.4	15.6
% thufurs producing bulging terrace fronts	14.4	0.0	7.2
% thufurs upheaving terrace treads	5.6	0.0	2.8
% thufurs made irregular by slope movements	7.2	6.4	6.8
% eroded thufurs	1.6	7.2	4.4
% thufurs made irregular by slope movements and erosion	3.2	5.6	4.4

gated hummock which consists of a simple downhill extension of the hemispherical thufur (Fig. 4B). Contrary to expectations, this type is of proportionally greater importance at the Knock Ore Gill site (Table I) due probably to the wider range of hummock deformations within field 1 and a consequent reduction in the elongated thufurs share of the total. Data for this and certain other categories illustrate that modification of hummocks by gelifluction can be significant on gradients of less than 10°, especially, it seems, where there is abundant moisture (as at field 2). Another product of hummock deformation is the ridged thufur (Fig. 4C) which is distinctly more important on the steeper slopes of field 1 (Table I). At Moor House there are two kinds of ridged thufur. Easily the most important is that ridged perpendicular to the local slope: the other kind has affinities with the elongated thufur as it is ridged parallel to the line of steepest available slope. Because thufurs characteristically develop in the zone of bound gelifluction, they are normally associated with the other microforms typical of that zone. Sometimes this association merely entails occurring in the same region and altitudinal zone: at other times there is a close morphological relationship, particularly between thufurs and gelifluction terraces. Forms compounded of the two occur on the Moor House Reserve where they are best developed on slopes of around 15°. Two basic kinds have been identified. One is the bulging terrace front whose shape indicates that it is the product of upward as well as downslope movements (Fig. 4D): it accounts for over 14% of thufurs examined within field 1, but was not recorded in field 2

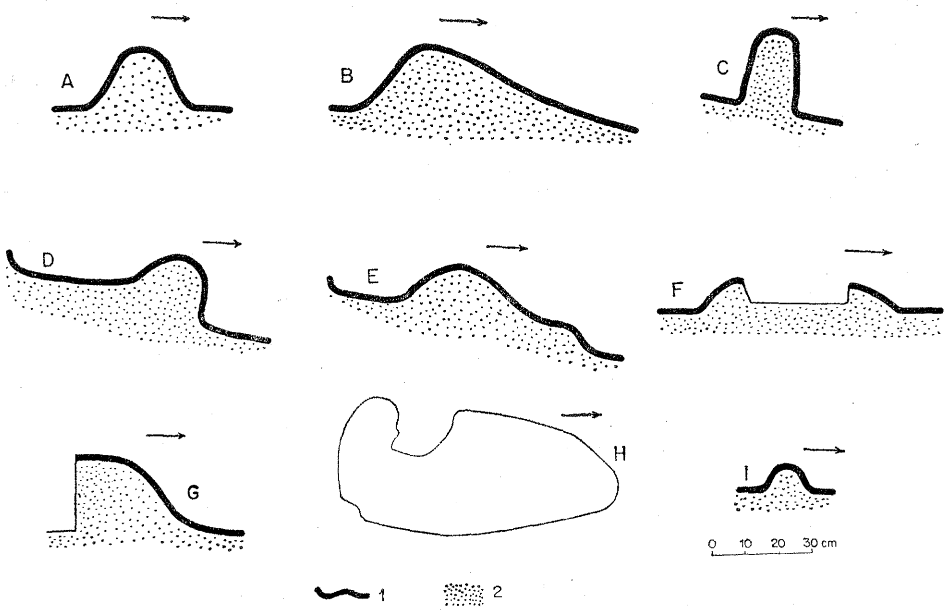

Fig. 4. Thufur types on the Moor House Reserve

All are drawn from actual examples within fields 1 and 2 except type I which occurs on the summit „flat" of Great Dun Fell 1. vegetation mat, 2. fine earthy material; arrows point downslope.
All examples are shown in section except type H which is in plan. A description of each type is given at the appropriate place in the text

(Table I). The other is found where terrace development has led to the creation of near-flat tread surfaces which provide small areas suitable for thufur formation on ground which might otherwise be rather steep (Fig. 4E): again this is a type present only within field 1 (Table I). Lastly, a few of the thufurs investigated were so altered by gelifluction that their irregular form could not be satisfactorily included under any of the previous headings (Table I).

Thufur form can also be affected by erosion. At Moor House this has created bare patches on some thufurs by removing either their centre or one of their sides (Fig. 4F, G) (Pl. 2). Particularly in the former case erosion must be rapid, because once a central depression has been initiated its bowl-like form makes it an ideal receptacle for snow and water. Thus, when field 2 was examined on 23 August 1970 most of its intra-thufur depressions contained water 1—2 cm deep. Under freeze-thaw conditions such a reservoir of moisture within the body of a thufur would facilitate its erosion. Also assisting the degradation of thufurs is needle ice formation (eg. see CAILLEUX and TAYLOR 1954). Since this process occurs frequently on the Reserve during winter, it must contribute significantly to thufur morphology. Erosion can also result from heavy grazing by sheep: there are distinct indications that this has occurred within several fields in the Knock Ore Gill valley, its effects here often being heightened by dampness of the ground. These various erosional processes have combined to modify 1.6% of thufurs sampled at field 1 (a dry site) and 7.2% of those examined on the much damper ground of field 2 (Table I).

Finally, the most complex variety of thufur on the Moor House Reserve is that whose irregular form is the result both of gelifluctional deformation and of erosion (Fig. 4H): 4.4% of the examples studied fall into this category (Table I).

Having ascertained the external form of 254 thufurs at Moor House, 25 of their number were then sectioned to determine internal composition. All displayed the characteristic arching of vegetation layers frequently mentioned in the literature (Fig. 4). Combined thickness of vegetation mat and principal root zone was always no more than a few centimetres, thus providing only a thin cover for a core of fine black material. This often contained a few roots, but rarely possessed even the smallest of rock fragments (Pl. 3).

VEGETATION ASSOCIATED WITH THE HUMMOCKS

The contrasts between fields 1 and 2 apply not only to hummock morphology, but also to composition of associated vegetation: this may be readily appreciated by glancing at the species lists for the two fields (Tables II and III). In particular, these show a far greater diversity at the calcareous flush site (field 2).

At least two interesting conclusions may be drawn from a study of vegetational distributions within the two fields. The first is that species composition varies greatly from one hummock to another; and from one inter-hummock area to another. This gives rise to a second conclusion: namely, that on the basis of species composition it was not possible at either site to discern a consistently clear zonation of vegetation from hummock to hollow.

ORIGIN AND AGE OF THE HUMMOCKS

Research has established that hummocky microrelief is polygenetic (eg. TUFNELL, 1965). Although some origins would never apply in an upland like the Moor House Reserve[3], the majority had to be given serious consideration as potential causes of the hummocks under investigation.

One possibility is that these hummocks might simply reflect an irregular subsurface microtopography. Examples of this occur when largish stones become overgrown by vegetation, thus producing hummocks with a solid core (TUFNELL 1965). However, the Moor House examples did not form in this way because their cores are of fine material with little or no stone content. A related possibility is that the hummocks reflect an underlying pattern of clints and grykes. Such an origin accounts for

[3] Eg., fallen tree microtopography; normal gilgaies; cattle stamping their feet on the ground.

Table II

Species list for field 1 (Great Dun Fell). Cover ratings are on the domin. scale

Galium saxatile L.	x	*Barbilophozia floerkii* (Web. & Mohr) Loeske	x
		Lophozia ventricosa (Dicks.) Dum.	x
Agrostis tenuis Sibth.	x		
Carex bigelowii Torr. ex Schwein.	1		
Deschampsia flexuosa (L.) Trin.	3		
Festuca ovina L.	5	*Cetraria islandica* (L.) Ach.	x
Rumex acetosella L.	x	*Cladonia uncialis* (L.) Web.	x
Vaccinium myrtillus L.	x	*Cornicularia aculeata* (Schreb) Ach.	x
Dicranum fuscescens Sm.	1		
Polytrichum alpestre Hoppe	2		
P. alpinum Hedw.	1		

hummocks in the Moor House field station — Moss Burn area of the Reserve (TUFNELL, 1965; HORNUNG, 1968). It does not, however, explain the hummocks described in the present article for they are different in form and size and bear no relationship to any clints and grykes.

In some areas hummocky microrelief is largely the product of erosion. Two facts made it necessary to examine this as a possible cause of the hummocks investigated on the Moor House Reserve. First, there has been in this area widespread erosion (usually of peat) and secondly a few of the hummocks examined bear unmistakable signs of erosion. However, it was concluded that any erosion is destroying rather than creating the hummocks. One indication of this is that some hummocks possess a central depression (Fig. 4F) (Pl. 2) which can only be satisfactorily interpreted as the result of destructive processes. Also relevant is the fact that most hummocks examined occur in areas which show no traces of erosion.

Consideration was also given to the possibility that the hummocks under investigation are mole hills which have acquired a vegetation cover. Again, however, there are reasons for discounting the idea. In the first place, many of the hummocks are situated at altitudes which would be rather unsuitable for extensive mole activity. This is particularly true of those at c. 825 m near the top of Great Dun Fell. On the other hand, it must be admitted that swarms of mole hills were noted up to altitudes of 730 m following the mild winter of 1970/71 which means that some of their number reached a level slightly higher than that of field 2 and many of its associates. However, even within the area of overlap there are factors demonstrating that the hummocks of the present article differ from mole hills. One is that the individuals in a group of mole hills tend to be wider apart and more irregularly spaced than are those in the hummock fields. Again, mole hills were occasionally found on slopes exceeding 30°, whereas the gradients across hummocky terrain were always below 18°. Another difference is that the mole hills were entirely bare, while most of the hummocks examined were totally vegetation covered. Finally, there is the question

Table III

Species list (excluding lieverworts) for field 2 (upper Knock Ore Gill valley)
Cover ratings are on the domin. scale

Achillea ptarmica L.	x	*C. dioica* L.	x
Alchemilla glabra Neygenf.	x	*C. echinata* Murr.	x
Bellis perennis L.	x	*C. flacca* Schreb.	x
Cardamine pratensis L.	x	*C. nigra* (L.) Reichard	2
Cerastium holosteoides Fr.	x	*C. panicea* L.	3
Cirsium palustre (L.) Scop.	x	*C. pulicaris* L.	x
Cochlearia alpina (Bab.) H. C. Wats.	x	*Deschampsia cespitosa* (L.) Beauv.	x
Epilobium alsinifolium Vill.	x	*Festuca ovina* L.	2
E. anagallidifolium Lam.	x	*F. rubra* L.	x
E. palustre L.	x	*Holcus lanatus* L.	x
Euphrasia confusa Pugsl.	x	*Juncus articulatus* L.	x
Galium palustre L.	x	*J. bulbosus* L.	x
Leontodon autumnalis L.	x	*J. triglumis* L.	x
Linum catharticum L.	x	*Nardus stricta* L.	x
Lysimachia nemorum L.	x	*Poa subcaerulea* Sm.	x
Minuartia verna (L.) Hiern.	x		
Polygonum viviparum L.	x	*Acrocladium cuspidatum* (Hedw.) Lindb.	x
Potentilla erecta (L.) Räusch.	x		
Prunella vulgaris L.	x	*Brachythecium rivulare* B., S. & G.	x
Ranunculus acris L.	x	*Bryum pseudotriquetrum* (Hedw.) Schwaegr.	2
R. flammula L.	x		
R. repens L.	x	*Cinclidium stygium* Sw.	x
Sagina nodosa (L.) Fenzl.	x	*Climacium dendroides* (Hedw.) Web. & Mohr.	x
Sedum villosum L.	x		
Selaginella selaginoides (L.) Link.	x	*Cratoneuron commutatum* (Hedw.) Roth.	3
Thymus drucei Ronn.	x		
Trifolium repens L.	x	*C. filicinum* (Hedw.) Roth.	x
Veronica beccabunga L.	x	*Ctenidium molluscum* (Hedw.) Mitt.	x
Viola palustris L.	x	*Fissidens adianthoides* Hedw.	x
V. riviniana Reichb.	x	*Hypnum cupressiforme* Hedw.	x
		Mnium pseudopunctatum B. & S.	x
Agrostis canina L.	x	*M. punctatum* Hedw.	x
Anthoxanthum odoratum L.	x	*M. seligeri* (Jur. ex Lindb.) Limpr.	x
Briza media L.	x		
Carex demissa Hornem.	2	*Philonotis fontana* (Hedw.) Brid	2

of size. With this in mind a group of 64 mole hills was examined at c. 720 m near the source of the Knock Ore Gill. Average maximum height for these mole hills was 9.5 cm and average maximum diameter 39.2 cm: this means that although they are significantly lower than the hummocks examined, their basal diameter is much the same. However, at the time (6 April 1971) these mole hills were probably quite fresh: by July of the same year they had become noticeably degraded. Thus, one of the largest was 19 cm high on 6 April 1971, but had been reduced to only 11 cm by 21 July of that year: when re-examined on 9 April 1972 its height was less than

7 cm. These observations suggest that mole hills can possess an upstanding form when new, but that this is rarely persistent enough for them to acquire an extensive vegetation cover before being substantially degraded.

In some places the formation of small hummocks can be attributed largely to the work of ants. A detailed account of how this may occur has been given by SCHREIBER (1969). He observed that fields of hummocks on high pastureland in the Swiss Jura are due to the activities of the yellow field ant (*Lasius flavus* F.) which builds hummocks around cow dung cakes. Significantly, yellow ants were found in all but one of 25 hummocks sectioned near Underbarrow and Scout Scars just west of Kendal at the southern edge of the Lake District (TUFNELL, 1965). The area examined lies between 150 and 230 m, is gently sloping and partly strewn with masses of loose angular limestone. Its hummocks are superficially like those examined at Moor House (Pl. 4): on closer inspection, however, several differences are revealed, as shown in Table IV. The obvious importance of ants to the formation of some hummock types necessitated bearing them in mind as a possible cause of the Moor House examples. Such an origin is, however, unlikely as no ants were found in any of the 25 hummocks sectioned on the Reserve.

Another possibility considered is that the hummocks under discussion might have a largely vegetational origin. For example, they could be degenerate tussocks of *Molinia caerulea* (L). Moench such as can occur in a bog area affected by overgrazing. However, this idea was quickly dismissed as *Molinia* is found at only one locality on the Reserve (EDDY and WELCH 1967) and that is distant from areas where the hummocks have developed. Indeed, any sort of common vegetational origin for these features is unlikely because of the differences in species composition from one hummock to another.

It was therefore eventually decided that the hummocks of the present article must be similar to the Icelandic thufur and are consequently of periglacial origins. This interpretation is first of all suggested by the way such hummocks form closely-packed groups and by their external appearance — in both characteristics they match up to the literature's definition of thufurs. Internal hummock form also suggests an origin which requires pressure from below such as frost heaving would provide. In addition, all hummocks examined were on gradients of less than 18° which places their occurrence within the range of slope values appropriate for thufur development. However, the interpretation suggested for these hummocks was primarily decided upon by considering the type of environment in which they are found. At present, this environment experiences bound gelifluction and hummocks are consequently associated with features like slope terraces and ploughing blocks. Morphological relationships between hummocks and terraces have already been described: it is also significant that the Reserve's ploughing blocks are moving at detectable rates and nearly all this movement is accomplished during winter, thus demonstrating periglacial origins (TUFNELL, 1972). While no such movements ocur within fields 1 and 2, they have been observed close by. Evidence of currently potent

Table IV

Comparison of the hummocks in fields 1 and 2 (Moor House Reserve) with those examined near Underbarrow and Scout Scars (Kendal area)

Moor House Reserve	Underbarrow and Scout Scars
Distribution	
On gentle slopes, always $< 18°$	Mainly on gentle slopes, though in some places well developed on gradients of 20-35°
In fields with hummocks juxtaposed	Dispersed (hummock juxtaposition rare)
Form in plan	
Many circular, but other types occur in significant proportions	Majority elliptical
Form in section	
Arched vegetation mat enclosing core of fine material	Arched vegetation mat enclosing core of fine material (though soil finer and of a lighter colour than in the Moor House examples)
Dimensions	
Average maximum diameter: 36.0 cm Average maximum height: 17.3 cm (data from a sample of 254)	Average maximum diameter: 71.1 cm Average maximum height: 27.9 cm (data from a sample of 50)
Associated vegetation	
Can vary from one hummock to another and from one interhummock area to another	Can vary from one hummock to another
Contrast between vegetation of hummock and non-hummock areas usually less pronounced than near Underbarrow and Scout Scars	Often pronounced difference between the vegetation of a hummock and that of its surroundings
Vegetation generally denser than on hummocks near Underbarrow and Scout Scars	Vegetation often decidedly sparse on hummocks
Main factors influencing hummock development	
Frost (assisted by snow, wind, etc.)	Ants (soil gives the impression of being thoroughly sifted) Wind (probably quite important as vegetation on hummocks tends to be sparse, their soil is fine and the area is exposed)

frost action on the upper parts of the Reserve has also come from observing the position of wooden stakes which were driven nearly 30 cm into the ground. During some winters these were frost heaved by around 3–5 cm and/or moved downhill. Furthermore, small hummocks occur on ground which must have been thoroughly disturbed in the late 1940s/1950s when the radio station and its masts were built on top of Great Dun Fell. These hummocks have therefore probably developed within the last 30 years: the example illustrated in Fig. 4 I is only 4.2 m from the base of a large mast which was constructed in the early 1950s. Finally, the station's climatic records prove that frost is severe on the higher parts of the Reserve for several months a year. As shown in Fig. 1, mean temperatures during the 1960s were usually lower on the summit of Great Dun Fell than at Reykjavik in Iceland. This is significant for the present discussion because during this period thufurs began forming in the parks of Reykjavik (COTTON, 1968). To this it should be added that a wet bleak upland like the Moor House Reserve has damper terrain than the well-kept parks of Reykjavik and is on this account also more susceptible to frost heave.

Available data therefore indicate that the hummocks considered in the present article are similar in nature and origins to the Icelandic thufur. Their development appears to have been very recent and probably continues. This interpretation is supported by COTTON's (1968) view that thufurs at much lower altitudes elsewhere in the Pennines are no older than the Little Ice Age and by an assessment of the harsh climatic environment and associated geomorphological processes currently existing on the Moor House Reserve.

ACKNOWLEDGEMENTS

I wish to thank Mr. M. RAWES, Officer-in-Charge, Moor House field station, for the way he has generously assisted and advised at various stages of the work. My thanks also to Vedurstofa Islands for allowing me to use some of their temperature data in the construction of Fig. 1.

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Pl. 1. A general view looking across part of field 2 (upper Knock Ore Gill valley) towards its associated flush and the steeper slopes beyond

The photograph was taken in early April after a light snowfall. Note how wind has removed much of this snow cover from the hummocks. A similar general view of field 1 was illustrated in TUFNELL (1969, Pl. 6)

Pl. 2. Thufur from field 2 whose centre has been removed by erosion (*cf.* Fig. 4F)

Scale is given by the glove which rests on a 'rampart' surrounding the central depression

Pl. 3. Artificially-sectioned thufur of the hemispherical type (field 2)

Note its fine-earth core and arched vegetation cover

Pl. 4. Hummock on limestone terrain near Underbarrow Scar, west of Kendal