*Lance Tufnell**
Huddersfield

PLOUGHING BLOCKS WITH SPECIAL REFERENCE TO NORTH-WEST ENGLAND

Summary

The downslope movement of blocks can occur under widely differing conditions. Should this movement be frost-controlled and on grassy terrain, it will often give rise to ploughing blocks. If well-formed, these have a mound downslope of the block and depression to its rear. The creation and positioning of such microfeatures is the result of a block's ability to move faster than the ground which surrounds it. Differences in the nature of mounds and depressions make it possible to recognise several varieties of ploughing blocks.

Areas experiencing a „mild", periglacial climate seem most likely to favour the development of ploughing blocks. Hence, such features are of value in defining the present lower boundary of morphologically-significant frost action in upland areas. To date, they have been observed chiefly in the mountains of Europe.

Most ploughing blocks appear to be currently developing. Thus, 5 examples studied on the Moor House Reserve (northern Pennines, England) all moved during the period 1965–9. Frost is the principal cause of movement, assisted by gravity, temperature fluctuations above 0°C., and water (often from melting snow).

In view of their significance, ploughing blocks have been unjustly neglected. They merit the degree of attention given in the past to features such as ice wedges and stone polygons.

INTRODUCTION

Blocks move downslope under conditions which range from tropical to periglacial. As they often travel at a rate which differs from that of the surrounding ground, it is quite common for them to produce microfeatures in the shape of depressions and mounds. On talus, where vegetation is sparse or absent, or in certain permafrost environments, the depression is frequently situated downslope of a block, while the mound accumulates at its rear. This is because the block is travelling more slowly than its surroundings. In Europe the resultant feature develops over a wide altitudinal range and has been called a *brake block*[1] (Fig. 1A). By contrast, the position of mound and depression is often reversed when blocks move down grassy slopes. Under humid temperate conditions the resultant feature is the *creeping boulder* which, due to a variety

* The Polytechnic, Queensgate, Huddersfield, England.

[1] In the present article the term *blocks* refers to fairly large, essentially angular rock debris. More rounded fragments are called *boulders*.

of factors, travels more rapidly than its surroundings (Fig. 1B). If however one of these factors is dominant, a somewhat different feature results. For example, the movement of boulders can be primarily due to excessive slope moisture; features developed under such conditions have been termed *sinking boulders* (Fig. 1C). Likewise, in periglacial environments frost becomes the main factor controlling block movement and is largely responsible for the development of *ploughing blocks*. If well-formed, these have a mound downslope of the block and a depression to its rear (Fig. 1D). Again, the creation and positioning of such microfeatures results from a block's ability to move faster than the surrounding ground. It is this important manifestation of periglacial activity which forms the subject of the present article.

Though ploughing blocks occur frequently in 'mild' periglacial regions where the ground is only temporarily frozen, they have rarely been examined in detail. Scandinavian writers were among the first to establish their main characteristics and attempt an explanation of their origins (R. Sernander, 1905; J. Rekstad, 1909; B. Högbom, 1914). Unfortunately, little advance was made on this work before about 1953 (E. de Martonne, 1920; B. Högbom, 1927; E. Antevs, 1932; T. Hay, 1937, 1942; M. Boyé, 1950). A much greater interest in the subject since then has led to the discovery that ploughing blocks are widespread in the mountains of Europe. They have been recorded in the Alps (H. Poser, 1954; C. F. Capello, 1955a, 1958a, b; C. F. Capello, C. Origlia and R. Amedeo, 1955; H. Jäckli, 1957; J. Schmid, 1958; A. Pissart, 1964; P. W. Höllermann, 1964, 1967; G. Furrer, 1965a, b; H. Stingl, 1969), Britain (R. W. Galloway, 1961; G. A. L. Johnson and K. C. Dunham, 1963; J. M. Ragg and J. S. Bibby, 1966; L. Tufnell, 1966, 1969), Rumania (G. Niculescu and E. Nedelcu, 1961; G. Niculescu, 1965; T. Morariu and Al. Savu, 1966), Apennines (M. L. Gentileschi, 1967; P. W. Höllermann, 1967; D. Kelletat, 1969), the uplands of central and southern Germany (J. Schmid, 1955, 1958), Sweden (S. Rudberg, 1958, 1962), Norway (A. Cailleux, and G. Taylor, 1954), Spain (O. Fränzle, 1959), Czechoslovakia (J. Sekyra, 1961), Pyrenees and Massif Central (P. W. Höllermann, 1967), and Greece (J. Hagedorn, 1969). Recent work has also demonstrated that several types of ploughing block exist (C. F. Capello, 1955a).

Field work during the present survey has been concentrated in and about the Moor House National Nature Reserve (north-east Westmorland, England). Supplementary investigations have been made in the central Lake District (north-west England) and on the cattlepastures near the *Luftseilbahn* Fiesch--Eggishorn (north-eastern part of Valais canton, Switzerland). The fact that ploughing blocks are well developed in these and other parts of Europe, plus the relative simplicity with which they can be investigated, makes it difficult to

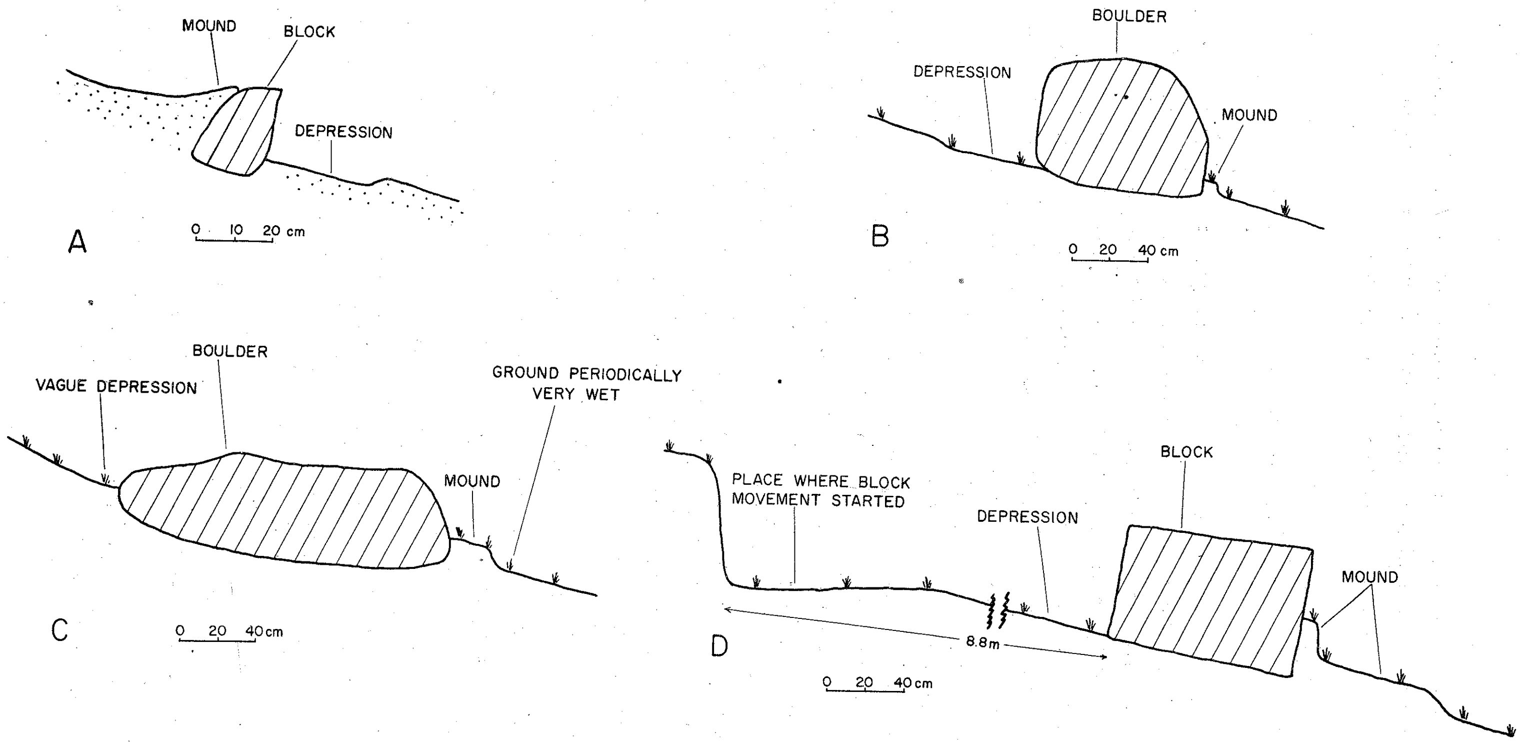
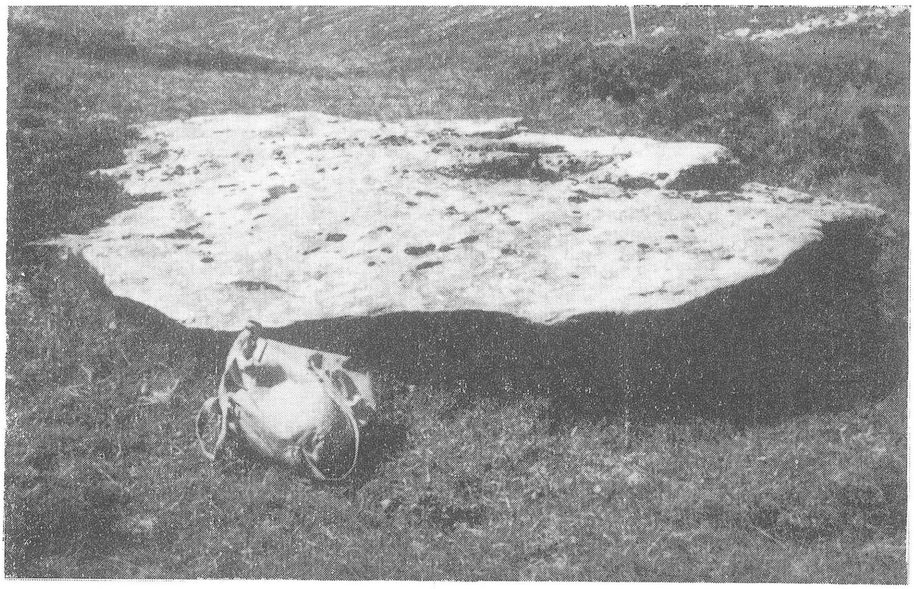


Fig. 1. Some types of block and boulder movement in north-west England: A – brake block on scree, Knock Pike, northern Pennines; B – creeping boulder, Flagdaw, northern Pennines; C – sinking boulder, Knock Pike; D – ploughing block, Little Dun Fell, Moor House Reserve, northern Pennines. All features are shown in longitudinal section

see why they have been neglected. Such features are an important aspect of 'bound' slope movement and merit the degree of attention given in the past to phenomena such as ice wedges and stone polygons.

TERMINOLOGY

The term *ploughing blocks* was coined by the present writer in 1966 to denote those blocky components of periglacial slope movement which travel faster than their surroundings and which force up the ground before them and leave a depression to their rear. Previously, such features had often been referred to by terms which contained one of two notions. First, the idea of movement by *gliding* (or *sliding*), which has been incorporated in terms such as *gleitende* Blöcke (Högbom, 1914, 1927), *glissements* de blocs (de Martonne, 1920; Niculescu and Nedelcu, 1961; Morariu and Savu, 1966), *gliding* blocks (Hay, 1937, 1942; the term is hyphenated by Johnson and Dunham, 1963), *gliders* (Hay, 1937), massi *scorrenti* (Capello, 1960), *alunecari* de blocuri (Niculescu and Nedelcu, 1961), *gliding* boulders (Rudberg, 1962), piatra *glisanta*, pietre *lunecatoare*, *alunecarea* blocurilor, bloc *glisant*, pierres *glissantes* (Niculescu, 1965), and blocs *glissants* (Gorbunov, 1969). Secondly, the idea of *travelling*, *migrating*, or *wandering* has been suggested by the use of terms like *Wander*block (Poser, 1954; Schmid, 1955, 1958; Jäckli, 1957; Fränzle, 1959; Capello, 1960; Höllermann, 1964, 1967; Furrer, 1965a, b; Hagedorn, 1969; Kelletat, 1969; Stingl, 1969), *Wander*steine (Schmid, 1955), massi *erranti* (Nangeroni, 1957; Capello, 1958a, b, 1960), massi *viaggianti* (Nangeroni, 1957), *wandering* boulders (Rudberg, 1958, 1962), and blocs *marchants ou errants* (Gorbunov, 1969). However, neither of these ideas is wholly satisfactory. The adjective *gliding* (or its equivalents) is unsuitable as it implies smooth, continuous movement, whereas in reality it is jerky and intermittent. Likewise, the notion of *travelling*, *migrating*, or *wandering* may be criticised because it suggests movement in any direction – blocks generally move down the line of steepest available slope. A further objection is that the term *Wanderblock* already has other meanings (eg. it may refer to glacial erratics). Owing to these difficulties the alternative term *ploughing block* was suggested. The fact that this contains notions about the type of movement and the kind of features it produces should recommend it for widespread usage. In addition to the terms already discussed, *sigende* stenblokker (Rekstad, 1909), *kriechender* Block (Högbom, 1914, 1927) massi *contornati* (Capello, 1955a, b, 1958a, b, 1960; Capello, Origlia, and Amedeo, 1955; Nangeroni, 1957; Gentileschi, 1967), and blocs *rampants* (Gorbunov, 1969) have been used. Occasionally,



Pl. 1. Large ploughing block with a lateral mound and levée depression at ca. 2200 m on the cattle pastures near the *Luftseilbahn* Fiesch-Eggishorn. See also note 3

Pl. 2. Ploughing block at 820 m on the east-facing slope of Little Dun Fell. This example is also illustrated in Fig. 1D and its movement is recorded in Fig. 9 (block no. 4). Note how snow melt on the downslope side far exceeds that at the upslope end of the block. The semi-circular hollow at the top of the photo is 8.8 m upslope of the block and indicates where movement began. Snow covers the block's depression which is 6 m long

authors have preferred long descriptive phrases such as 'à l'avant des blocs, un bourrelet de terre soulevée et, à l'arrière, une dépression en forme de sillage' 'blocs... (avec)... bourrelet de terre à l'aval, creux à l'amont' (Cailleux and Taylor, 1954), and 'blocs déplacés par solifluxion avec bourrelets retroussés devant et un sillon laissé derrière eux' (Sekyra, 1961).

Though the material pushed up by a moving block assumes a variety of forms, there must be a general term to describe it; the word *mound* fits this role as well as any. When a more specific description is required, this can be given by referring to surface form and internal composition. Thus, mounds are generally divisible into *single*, and *double* varieties, and can be further divided into *frontal*, *frontal-lateral*, and *lateral* types. Similarly, they may be composed predominantly of *soil*, *vegetation*, or *stones;* when two or all of these occur in significant proportions, the phrase *composite* mound seems appropriate. Illustrations of how this terminology may be applied are given in later paragraphs. Of the terms used to describe mounds (or parts thereof), two have gained widespread popularity. First, there is the German noun *Wulst*; this has appeared either singly (Högbom, 1914; Schmid, 1955, 1958; Kelletat, 1969) or in conjunction with an adjective (Schutt*wulst* – Poser, 1954; Kelletat, 1969; Stauch*wulst* – Schmid, 1958; Höllermann, 1964 1967; Furrer, 1965a; Stingl, 1969; Kelletat, 1969; Rasen*wulst* – Furrer, 1965a; Stirn*wulst* – Hagedorn, 1969). Secondly, the noun *bourrelet* has been used in a number of French-language publications: again, the term has occurred either on its own (de Martonne, 1920;Sekyra, 1961; Gorbunov, 1969) or it has been linked with an adjective (*bourrelet* de labour – Boyé, 1950; *bourrelet* de terre – Cailleux and Taylor, 1954; Pissart, 1964; *bourrelet* de boue – Tricart and Cailleux, 1961). Among the less popular terms for mounds there is jordvold, vulstformet vold (Rekstad, 1909), Wall (Höbgom, 1914, 1927; Kelletat, 1969), roll of turf (Hay, 1937), Schuttkrausen, Vegetationskrausen (Poser, 1954), bordo, cuscinetto, margine, ripianetti (Capello, 1955a), contorno (Capello, 1955a, 1960), argine (Capello 1955a, 1958a, 1960; Gentileschi, 1967), ripiani (Capello, Origlia and Amedeo, 1955), rialzo convesso, emergenza terrosa (Nangeroni, 1957), Erdwall, Welle (Jäckli, 1957) anello (Capello, 1958a), bow-wave (Galloway, 1961; Ragg and Bibby, 1966), val (Niculescu and Nedelcu, 1961; Niculescu, 1965), earth-bank (Rudberg, 1962), ridges of soil (Johnson and Dunham, 1963), cercine (Gentileschi, 1967), and Stufe (Höllermann, 1967).

Directly upslope from a moving block is a feature whose general morphology suggests the term *depression*. In the past, this has been described by a variety of words and phrases and, with the possible exception of 'Gleitbahn', no one term has gained a widespread currency. However, some writers have distinguished two genetically similar, though morphologically contrasting types of depression. For example, Poser (1954) distinguishes 'Auswanderungsnischen' from 'längere Rinnen', while Höllermann (1964, 1967) uses the terms 'Auswanderungsnische' and 'länger gestreckte Gleitbahn'. It is proposed that the corresponding English terms for these two kinds of depression should be *niche-shaped* and *elongate*. Other terms for depressions (or their parts) include ränna (Sernander, 1905), fure, glidebane (Rekstad, 1909), Grube (Högbom, 1927), furrow (Hay, 1937; Galloway, 1961), sillage (Boyé, 1950; Pissart, 1964), un dépression en forme de sillage (Cailleux and Taylor, 1954), creux (Cailleux and Taylor, 1954; Gorbunov, 1969), solco, conca (Capello, 1955a, 1960; Gentileschi, 1967), cavo (Capello, 1955a, 1958a; Capello, Origlia and Amedeo, 1955), Vertiefung (Schmid, 1955), depressione (Nangeroni, 1957), Fahrspur (Jäckli, 1957), Ausbruchsnischen (Schmid, 1958; Fränzle, 1959; Stingl, 1969), Gleitwege (Schmid, 1958), sillon (Tricart and Cailleux, 1961; Sekyra, 1961; Gorbunov, 1969), sant (Niculescu and Nedelcu, 1961; Niculescu, 1965), open ditch (Rudberg, 1962), hollows (Johnson and Dunham, 1963; Ragg and Bibby, 1966), (micro) depresiune (Niculescu, 1965), Spur, Schleifspur, Gleitspur (Furrer, 1965a), Rutschbahnen (Höllermann, 1967), Gleitrinnen (Kelletat, 1969; Stingl, 1969), Wanderrine, and Nische (Kelletat, 1969)[2].

THE CHARACTERISTICS OF PLOUGHING BLOCKS

NATURE OF BLOCKS

In periglacial environments blocks move not only by ploughing, but also by rolling, overturning, and bouncing. Hence, there exist conditions which are favourable or even essential for the development of ploughing blocks. Some of these relate to the form and dimensions of blocks. Thus, an examination of the better-developed blocks indicates that the optimum shape for movement by ploughing is the rectangular prism. Naturally, divergence from this optimum takes on a variety of forms and has several consequences. For example, a highly irregular form is likely to slow down the rate of block movement. Similarly, displacement of thin, platy material rarely leads to the

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[2] Unfortunately, some of these terms have been used in a confusing manner. For example, in 1955 Capello noted that upslope of a block one might find „. . . una *conca* . . . che spesso segna il termine di un *solco* allugato". However, later (1960) he appears to use these terms differently when he writes „Massi rocciosi . . . aventi a monte un *solco* a forma di canale, oppure una *conca*, asciutta, . . . ".

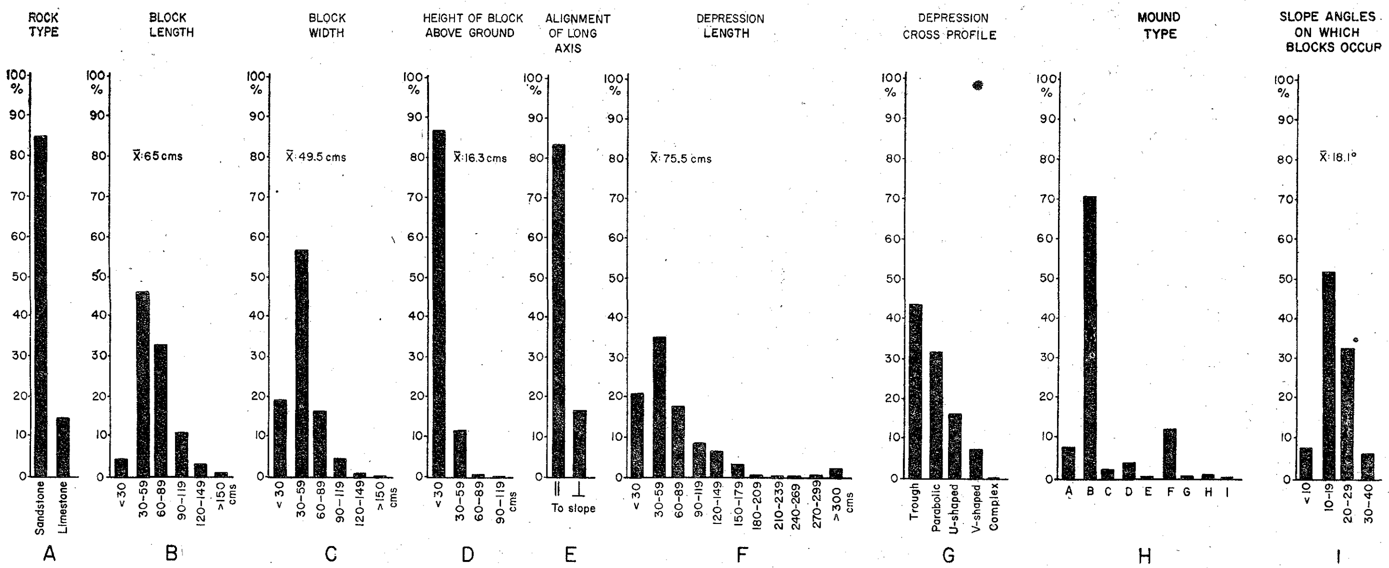

Fig. 2. The characteristics of 500 well-developed ploughing blocks at altitudes of 685 to 840 m on the Moor House Reserve (200 examples were studied on Little Dun Fell, a further 200 in the upper Knock Ore Gill valley, and 100 on Knock Fel.)

Measurements were recorded to the nearest whole number and in the case of items B, C, D, and F were of the maximum value obtainable. The mean ($\bar{x}$) of some variables is also given formation of good mounds and depressions, while a triangular-shaped fragment whose apex points downslope frequently possesses an incomplete (lateral) mound.

The optimum size for a block which is moving by ploughing varies with the conditions. However, in any situation there are factors limiting the dimensions of such a feature. Thus, the smaller a block, the less likely it is to possess enough weight to form an associated mound and depression (the smallest block with well-developed microfeatures noted on the Moor House Reserve had a long axis of 14 cm). Conversely, the larger a block the greater the frost action needed to move it. In this context it is worth recalling that the largest ploughing block discovered on the Moor House Reserve has a length of 2.5 m, a width of 1.4 m, and stands up to 70 cm above the surrounding ground. A yet larger example was seen near the *Luftseilbahn* Fiesch-Eggishorn. This had a length of 3.7 m, a width of 2.9 m, but stood only 40 cm above ground level (pl. 1)[3]. Even more remarkable are the observations by Höllermann (1964) and Furrer (1965a) of blocks whose long axis measures around 5 m. Although it is not possible to state the most generally occurring dimensions of blocks which move by ploughing, it is pertinent to note that of 500 such blocks examined on the Moor House Reserve just over 90% had maximum lengths of 30–120 cm, and 93% had maximum widths of below 90 cm (Fig. 2B, 2C)[4]. On the other hand, data from near the *Luftseilbahn* Fiesch-Eggishorn show that there are places where the most frequently occurring block size is distinctly greater than at Moor House (Fig. 3A, 3B).

A further aim of investigations at Moor House was to determine the orientation of the long axes of ploughing blocks. Again, 500 examples were studied and of these nearly 17% had their long axis perpendicular to the direction of steepest available slope (Fig. 2E). Virtually identical results were obtained from near the *Luftseilbahn* Fiesch-Eggishorn (Fig. 3C)[5]. These findings support the claim made, for example, by Höllermann (1964) that this type of situation is not uncommon and they agree with figures given by Cailleux (1947) for the alignment of blocks in *coulées limoneuses à blocailles*.

The number of rock types which can be broken down into a form suitable for ploughing is limited. Those which can include the Carboniferous sand-

[3] These measurements were made in the summer of 1968. When this locality was revisited a year later it was found that construction work at the site had destroyed this ploughing block.

[4] 'Length' is defined as the downslope measurement of a block; 'width' refers to its cross-slope measurement. The long axis of a block may be aligned either downslope or across the slope.

[5] The alignment of ploughing blocks was defined according to the Cailleux (1947) index.

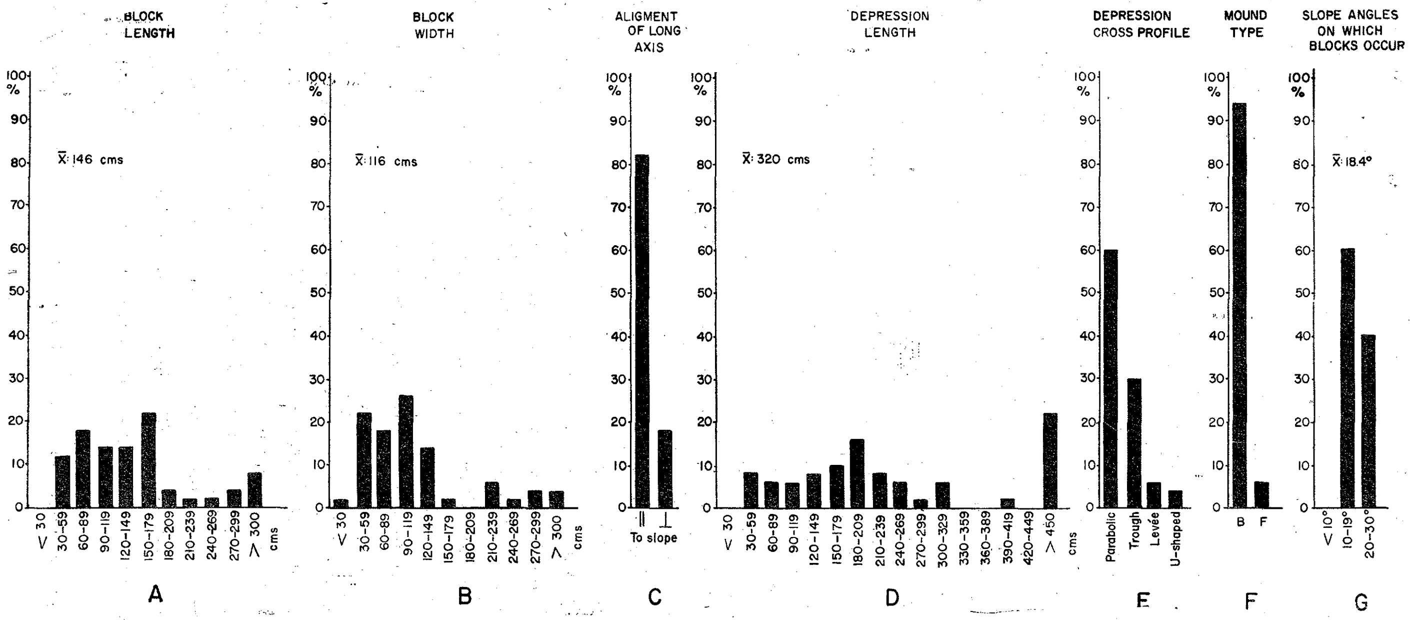

Fig. 3. The characteristics of 50 well-developed ploughing blocks at c. 2200 m near the *Luftseilbahn* Fiesch-Eggishorn.

Measurements were recorded to the nearest whole number and in the case of items A, B, and D were of the maximum value obtainable. The mean ($\bar{x}$) of some variables is also given stone[6] and limestone of the Moor House Reserve (Fig. 2A), and the Ordovician andesites, rhyolites, and tuffs of the central Lake District: weathering of granite (Högbom, 1927) and gneiss (Fränzle, 1959) can also lead to the formation of ploughing blocks. Many of these blocks were no doubt produced by gelifraction of bedrock, though some might be glacial erratics.

NATURE OF DEPRESSIONS

In plan, depressions can be niche-shaped or elongate (Fig. 4A, 4B-D). These two basic forms may be ascribed to differences in the speed of block movement relative to that of the surrounding ground. Thus, when a block travels decidedly faster than adjacent parts of a slope, it will create an elongate (ie. long, narrow) depression. If, however, movement only just exceeds that of surrounding material, a niche-shaped depression is likely to form. Alternatively, should a once-moving block become virtually immobile, its depression, if elongate, may be gradually reduced by other slope processes to a niche form.

While all the niche-shaped depressions examined had more or less the same form in plan (Fig. 4A), their elongate counterparts were of three main varieties (Fig. 4B-D). The first shows no change of direction throughout its length and is therefore basically a 'straight' feature (Fig. 4B). An example of this is illustrated in Fig. 1D and pl. 2; here the depression is straight for its entire length of 6 m. On the other hand, a block sometimes alters its direction of movement and creates a depression whose plan is either 'curved' or 'angular' (Fig. 4C); several examples of this occur in the upper Knock Ore Gill valley (Moor House Reserve). Another possibility is that the direction of block movement has been altered on several occasions, with the resultant formation of a 'winding' depression (Fig. 4D); instances of this occur on the north-west margins of the summit plateau of Knock Fell (Moor House Reserve). The factor most likely to induce changes in the direction of block movement is slope irregularity. However, obstacles such as trees may have a comparable effect (Högbom, 1914, 1927).

The ability to distinguish elongate from niche-shaped depressions indicates that the length of such features is extremely variable – in fact, it ranges from a few centimetres to a maximum value of around 20–25 m (Högbom, 1914, 1927; Höllermann, 1967; Stingl, 1969; Kelletat, 1969; see also note 7 below). Within these limits there are certain more frequently occurring values, as shown by the examination of 500 depressions at Moor House (Fig. 2F). Thus, 75% of the examples studied at this locality were below 90 cm in length.

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[6] Sandstone ploughing blocks have also been noted by Höllermann (1967) and Kelletat (1969).

Indications that these findings are not however representative of some areas have come first from the discovery that in north-west England the largest depressions have a length which is only one-third of the maximum value quoted

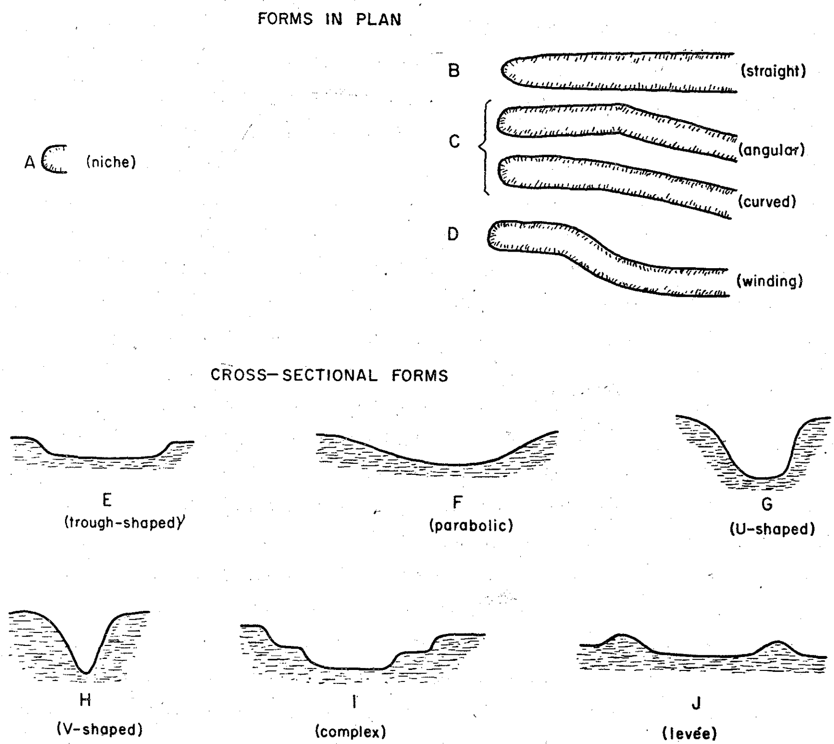


Fig. 4. Types of depression on the Moor House Reserve and near the *Luftseilbahn* Fiesch–Eggishorn

The cross-sectional forms are drawn at a scale which is larger than that for the forms in plan

above[7]. Secondly, of 50 ploughing block depressions studied near the *Luftseilbahn* Fiesch-Eggishorn, only 14% were under 90 cm long, whereas 72% exceeded 1.5 m in length. Therefore, at Moor House the most frequently occurring depression lengths are smaller than in certain other areas. Despite variations in size, the lengths of all depressions are a sure indication only of the minimum distance which a block has moved by ploughing. This is because

[7] The longest depressions examined during the present survey were:

(a) 20.1 m, 10.7 m, 10.6 m, 9.5 m, 9 m, 6.7 m, 6.6 m, and 6.2 m near the *Luftseilbahn* Fiesch-Eggishorn (data from a sample of 50),

(b) nearly 8 m, and 6.4 m on Little Dun Fell (Moor House Reserve) (data from a sample of 500).

part of the feature may have been destroyed by other types of slope movement. At times, evidence can be found of where these destructive processes are currently active. For example, one depression on Knock Fell is in two halves, whose respective lengths are 57 cm (upper section) and 2.6 m (lower section). These are separated by a gap of 1.3 m. A check was made to see if the upper part might have been formed by a second block which is now covered by soil and vegetation, but none was found. Another instance of where a depression is being altered by slope processes was that examined near the *Luftseilbahn* Fiesch-Eggishorn. This feature can be divided into two sections, of which the lower has a fairly constant width and is ca. 8 m long. By contrast, the shorter, upper section is narrower, for it is here that the depression shows evidence of being destroyed by another form of slope movement. Thus, gelifluction terracing with risers up to 28 cm high was found at this point.

The cross-sectional form of depressions is rather more varied than their shape in plan. Consequently, on the Moor House Reserve there are five basic types which may be designated as trough-shaped, parabolic, U-shaped, V--shaped, and complex[8] (Fig. 4E-I). A sixth type of depression, whose cross--section resembles that of stream levées, was identified only near the *Luftseilbahn* Fiesch-Eggishorn (Fig. 4J; pl. 1). Unfortunately, the cross-profiles of some depressions are hard to classify because of their transitional nature, while others experience an alteration of form. Despite these problems, an attempt was made to find the commonest varieties, applying the principle that where changes occur in the form of a cross-profile only the dominant type is recorded. Of the 500 examples studied in the Moor House area 44% were trough-shaped, 32% were parabolic, 16.4% were U-shaped, 7.4% were V--shaped, and only 0.2% had a complex form (Fig. 2G). A different situation was, however, observed near the *Luftseilbahn* Fiesch-Eggishorn. Here 60% of the depressions examined had a parabolic cross-profile, 30% were trough--shaped, 6% had a form resembling that of stream levées, and only 4% were U-shaped. A proper elucidation of the factors responsible for the cross-sectional form of depressions has yet to be made, but it seems likely that these include shape of a block, the way it moves, and the effects of other slope processes.

Along most of its length the width of a depression may approximate that of the block which produced it. However, this is not always the case. For example, the block illustrated in Fig. 1 D and pl. 2 has a maximum width of

[8] A complex depression forms when two blocks move by ploughing and the smaller creates a depression within that of the larger. This situation is, however, rare. More common are those blocks which utilise the depression of another, but which create no depression of their own. Nearly 6% of the 500 examples studied on the Moor House Reserve have a depression which is being used by another block.

63 cm, yet its depression is never more than 41 cm across. This difference can be attributed to the tilted fashion in which the block has moved downslope. Of greater importance in the formation of relatively narrow depressions are those slope processes which can (as mentioned above) effectively reduce the width of such features. Complicating the situation further are those depressions whose width is greater than that of their associated block. Thus, in one example on Little Dun Fell the block was at most 85 cm across, whereas its depression had a maximum width of 1.2 m. Erosional processes may play a significant role in the formation of this kind of depression.

As depressions are usually shallow features, only 6.2% of the 500 studied at Moor House had a maximum depth exceeding 30 cm. In some cases deptn remains virtually constant throughout the length of a depression, while in others it increases in the younger, downslope part of the feature. This latter situation arises when the downhill movement of a block is accompanied by its progressive sinking into the ground. Eventually, the block may get so deeply embedded that it becomes covered with vegetation. This can produce a depression which seems to lack an associated block. However, a small amount of digging at the lower end of such a depression will reveal that a block is present. Examples of this occur on Knock Fell and on Little Dun Fell.

Most depressions investigated during the present survey were vegetation covered, even though they may still be forming. This is due to their slow rate of development which allows time for vegetation effectively to colonise an area as it is being vacated by the moving block. However, a block which consistently travels at a fairly rapid rate[9], or which experiences a large displacement in any one year may create a depression which for some time at least is partly free of vegetation.

NATURE OF MOUNDS

Often, the most complex section of a ploughing block is its mound. Some of the varied attributes of this feature have been described by Capello (1955a) and others have been identified by the present writer (Fig. 5). No doubt, additional varieties will be recorded.

The mounds studied at Moor House may be 'classified' according to their position relative to a block, their general surface form, and their internal composition. An examination of these variables has led to the identification on the Reserve of nine mound types which may be grouped under two principal

[9] It is difficult to say what constitutes a 'fairly rapid rate'. However, of relevance may be the observation that only the fastest of the 5 moving blocks examined at Moor House (see Fig. 9) has a vegetation-free depression. It usually travels 5–7 cm *per annum.*

headings. First, there are six varieties of *single* mound and these fall into three categories (Fig. 5). The first of these (type A) is the simplest kind of mound possible. Being no more than a rudimentary pushing up of soil and vegetation on the downhill side of a moving block, it may be regarded as a *frontal* variety of single mound. When, however, such a mound also extends for at least part of the way along the two sides of a block, it forms the type B variety of *frontal--lateral* mound. Work by Capello (1955a) and the present writer (Figs. 2H and 3F) has shown that this is the commonest type of mound. Less frequently, one can discover mounds of the same general form and in the same position as those of type B, but which contain a high proportion of stones rather than of soil. Often, these are concentrated in the frontal part of a mound and are in an erected position (type C, single mound, frontal-lateral variety). Another possibility is that general form and internal composition will be as for type B, but instead of being contiguous with a block, the mound will be separated from it by a distinct gap (type D, single mound, frontal-lateral variety). Also similar to the members of group B, but having the additional characteristic of a bare patch close to their downslope border, are mounds of type E (single mound, frontal-lateral variety). The final type of single mound is that developed only along the sides of a block and therefore described as *lateral* (type F). More complicated than any of the types yet mentioned are the three varieties of *double* mound. One has an upper section which consists of a small type B mound and a lower part of similar form but greater dimensions (type G, double mound, frontal-lateral variety). Another is identical to type G, except for a bare patch just downslope of the smaller, upper part of the feature (type H, double mound, frontal-lateral variety)[10]. The final type of mound distinguished on the Moor House Reserve consists of two vegetation-covered areas separated by a bare-floored depression which sometimes contains water or ice (type I, double mound, frontal-lateral variety; illustrated in Tufnell, 1969, Pl. 2).

A comparison of the mound types in Fig. 5 with those shown on p. 112 of Capello's (1955a) paper underlines the contrast between the two sets. This diversity indicates that several explanations will be necessary to account for the origins and development of such features. Thus, while mounds generally result from the pushing up of ground by a moving block, the exact manner in which this takes place often varies and may well be rather puzzling. For example, it is easy to see that type A mounds represent a simple deformation by a moving block of the uppermost parts of the regolith, but it is difficult to say why such a mound is confined to the frontal part of its associated block. Help in under-

[10] Mound types G and H should be carefully distinguished from those members of groups B and E below which is a break of slope due to some factor other than block movement (eg. the development of a gelifluction terrace).

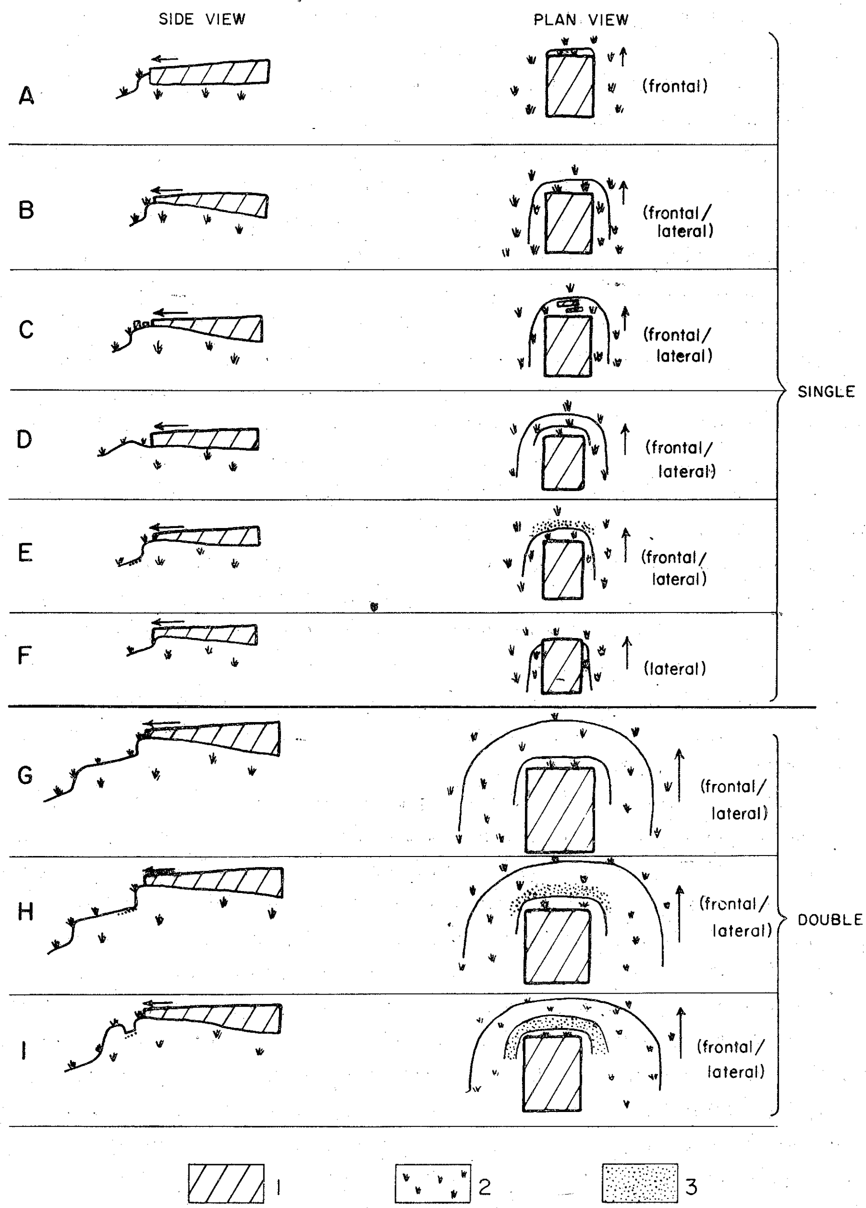


Fig. 5. Types of ploughing block mound on the Moor House Reserve. Arrows indicate direction of movement

1. rock; 2. vegetation; 3. bare ground

standing this problem may be derived from observing the effects of pushing a clenched fist through sand. If the fist is moved a short distance, sand tends to pile up only in front of it, but when it is moved further an excess of sand accumulates and there is spillage round the sides of the fist. This analogy suggests that type A mounds may be correlated with short depressions, whereas those of group B will have longer depressions associated with them. Unfortunately, attempts to verify this are fraught with difficulties. The obvious approach would be to measure depression lengths and correlate these with mound types. The examination of 500 ploughing blocks at Moor House did, in fact, make such a correlation possible. Furthermore, results appeared to bear out the suggested correlation, for of the type A mounds examined 84% were associated with depressions of under 90 cm in length: by contrast, such depressions were associated with only 73% of the type B mounds studied. However, these data must be treated with reserve. In the first place, it was impossible to quantify any reduction of depression length by other slope processes. Hence, no appraisal could be made of the extent to which a correlation was distorted by such modifications. Likewise, any alteration of a mound by erosion could not be assessed, thus raising the possibility of an erroneous correlation. For example, a depression may form in conjunction with a type B mound, but during a period of block stability those parts of a mound most susceptible to erosion (ie. the lateral portions) may be removed, without there being a corresponding modification of the depression. Hence, one would naturally correlate such a depression with a type A mound, whereas in reality it formed in association with a B type variety. Another complicating factor would be the variability of block form. Despite these problems, there appears to be some validity in the idea that the distance a block has moved can have *inter alia* a bearing on the formation of type A mounds. On the other hand, this is not the only thing involved in their formation. Already, reference has been made to a second, namely erosion of the lateral parts of a type B mound which is thereby reduced to the type A variety. In addition, one must take into account the depth to which a block is embedded in the ground. Where this is small, the block will 'skim off' merely the topmost part of the regolith and will therefore push up only a little material; this would favour the development of type A mounds. If, however, a block is more deeply embedded, it will probably force up a greater amount of material and this is likely to favour the development of B type mounds. Preceding remarks about the latter type of mound usually apply to the mounds of group C as well. Indeed, the two varieties differ only in their internal composition – type B mounds are largely composed of soil, while those of group C have a high proportion of stones. This difference results solely from the kind of terrain through which a block is passing. Similarity also exists between the mounds of groups B and D, though again there are noteworthy differences. These relate to the gap between mound and block in type D varieties and the absence of this phenomenon in their group B counterparts. The most frequent cause of this gap is probably the upslope settling of a block during the spring thaw. If this idea is correct, many gaps should be narrower or may even be closed up during winter. Another pair of mound types whose similarities outweigh their differences are those in groups B and E. Such differences as occur relate to the bare patch near the downslope border of type E mounds and the lack of a comparable feature in association with their type B counterparts. As bare ground also forms in conjunction with mound types H and I and is polygenetic, an attempt must be made to explain its origins. Work in the Moor House area has led to the identification of four processes which help to form bare patches. One is the cracking of ground by frost action, a process observed not only on ploughing block mounds but also on the treads of gelifluction terraces. Such cracks initiate weaknesses in a vegetation cover and provide starting points for its further disruption. When a bare patch has formed, cracking may also occur tbrough desiccation and this helps to maintain and enlarge that patch. Water and ice also contribute to the development of bare ground. Evidence suggests that group I mounds often acquire and retain water better than do those of categories E and H. Lastly, sheep have been seen contributing to the development of bare patches, especially where these are associated with large blocks which provide shelter. Investigations of the final type of single mound (i.e. the lateral variety) have revealed that this can develop in at least two ways and in both the decisive factor is block shape. Thus, lateral mounds are often associated with blocks whose shape in plan approximates that of a triangle with its apex pointing downslope. Clearly, the form of such blocks militates against the development and preservation of the frontal section of a mound. Likewise, blocks with a pronounced overhang along their downslope edge may be associated with a lateral mound (pl. 1). It would appear that the shape of their front enables such blocks to 'ride over' the ground and thus avoid pushing up material in front of them.

Double mounds have a more complex evolution than do any of the single varieties and their origins are harder to explain. Thus, while types G and H must develop in a basically similar fashion, the precise course of events is by no means apparent. Nevertheless, it was found that the examples studied were invariably associated with large blocks and/or long depressions. While this explains the large amounts of material which form the lower portion of such mounds, it fails to account for their smaller upper part. Indeed, the origins of the latter are a mystery and the only plausible idea is that they result from vegetation (eg. *Polytrichum*) growth during a period of block stability. No doubt, it is the large amount of material which has been piled up in front of a block that is responsible for halting its movement (? together with a decrease in the intensity of frost action). Once stability has been achieved, vegetation growth will be relatively fast adjacent to the block owing to the warmth and

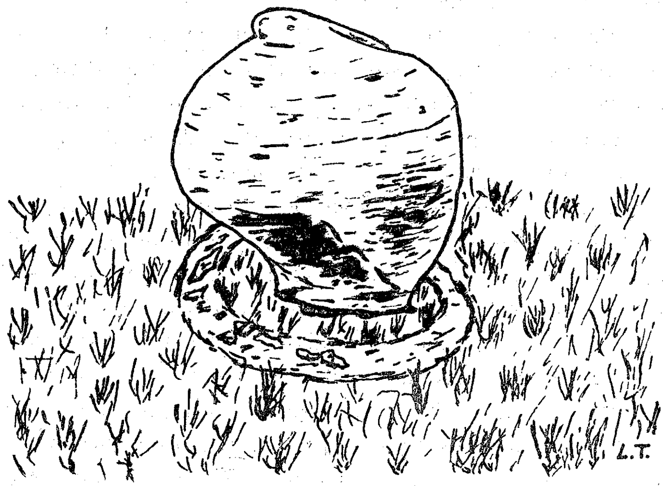


Fig. 6. Boulder surrounded by 'moat' of unvegetated ground near the summit of Steel Fell (central Lake District)

Altitude 545 m. The feature occurs on very gently sloping ground and has stones in its 'moat'. Drawn from a photograph

shelter it provides and therefore a mound-like feature may develop. Naturally, the bare patch associated with group H mounds, but lacking in type G varieties, forms as a result of the processes already mentioned. Block stability and the development of bare ground also contribute to the formation of type I mounds. These probably originate through the modification by erosion of large type B mounds. Thus, the tread of such a mound can be partly eroded to give a bare--floored depression whose axis is roughly parallel to the front of its associated block. Cracking of the ground by frost, desiccation, water, ice, and sheep have all been observed to take part in the formation of such mounds. Additional proof that erosion contributes to the surface form of type I mounds comes from those blocks on almost level terrain which are surrounded by a 'moat' of bare ground (Fig. 6). During the present survey these features were noted in the central Lake District (eg. on Steel Fell) and in the Moor House area (eg. on Little Dun Fell). They have also been recorded in the Lake District by Hay (1937) and were discussed by Högbom in his classic (1914) paper on frost phenomena. As 'moats' occur on nearly level terrain, they cannot be attributed to block movements, unless these were in an essentially vertical plane due to sinking; more likely, they were formed by those erosional processes already described and which give rise to patches of bare ground. Evidence therefore suggests that type I mounds have a two-stage development. While block movement is necessary for the pushing up of the mound, block stability may well be a prerequisite for the development of the erosional phase.

Three main conclusions emerge from this study. First, of the 15 or so varieties of mound already identified, type B is the most common. Second, there appears to be a general relationship between mound form and block movement; the simpler kinds of mound tend to be related to the faster moving blocks, while the complex varieties are more likely to be associated with near stationary blocks. Finally, it seems that the main factors responsible for the nature and development of ploughing block mounds are periglacial slope movements, certain erosional processes, and vegetation.

MOVEMENT OF BLOCKS

DIRECTION OF MOVEMENT

Generally, blocks move down the line of steepest available slope and where this changes their direction of movement may alter accordingly. However, blocks exist whose depression indicates that they have moved *across* the line of steepest slope (Fig. 7). Probably the most frequent cause of this is an obstacle in the path of the advancing block; such obstacles may be due to other blocks, erected stones, rock outcrops, or small trees and bushes.

AMOUNT OF MOVEMENT

There are several ways of determining amounts of block movement. For example, the *minimum* distance a block has travelled can be found by measuring the length of its depression; the value obtained also represents the minimum distance over which ploughing has occurred. Again, it may be possible to determine the *total* amount of movement by ascertaining the distance between a block and the outcrop from which it was derived. Thus, in the upper Knock Ore Gill valley there are blocks of limestone which lie 46 m from the outcrop where their movement began. Unfortunately, this technique is of limited application, because it is sometimes impossible due to lack of outcrops to tell where movement started and also because there is usually no way of deciding what proportion of movement was by ploughing and how much was the result of other processes (eg. rolling). Lastly, by establishing fixed points one can measure block movement over a given period; the results so far obtained by this method are considered in the next section.

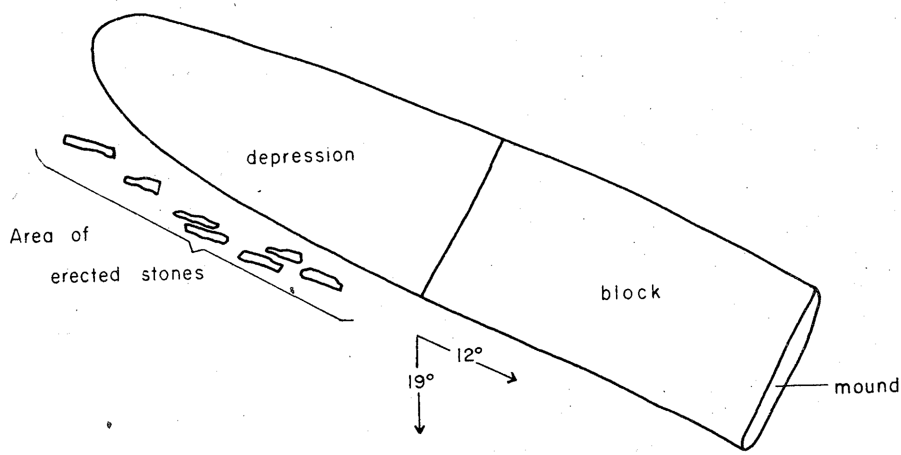


Fig. 7. Block moving across the line of steepest slope (plan view). West-facing slope of Little Dun Fell. Altitude 810 m. The block has a length of c. 1 m

RATE OF MOVEMENT

Virtually no attempt has been made to determine accurately the rate at which ploughing blocks travel. Admittedly, Pissart (1964) has examined blocks in the French Alps whose mean annual rate of movement was between about 1 and 1.5 cm, but these were not typical ploughing blocks, as the ground surrounding them lacked vegetation. Nevertheless, his results correspond with the statement by Johnson and Dunham (1963) that ploughing block movements are usually slow; conversely, rapid movements are seldom experienced (however, these two authors did record a shift of 1.5 m in one year on the Moor House Reserve).

Because of the need for precise information on the rate at which ploughing blocks move, an attempt has been made during the present survey to begin filling this gap. Hence, five well-developed examples were selected at varying altitudes on the Moor House Reserve with a view to determining their rates of movement (Fig. 9). The equipment used for this purpose consisted of wooden stakes, nails, paint, a tape, a penknife, and a hammer. As suitable outcrops were lacking, fixed points had to be made by driving stakes into the ground.

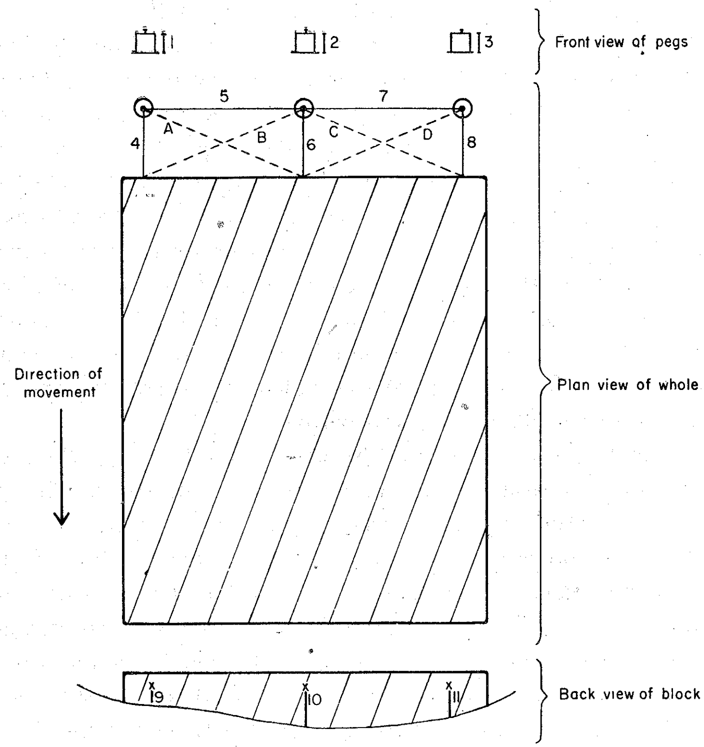


Fig. 8. The measurements taken when recording ploughing block movement. Numbers refer to the most important distances measured: leters indicate measurements of secondary importance

Three such stakes (not one) were placed upslope from a block, so that if any should move this would be detected by a change in its position relative to that of the other two. Using this technique it was found that large stakes driven ca. 90 cm into the ground showed no detectable amounts of movement, but smaller ones 30 cm in length occasionally had their position altered by frost heave and/or downslope movement. This situation is comparable to that recorded by J. Smith (1960) in South Georgia. Fortunately, most of the stakes put behind the five blocks were of the large variety, so that the rates of movement given in Fig. 9 should be accurate. Points from which to measure were established by driving a nail into the top of each stake and by putting three small crosses on the upslope face of each block. To ensure the crosses would not vanish between observations, they were first deeply scratched onto the block with a penknife, and then overpainted in yellow[11]. Three sets of

[11] Yellow is suitable for use on dark blocks, though red may be preferred for lighter ones.

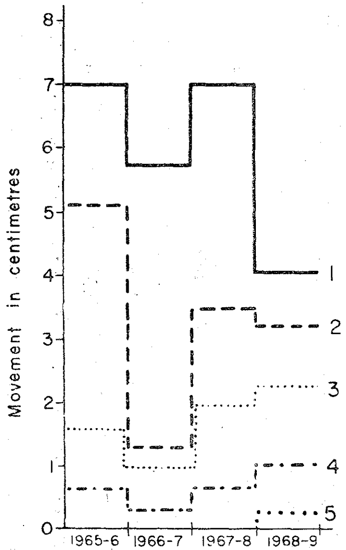
measurements were taken when recording changes in the position of each block. First, distances were measured between nails and from these to the centres of the three crosses; as a further check the diagonal measurements between nails and crosses were ascertained. Secondly, despite uneven terrain, an attempt was made to detect any vertical change in a stake's position by measuring the height to which it protruded above ground. Lastly, in order to detect vertical movements of a block, distances were measured between the centres of the crosses and the ground. Fig. 8 shows how measurements were recorded in the field. To minimize the risk of inaccuracies none of these measurements was over a longish distance. Finally, when a moving block was found to be turning relative to a line of pegs, the middle of the three measurements from nails to crosses (ie. no. 6 on Fig. 8) was taken as representing the distance that the block had travelled in a given period.

Though investigations cover only the years 1965–9, it appears justifiable to draw from them several conclusions about the nature of ploughing block movement on the Moor House Reserve. First, this is nearly always slow, being on the whole no more than 5 to 7.5 cm *per annum*. Results therefore agree with the statements noted above by Pissart (1964), and by Johnson and Dunham (1963); they should also be compared with figures given in a table by Embleton and King (1968, p. 511) which summarizes known rates of surface movement for other types of periglacial mass wasting. A second conclusion and one well illustrated in Fig. 9 is that those blocks which move fastest in any one year tend to do so in other years as well and *vice versa*. Thirdly, there has been a tendency for blocks to exhibit accelerated rates of movement during some years and decreased rates in others. This is presumably connected with the general severity of winter. Fourthly, results uphold Pissart's (1964) claim that fragment size has a bearing on the rate of displacement, as smaller fragments were observed to travel more rapidly than their larger counterparts. Finally, results support the view that rates of movement can differ on slopes of approximately equal steepness (cf. A. Pissart, 1964).

As these conclusions are derived from only a small amount of data, their widespread acceptance, together with the establishing of new conclusions, must await further investigations. Above all, one would wish to know the relationships between microclimate and periods of block movement and the relative speeds of a block and its surroundings.

CAUSES OF MOVEMENT

Several factors contribute to ploughing block movement. First, changes in temperature assist a block's migration by producing contraction from its upslope end and expansion towards its downhill side (fig. 10A). Secondly,



Locality	Altitude	Block size (maximum values) length	width	ht. above ground	Slope angle
Knock Ore Gill valley (N-facing slope)	730 m	58 cm	55 cm	10 cm	21°
Middle Tongue Beck (N-facing slope)	760 m	45 cm	37 cm	20 cm	22°
Knock Ore Gill valley (S-facing slope)	685 m	90 cm	105 cm	37 cm	22°
Little Dun Fell (E-facing slope)	820 m	95 cm	53 cm	62 cm	5°
Little Dun Fell (N-facing slope)	820 m	122 cm	85 cm	65 cm	7°

Fig. 9. The rates of movement and characteristics of five ploughing blocks on the Moor House Reserve

a block lifted perpendicular to the ground surface by frost heave will due to thawing settle a little below its former position (Fig. 10B). Other things being equal, the amount of displacement will increase in proportion to the slope angle. Thirdly, movement will to some extent be the result of a block's ability to store and conduct heat (Fig. 10C). This property is illustrated by pl. 2 which shows that blocks are relatively quick to loose their snow cover. Also interesting is the way in which melting on the downhill side of the block has far exceeded that directly upslope of it. This is due to water from melting snow which has run off the block's downslope edge and has thereby accelerated thawing of snow with which it came into contact. Sometimes, a comparable result is produced by wind when it removes snow from a block and its mound quicker than from surrounding, less exposed parts of a slope. Hence, the area immediately downhill of a block often looses its snow comparatively early and is therefore exposed to freezing and thawing for longer; this facilitates migration. Snow and water also contribute to movement by gathering in the depression upslope from a block (Fig. 10D). Often, this depression traps a greater depth of snow than do areas nearby and it therefore usually contains an abundant source of moisture for long periods in the colder months of the year. Particularly during spring, it is not uncommon to find that water has collected to a depth of several centimetres just behind a block. Thus, when examined on March 17th 1965 ploughing block depressions on Little Dun Fell had water (or ice) up to 20 cm deep standing in them. The freezing of water creates expansion and as a result pressure is exerted on the back of a block thereby assisting its downslope migration. Lastly, it has been claimed (eg. by Johnson and Dunham, 1963) that movement is facilitated by the sliding of a block on the upper surface of frozen ground which lies directly beneath a rather wet and fluid active layer (Fig. 10E).

The preceding remarks underline that cryergic activity is the dominant cause of ploughing block movement. Hence, where such action is weaker, as in temperate regions, blocks travel more slowly and have associated with them less pronounced microfeatures[12].

TIME OF MOVEMENT

Most ploughing blocks described in the literature or noted during the present survey are the result of *current* periglacial action. Quantitative evidence has been given which proves this for the Moor House area. Such evidence

[12] Whereas the annual displacement of ploughing blocks can frequently be measured in centimetres, that of creeping boulders in temperate environments is at most only a few millimetres.

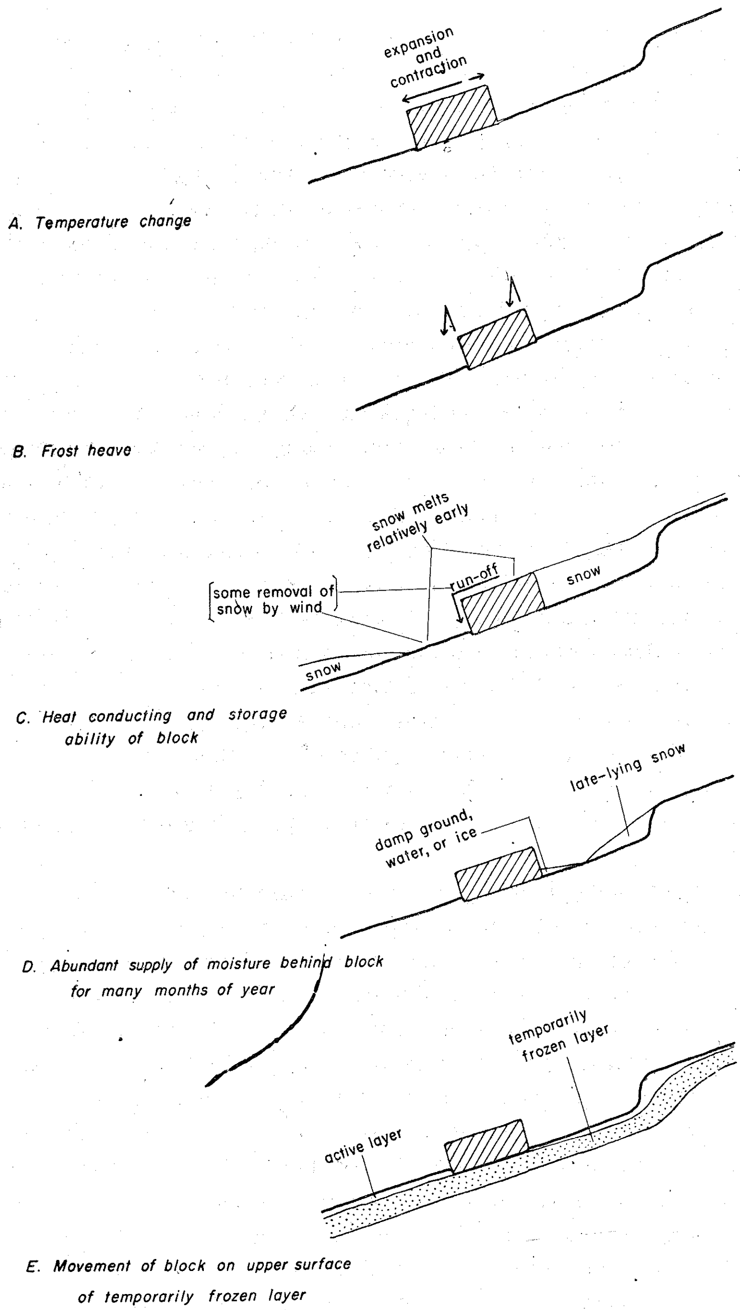


Fig. 10. Causes of ploughing block movement. For clarity mounds have not been included in the diagrams

constitutes the best proof that a block is active. In some cases, however, other types of data will verify this almost as well. For example, Högbom (1914, 1927) found ploughing block depressions which had been diverted by fairly young trees, thus indicating present-day movement. Similarly, if the floor of a depression more or less lacks vegetation, this is usually a sign of recent movement. On the other hand, the reverse is not necessarily true, as vegetation in some periglacial regions is quick to colonise bare ground. Thus, at the head of the Knock Ore Gill valley (altitude 730 m) a block movement of 6.4 m occurred (presumably by rolling and/or bouncing) during the winter of 1964–5. The place where movement started was initially marked by a bare patch 30 cm across. However, by summer 1969 this had been totally covered with vegetation. It therefore seems that a block can move a few centimetres *per annum* and yet have a depression whose floor exhibits no significant bare patches.

Having established that a block is active, one next wishes to know the time(s) of year when movement is likely to occur. According to some writers (eg. Johnson and Dunham, 1963), this will be mainly in spring. Unfortunately, no quantitative information is available to support these remarks. However, data illustrated in Fig. 11 prove that block movement is far greater during the colder part of the year than in summer, although they do not indicate the relative amounts of movement during autumn, winter, and spring. Clearly, such a breakdown of events is possible only by detailed observations of block movement throughout the year, together with a close scrutiny of any high-level temperature records which may be available. Until this has been done, it remains to be proven that movement in spring is greater than in autumn or winter.

Indications that a ploughing block is fossil are difficult to obtain. Generally, the ephemeral nature of mounds and depressions makes it unlikely that they will survive for long in a fossil condition. Moreover, several possible indications that a block is inactive were found to be misleading. Thus, it has been claimed that the existence of lichens on debris is proof of stability. Yet, at Moor House blocks whose upper surfaces are lichen-covered are being displaced by several centimetres *per annum*. It therefore appears that in such cases lichens indicate merely the stability of a surface (ie. that it is not undergoing gelifraction or being overturned) but they do not prove stability of the block as a whole. Likewise, the existence of vegetation on the upper surface of a block might be regarded as a sign that it is fossil. Yet, on Knock Fell vegetation-covered blocks occur which have small, though fresh gaps behind them, thus proving their recent movement. Hence, it seems that immobility of a block can only be demonstrated satisfactorily by measurement over a long period. Using this technique it has, for example, been shown that one large block on a 7° slope near the top of Little Dun Fell is virtually inactive, though it did

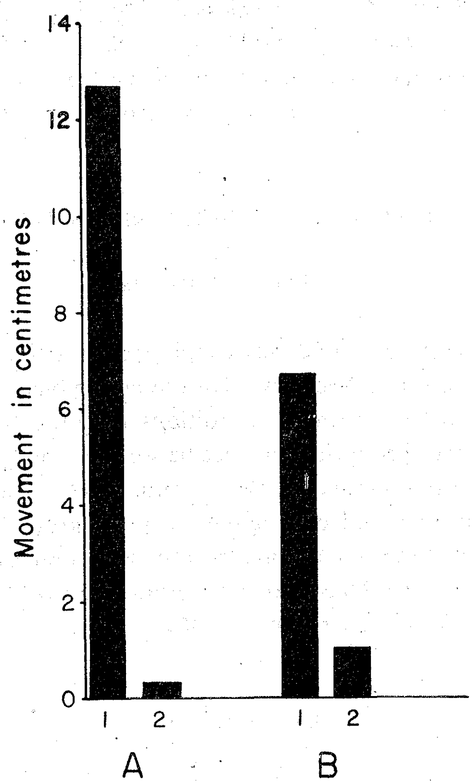


Fig. 11. The movement of ploughing blocks at different times of year

A 1 – combined movement of 5 ploughing blocks at altitudes of 685–820 m on the Moor House Reserve from mid-August 1967 to early April 1968; A 2 – combined movement of the same 5 blocks from early April to mid--August 1968; B 1 – combined movement of 4 ploughing blocks on the Moor House Reserve from mid-August 1968 to early April 1969 (a fifth ploughing block was under a deep snowdrift in April 1969 so its movement could not be recorded); B 2 – combined movement of the same 4 blocks from early April to early August 1969

move slightly between August 1968 and April 1969 (block 5 in Fig. 9). Clearly, it will be just such a large block on a gentle slope which is among the first to cease moving should there be a general decrease in the intensity of frost action. As such a decrease has occurred during the last hundred years, a few of the larger blocks on gentle slopes in north-west England may have been rendered inactive, except perhaps under severe conditions. They may therefore be described as fossil in the sense that most of the movement which formed their associated microfeatures probably occurred during the Little Ice Age. Climatic amelioration since then has produced widespread glacier retreat and it seems reasonable to imagine that it might also have retarded or in some cases halted ploughing block movement. On the other hand, to suggest without concrete evidence that what are still well-developed ploughing blocks might pre-date the Little Ice Age is unwise. No doubt, blocks did move by ploughing in the Vistulian/early Flandrian, but the subsequent destruction of their associated microfeatures prevents us from identifying them with certainty.

FACTORS AFFECTING PLOUGHING BLOCK DISTRIBUTION

GENERAL COMMENTS

As there are several types of cryergic region, each with a distinctive assemblage of landforms, it is not surprising that ploughing blocks are well developed only in certain of these. Optimum conditions for their formation appear to exist when there is the appropriate balance between intensity of cryergic activity, block dimensions, and nature of the terrain. Such conditions occur most frequently in less severe periglacial regions where the ground is only temporarily frozen. As yet, ploughing blocks have been observed chiefly in the mountains of Europe, but are undoubtedly forming elsewhere (eg. in North America – Antevs, 1932; in Asia – Gorbunov, 1969).

NATURE OF THE TERRAIN

Ploughing blocks usually occur on grassy slopes where there is sufficient, though not necessarily abundant moisture. On the other hand, they are rarely found in areas which lack vegetation. This is because vegetation binds a slope and may cover smaller debris, thus retarding its movement; larger material (ie. blocks and boulders) which protrudes above the surface can at least partly counteract this retarding effect and is therefore able to move faster than its surroundings. Where, however, vegetation is absent, smaller fragments move more freely and can travel faster than blocks (see later remarks on brake blocks). The only type of slope on which vegetation militates against ploughing block formation is the one possessing bushes and/or trees.

Composition of the regolith is also important. If ploughing blocks are to form, slope debris must be of at least two contrasting sizes – blocks on the one hand and finer material on the other. In addition, the regolith must have an adequate thickness, rock outcrops should be few or absent, and individual blocks must be some distance apart to provide room for movement and for the creation of mounds and depressions. Where spacing is closer than desirable, block 'collisions' may occur, as on Little Dun Fell.

Another factor influencing the distribution of ploughing blocks is slope angle. Though the optimum gradient for periglacial block movements varies with the situation, there will be a range of values which are especially favourable to ploughing block development. The limits of this range have not been fully established but are thought to lie between about 5° and 50° and are probably from around 10° to 30°. Thus, ploughing blocks on the Moor House Reserve can occur on gradients of as little as 4° or 5°, while in other areas they have been found on slopes as high as 40° to 50° (de Martonne, 1920; Capello, 1955a; Furrer, 1965a; Gentileschi, 1967). Naturally, these figures are extreme, rather than optimum values. For an ndication of the latter the work of Furrer (1965a) is useful. Of 120 ploughing blocks which he examined in the Swiss Alps, 85% were on 9° to 32° slopes. Likewise, just over 85% of the 500 blocks studied on the Moor House Reserve occur on 10° to 29° slopes (Fig. 2I). Again, many of the blocks noted by Höllermann (1964, 1967) and Stingl (1969) were on slopes with similar gradients. Despite the concordancy of these figures, their acceptance as optimum slope values for ploughing block development must await further investigations. Above all, it must be conclusively shown that these values do not merely represent the most frequently occurring slope angles in the areas examined. One indication that this is not so comes from the fact that as gradient increases so does the risk of slope failure and the tendency for a block to roll or bounce rather than to plough; in addition, it is only with much greater difficulty that mounds and depressions can be formed and maintained on relatively steep terrain. Likewise, owing to the severity of frost required for movement, very gentle slopes are also unlikely to provide optimum conditions for the development of ploughing blocks.

ALTITUDE AND LATITUDE

Furrer (1965a, b), Höllermann (1964, 1967), and others have demonstrated that ploughing blocks occur at lower levels in a vertical zonation of present-day frost phenomena and are therefore of value in defining the lower boundary of existing cryergic regions in mountain areas. Similar block movements in north-west England also extend to relatively low altitudes (Hay, 1937, 1942; Tufnell, 1969). Thus, while ploughing blocks have been studied mainly in Europe, they are probably forming towards the base of less severe periglacial regions elsewhere. Consequently, the altitudes at which they occur will decrease from the equator polewards.

The lower altitudinal boundary of ploughing block occurrence is determined by a reduction in the intensity of cryergic activity, while the upper limit results from excessive periglacial action. This breaks up the vegetation cover and can lead to the development of permafrost. The significance of vegetation has already been discussed: permafrost may slow down, rather than facilitate, block movement. Thus, any large fragment which is even partly embedded in continuously frozen ground will be held as in a vice and thereby prevented from moving (Högbom, 1914). However, smaller fragments which are wholly contained within the active layer will also be incorporated in its movement. This explains why blocks in some areas of permafrost travel less rapidly than do smaller fragments. Evidence therefore suggests that well-developed ploughing blocks are rare in high latitudes, at relatively high altitudes, and in some continental interiors.

PHENOMENA RELATED TO PLOUGHING BLOCKS

CREEPING BOULDERS

Like ploughing blocks, creeping bulders move faster than does the ground surrounding them. As a result, they too push up a mound before them and leave a depression to their rear. However, since creeping boulders occur in temperate and tropical environments (Sharpe, 1938), frost is not the principal cause of movement. Instead, this results from a variety of factors (wetting and drying, all kinds of temperature fluctuation, vegetation, etc.) none of which is particularly dominant. On the other hand, movement is sometimes largely controlled by one factor other than frost. This is the case, for example, with sinking boulders, whose migration is principally the result of excessive slope moisture (Fig. 1C) (Tufnell, 1966).

An important problem with creeping boulders is that of distinguishing them from ploughing blocks, especially in areas near the lower boundary of the current periglacial zone. Unfortunately, the only satisfactory method of establishing a block's identity, that of plotting movement against changes in climate, is both tedious and protracted. Much quicker, though less accurate, is to note the features associated with a moving block. The difficulty with this approach is that the origins of these associated features may also be in doubt. For example, thufurs can be similar in appearance to various types of non-periglacial hummock, while mass-movement terraces in both cryergic and temperate environments can be deceptively alike. Another useful, though not infallible guide to a block's origins is its relationship to the lower boundary of an area's periglacial zone. Naturally, the problems of this approach increase the closer one gets to the boundary, since this is in reality an area of transition. Therefore, however accurately one tries to define such a boundary, there will be blocks in a periglacial zone whose movement is not primarily frost controlled, while others at lower altitudes may have been shifted downslope chiefly by winter frosts. Lastly, a guide to the causes of block movement is sometimes given by the form of mounds and depressions; where this is clearly developed the block has often moved by ploughing, but if it is faint this probably implies movement under temperate conditions. Again, the technique is not infallible, since blocks at rather low altitudes occasionally have pronounced mounds and depressions associated with them, while those on higher ground may develop only weak microfeatures.

BRAKE BLOCKS

Whereas ploughing blocks and creeping boulders move faster than their surroundings, other blocks can travel more slowly than the adjacent parts of a slope. Because of this, they retard the downhill migration of smaller debris and may therefore be called *brake blocks*. Such features usually have a mound of stony fragments upslope of the block and a depression just below it (Fig. 1A). Occasionally, they may have a second mound (of fine material) which is located along the downslope edge of the block. This type of occurrence clearly indicates that the block is in motion, but is travelling less rapidly than are the smaller, stony fragments (Tufnell, 1966).

In contrast to ploughing blocks and creeping boulders, brake blocks develop well on vegetation-free ground and can often be regarded as a form of talus creep. Hence, they have been noted on scree at varying altitudes in north-west England; they have also been found in high latitudes (eg. in Greenland – Boyé, 1950) and at high altitudes (eg. in the Alps – Höllermann, 1964). Conditions suitable for brake block development occur in both temperate and periglacial regions.

The main reasons why blocks travel more slowly than the adjacent ground are the existence of permafrost at or near the surface and the lack of vegetation to bind a slope.

CONCLUSIONS

Research has yet to give a balanced view of the periglacial environment. In the past the tendency has been to concentrate investigations on selected phenomena with a resultant failure to examine properly certain other important frost features. Thus, our understanding of ploughing blocks is very limited, even though such features are relatively easy to investigate and despite their widespread occurrence in certain types of periglacial environment. Moreover, ploughing blocks are of considerable value as indicators of both periglacial slope movements and the less severe types of cryergic region. The most important contributions to our understanding of such block movements will probably come from quantitative work of the type illustrated in Figs. 2, 3, and 9 of the present article and of the kind described in Caine's (1968) study of Tasmanian blockfields.

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