SOME WEICHSELIAN FOSSIL FROST WEDGES FROM EAST CHESHIRE

by

Peter Worsley

Summary

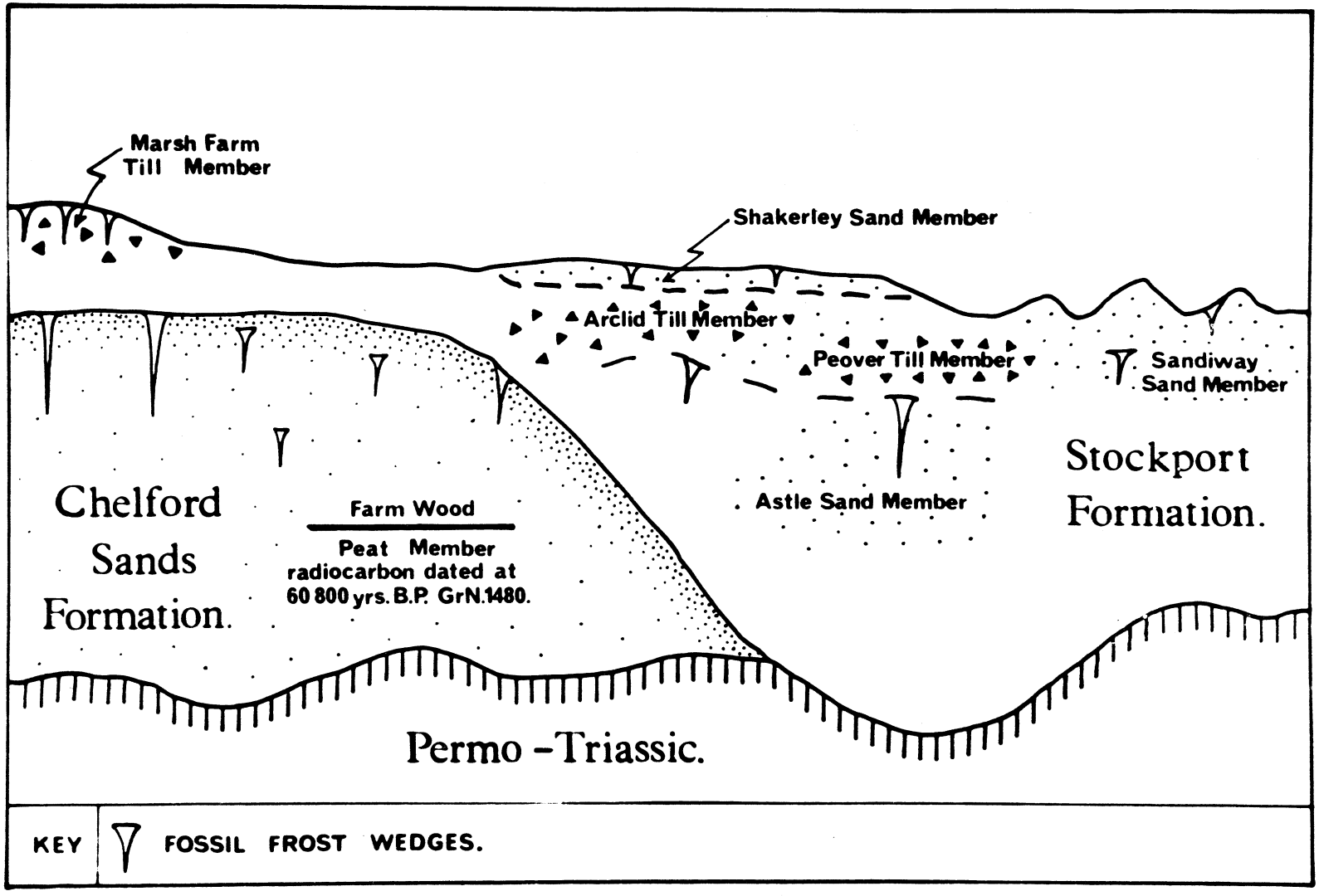
The occurrence of intra, inter and supra-formational horizons of frost wedge growth within alluvial and till deposits are recorded. They are interpreted as signifying recurrent permafrost episodes within the last glaciation.

Introduction

An examination of present day areas underlain by more or less continuous permanently frozen ground or permafrost, often reveals a polygonal pattern on the ground surface. Excavation shows that, beneath the zone forming the polygons, there is invariably a wedge shaped structure narrowing with depth and usually ending in a sharp apex. Close observation of these areas demonstrates that the growth of the features is related to the seasonal thermally induced contraction and expansion within the upper part of the permafrost. The response to the contraction stresses is a crack consequent to the rapid temperature fall with the onset of winter. It is the cracking which produces the polygonal ground forms and, once initiated, the annual rupturing occurs within the same narrow zone. The open cracks are liable to be infilled by the surface material whether it be ice, water or rock particles. The most common infill is ice and, in these instances, it is termed an ice wedge. Upon climatic amelioration the annual cracking will cease, the ice will melt, and the void so produced will be filled by material being slumped down and blown in from the ground surface. The end product of this process is a cast of the former ice body or, more aptly, an ice wedge pseudomorph. Not all wedges were originally occupied by ice, however, and in some instance the contraction crack is infilled directly by clastic material, often sand. These latter types are called sand wedges and characterise arid environments. It is not always possible to identify the original wedge type and the 'umbrella' term fossil frost wedge embraces all the genetic varieties.

During an investigation of the Pleistocene sequence in the East Cheshire Plain, fossil frost wedges were discovered at several localities. No published records of such structures in the area are known, and, because palaeoclimatological implications arise from the finds to be described, it was considered that they should be recorded, together with some comment on their genesis.

Recent investigations, in areas currently experiencing a climate which permits frost wedge growth, have shown that compositionally a continuous series of wedges, with ice and sand or some other clastic material as end members, exists (Black and Berg, 1964). The terminology of frost wedges as used in the



Text-Fig. 1 Schematic diagram to illustrate the stratigraphical relationships of the Quaternary sequence in east Cheshire and the horizons of frost wedge growth.

literature is rather confusing, because terms strictly applicable only to present day active forms have been used to describe fossil forms. Poser (1947) has suggested a classification of fossil frost wedges based upon their size in cross section. The two major parameters utilised are the breadth and depth dimensions, resulting in the 'frostspalten' class having a 1 - 3: 10 - 20 dcm. ratio and the 'lehmkeile' class with a 6 - 18: 18 - 80 dcm. ratio. Structurally the 'frostspalten' are simple cracks and do not exhibit any upfolding of the immediately adjacent strata. On the other hand, the 'lehmkeile' are more complex and commonly have produced marked disturbances to the enclosing material. It is apparent from the field data that dimensionally the Cheshire examples are not compatible with this classification, although basically there are two morphological types - very narrow zones without any appreciable taper and stubby 'V' forms. However, evidence from a comparatively small geographic area is insufficient to erect a viable universal classification and, in the absence of any comprehensive scheme, the wedges to be described (whether they be fossil ice, sand or intermediate types) will for the present be referred to jointly as fossil frost wedges.

Quaternary Stratigraphy of East Cheshire

A revised interpretation of the Quaternary stratigraphy of the Cheshire-Shropshire Basin has been outlined by Boulton and Worsley (1965). The fossil frost wedges to be considered occur at inter-, infra- and supra-formational stratigraphic horizons and this leads to a convenient grouping for the purposes of description. Litho-stratigraphic divisions will be used in accordance with the terminology proposed earlier by the writer (Worsley, 1966).

The stratigraphic relationships between the various member and formational litho-stratigraphic units are shown schematically in Text-fig. 1. Above the solid Permo-Triassic, both the Chelford Sands Formation and the Stockport Formation are assigned to the Weichselian Stage. This stage is equivalent to the 'last' major glacial phase in the Pleistocene and is often rather inappropriately referred to as the Wurm in Britain. The results of radiocarbon dating would indicate that this cold period lasted from approximately 70,000 years B.P. to 10,000 years B.P. In the area under discussion it is likely that the ice advanced to the limit shown in Text-fig. 2 about 20,000 years B.P. at the same time as the 'last' glaciation maximum ice advance was occupying the Brandenburg Moraines in north Germany.

Description and Interpretation

1. Intraformational wedges

(a) Chelford Sands Formation

For a reason which is not fully understood, the fossil frost wedges are not ubiquitous throughout the formation. When the sites are plotted geographically, there arises a distribution pattern that suggests that the incidence of wedge growth increases away from the Pennines. However, the number of sites with major exposures is only six, which is insufficient to make any significant deductions from any trend which may be apparent.

(i) Taxmere Quarry, Arclid (SJ 777623)

Up to 10 m. of Chelford Sands were seen at outcrop in the period 1963-66. As is usual with unconsolidated sand deposits, the sedimentary structures are visible only after a face has dried out and been subject to differential etching by sand blast. Once these conditions have been fulfilled, the Arclid sections invariably display a magnificent set of intraformational fossil frost wedges, only up to 5 cm. in width but ranging from 10 to 250 cm. in depth (see pl. 22 fig. 1) The wedges are extremely slim, there being very little infill, and the casts are manifested by a minor down -sag of the stratification and a tendency to be more coherent when wind etched. Without exception, the wedges extend downwards from the interface between successive sets of cross-strata. The usual angle of penetration is invariably in the range 65 - 90 degrees to the horizontal. As most of the set boundaries are erosional, it is unlikely that many wedges display their

full development, since the upper parts may have been truncated during successive periods of sediment influx. This evidence contributes to the interpretation of the sedimentary environment, the dynamic aspects of which appear to have been occasional brief high energy fluvial episodes.

(ii) Dingle Bank, Withington (SJ 808717)

Although not so common in total as at Arclid, the Dingle Bank examples show a greater variety of wedge morphologies and structures. The narrow wedge type described above occurs sporadically and to a similar range of development. Another morphological type consists of a gentle downwarp of the plane bed stratification into the fossil crack zone. This fold was of gentle slope and low amplitude and in one example the dimensions were 25 cm. and 5 m. respectively for a set 5 cm. thick. The most interesting type, illustrated in pl. 22 fig. 2, possesses a series of step faults with small displacements throwing towards the axial zone. Immediate thoughts on the genesis of the structure suggests that the sands may have been in a state of some cohesion, as apparently the sands yielded to the stress field by "brittle tectonics". This interpretation must, however, recognise the results of experimental work on the deformation of unconsolidated materials as first reported by Rettger (1935). This and subsequent work has demonstrated that the formation of faults in incoherent sediment is compatible with a state of little cohesion between the constituent particles. Hence there is no necessity to invoke temporary phases of cohesion in the sands whilst they faulted. Along the axial trace there is very little external infill and thus the void, when created, was infilled by successively faulted increments of the adjacent sediments. A reconstructed sequence of events, compatible with structural evidence, would be:-

(i) cessation of sediment supply;

(ii) ice wedge growth;

(iii) melting of the vein ice both downwards and inwards from its vertical sides whilst the adjacent sediment retained some cohesion.

(iv) an unbalanced shear couple between the void and confining sediments;

(v) equilibrium being restored by multiple faulting;

(vi) renewed sediment influx over the wedge site;

(vii) final ice dissipation and minor readjustment involving the slight sagging of the superincumbent sediment.

Fossil wedges exhibiting a similar structural pattern have been recently described by Brüning (1964) from the Hanover area, West Germany, with breadth/depth ratios of 0.70: 1.60 m. and with a plan geometry of polygons 5 - 6 m. in diameter, though occasional forms occur with twice these dimensions.

(iii) Farm Wood, Chelford (SJ 810730)

In comparison with the above two localities, fossil wedges are rare and those found are of the Arclid variety, displaying similar sedimentary relationships.

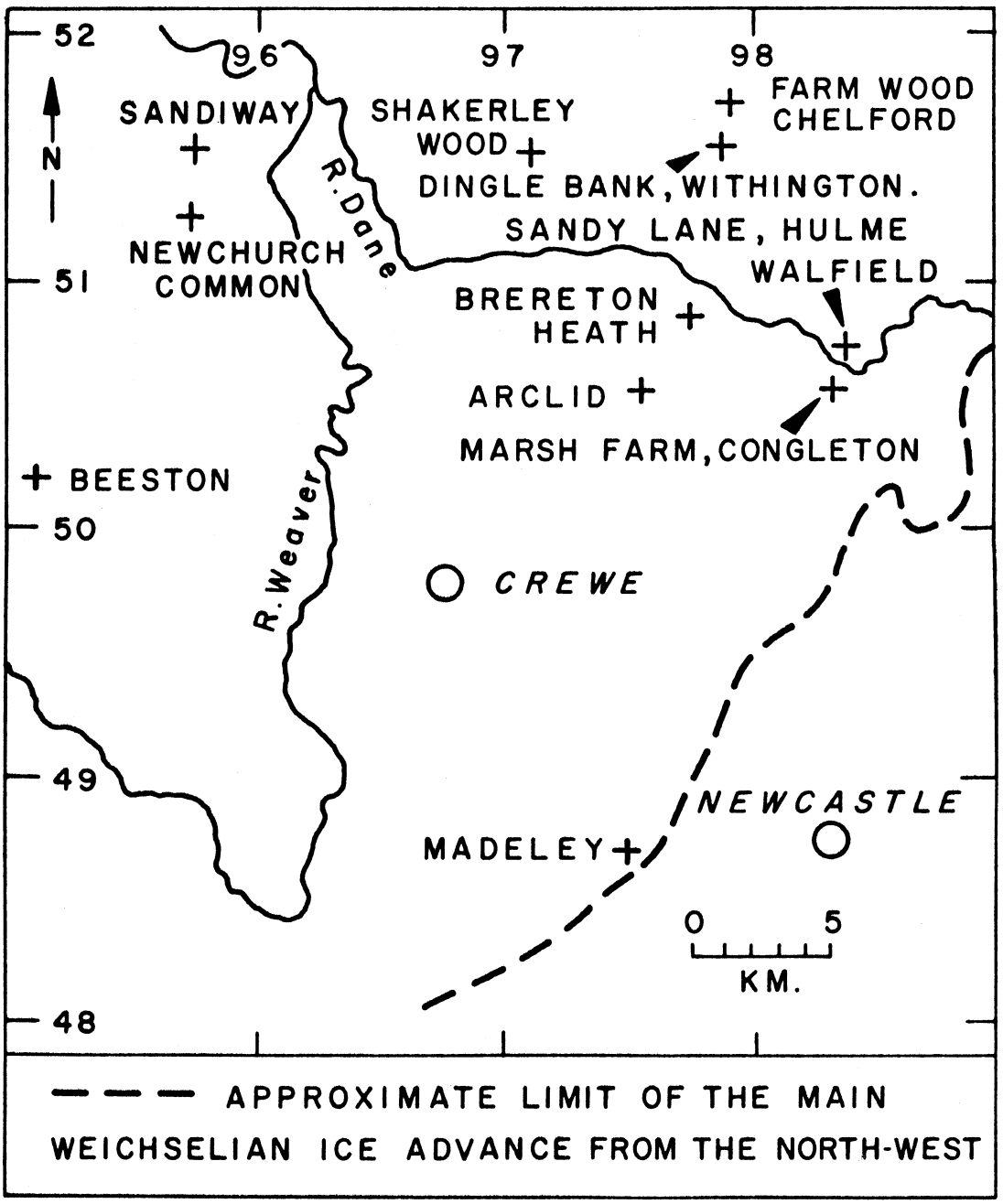
(iv) Marsh Farm, Congleton (SJ 846625)

Fossil frost wedges are exceedingly rare and, when found, correspond morphologically to those described from Arclid.

(b) Stockport Formation

(i) Farm Wood Quarry, Chelford (SJ 810730)

In a preliminary re-interpretation of the stratigraphy of this site (Boulton and Worsley, 1965)



Text-Fig. 2 Location map of the sites exhibiting fossil frost wedges.

the Stockport Formation was described as a boulder clay-sand complex overlying pebbly outwash sands. This lithological subdivision is supported by the occurrence of fossil frost wedges at the interface between the two members. One example is illustrated in pl.23 fig.1, where it is seen that the wedge is 96 cm. wide at the top narrowing to 15 cm. for the lower part. It is not a simple 'V' form but has a blunted apex. The infill consists of medium grained red-coloured sand in the lower half; in the upper part it is predominantly a red-brown clay till. This infill contrasts with the surrounding Astle Sand Member, which consists of light brown and grey sands with the cross stratification indicating current flow to 210° N. The bedding is emphasised by concentrations of comminuted coal debris in bands; the sands adjacent to the wedge are step faulted, throwing a few cms. towards the axial plane. Limonitic enrichment of some bedding planes and shear planes is seen to post-date the wedge formation. No till lenses or armoured mud balls have been found in these sands and they thus appear to be aggradation deposits prior to the arrival of the glacier, which deposited the complex or Peover Member. No wedge structures have been detected in the overlying Peover Member or any other sediment deposited directly from the ice in the area under consideration. The presence or otherwise of wedges may thus be an aid in distinguishing these two members.

(ii) Madeley, Staffordshire (SJ 773454)

During the construction of the new County of Stafford College of Education at Madeley, excavations were made which revealed an intraformational frost crack penetrating cross stratified poorly sorted sands and sealed by a gravel-rich till. After a preliminary inspection of the section, an observer might reasonably suspect that, judging from the surface angle of slope, the till was a solifluxion deposit. However, an analysis of the fabric at a station just above the till/sand contact and approximately 2 m. from the surface produced a marked preferred orientation along a west-east bearing perpendicular to the regional slope. The underlying sands displayed a wide variety of sedimentary structures and, in particular, enclosed irregular masses up to 1.5 m. in diameter within the cross strata. A reasonable interpretation would be that these large clasts were emplaced as frozen blocks of sediment by a fluvial system. Following this event the alluvial succession became frozen under permafrost, and the fossil frost wedge developed on the exposed upper surface. The frost wedge measured 10 cm: 80 cm. and was infilled by material indistinguishable lithologically from the overlying till. Indeed the till base was seen to sag over the wedge, which would suggest that it still had ice in it at the time when the site was covered by the till. Beyond this, the date of infill emplacement is indeterminate. The long axes of the greater than granule-sized material possessed a marked concordance with the wedge sides, most being vertical.

(iii) Newchurch Common (SJ 755688)

For most of its extent the Delamere Forest covers a complex alluvial outwash fan, with an upper surface which declines gently to the south. The major lithology is a well sorted medium to coarse grained sand, with occasional gravel lenses. At the Newchurch Common locality, excavation of the top 3 - 4 m. above the ground water table revealed rare frost wedges. A typical form was 90 cm. wide, narrowing to a sharp apex at 1.7 m., developed in sands with large scale cross stratification. Above the overlying material was a well rounded gravel and this supplied the infill media, which showed a collapse fabric. Again, this find would suggest that a given horizon in the outwash sediment was for a period subject to sub-aerial and permafrost processes.

II. Interformational wedges

Chelford Sands - Stockport Formations

(1) Taxmere Quarry, Arclid (SJ 777623)

At this locality a wedge of till was seen to penetrate downwards from an unconformity into the Chelford Sands Formation. The wedge averaged 6 cm. in width and was some 35 cm. in depth, terminating in a blunt apex which curved off centre (see pl.23 fig.2). Its axial trend could be traced for

Fig 1. Intra-formational fossil frost wedges, Taxmere Quarry, Arclid.

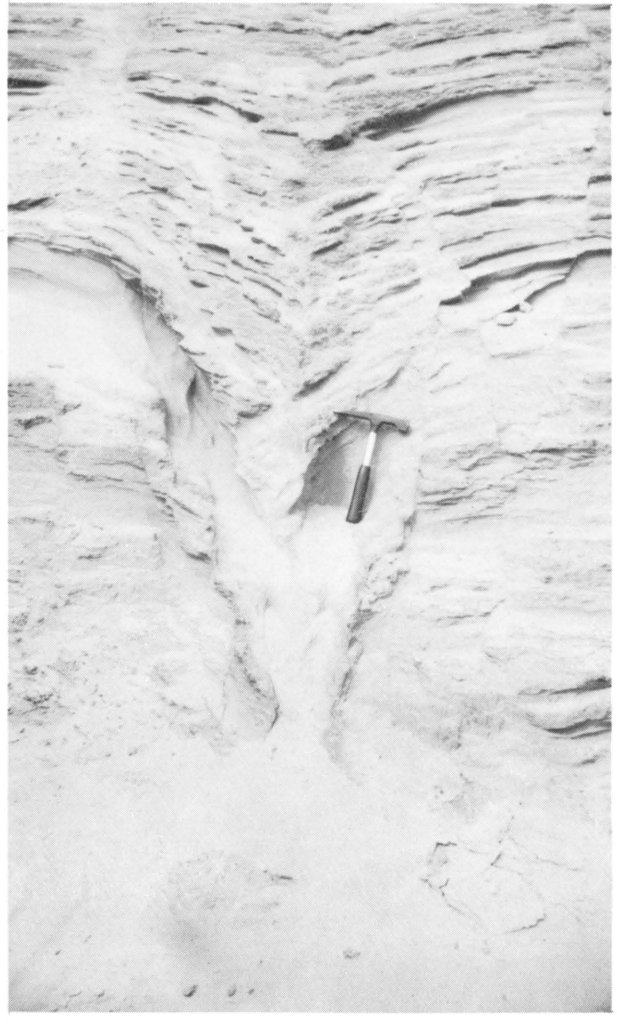


Fig 2. Intra-formational fossil frost wedge, Dingle Bank Quarry, Withington.

over 75 cm. along a bearing of 50° N beyond which extensive excavation would have been necessary to prove its further extension. The axial plane dipped at 80° to the south west. The shear planes in the immediately adjacent sand trended 50° N dipping at 60° to the south west. The significance of this concordance of trend is uncertain, but it could be that, under ice loading, the frozen sands may have adjusted in response to the stress by shearing along the zone of least cohesion (which in this case was parallel to the trend of the frost wedge).

A similar feature, where till projected into underlying interstadial loess, has been described by Horberg (1949). This relationship was interpreted as resulting from an ice advance over frozen ground which had ground ice wedges already developed in it, the subsequent melting of the ice creating a void and permitting the overlying till to enter it. The evidence at Arclid would appear to favour a similar pattern of events. That the Chelford Sands were frozen prior to being over-ridden by the glacier is supported by the lack of any major stratification disturbance immediately below the unconformity. In hand specimen, the till was identical to that forming the overlying Arclid Till Member, being a red-brown calcareous till. Unfortunately the overlying main till sheet had been stripped off at the time of discovery by the writer and hence the wedge infill was not seen in direct contact with the till sheet, but there seems no reason to doubt that it was originally in contact. It follows that the basal till, at least, must have been in a saturated or semi-mobile state at the time when the ice wedge melted, flow probably being facilitated by the interstitial pore water.

(2) Dingle Bank Quarry, Withington (SJ 808717)

As at Arclid, the members of the Stockport Formation are removed to permit the quarrying of the Chelford Sands. This procedure has thus re-exhumed a former landscape represented by the unconformity and, in the period 1962-66, the buried topography has proved to possess an amplitude of relief exceeding 20 m. Considerable parts of the unconformity are essentially planar and concordant with the present day land surface, but on average buried to a depth of 3 m. In these latter areas the unconformity would appear to represent a period of non-deposition only, but during this interval frost structures were developed. From this plane the fossil frost wedges (or cracks) have been seen to penetrate the Chelford Sands to a maximum depth of 5 m. Their presence is confirmed only in exceptionally favourable circumstances when the quarry face has been left in a near vertical state for some months, permitting wind erosion to etch the unconsolidated sands. The deep frost cracks are manifested by a zone not exceeding a few dcm. in width, in which the cross stratification sags downwards or is obliterated. This zone of fracture has been utilised by migrating solutions in the ground water and is often stained by limonite, which gives the zone greater cohesion and visually makes a striking colour contrast with the white sands. As a result, differential wind etching erodes the surrounding sand leaving the more resistant wedge in relief. It proved impractical to establish the crack ground pattern.

The cracks appear to be true fossil frost wedges, the products of contraction associated with deep permafrost. Evidently the palaeoenvironment was predominately arid, for there is hardly any wedge infill. As both these wedges and the Chelford Sands interformational wedges have this latter property in common, it may be suggested that this, in part, is a function of the relatively weak contractional stress in the sands. Also it may be noted that there is a total lack of any signs of stratification upturning along the margins of the cracks; indeed the deformation, if any, is only a slight down-sag into the axial plane. This is interpreted as confirming the initial suggestion that the contractive stresses were weak, for any appreciable expansive force following contracting would inevitably cause upward folding. Usually observers have noted pronounced upturning of the stratification immediately adjacent to deep wedges.

III. Supraformational wedges

(1) Marsh Farm, Congleton (SJ 846625)

An extensive system of fossil frost wedge polygons developed on till has been investigated

at this locality and will be described in detail on another occasion (Worsley, 1967). In this case, it has been possible to determine a portion of the system's plan geometry of irregular polygons besides the vertical wedge morphology. The infill is of sand and it is thought that the wedges are genetically relict sand wedges.

(2) Beeston (SJ 553596)

This quarry, working outwash sands, is capped by a till sheet up to 3 m. thick. A single fossil frost wedge 30 cm. in width, narrowing to an apex at 1.2 m. depth, was seen to penetrate the till. The infill consisted of coarse silt and fine sand-sized material without any visual internal structure.

(3) Shakerley Wood (SJ 553596)

Here an extensive tract of well sorted sands, averaging some 3 m. in thickness, overlies the Stockport Formation. These sands are, in part, thought by the writer to be probably derived from the Chelford Sands Formation, being deposited after the ice dissipation when the western Pennine drainage was re-establishing itself across the newly deglaciated terrain. The high local ground water table results in poor sections when the sands are exploited but one face revealed a frost wedge 90 cm. wide and 1.9 m. deep. Morphologically it was of a broad 'V' form and the infill comprised a material similar to the enclosing media.

(4) Sandy Lane, Hulme Walfield (SJ 855643)

The Sandy Lane Quarry is excavated into the northern flanks of the major east-west trench occupied by the River Dane. At this locality, the upper valley sides are composed of Chelford Sands on Keuper Marl, overlain by a mantle of glacial sediments which thicken downslope. The latter sediments consist of poorly sorted pebbly outwash sands with angular clasts of bedded sands up to 20 cm. in diameter, in large scale through cross-stratified sets. These pass upwards into better sorted material, which appears to be secondarily derived Chelford Sands containing thin sheet-like lenses of material lithologically indistinguishable from till. From the present day land surface of these latter sediments, several fossil frost wedges penetrated downwards, one of which trended 175° N dipping at 72° to the south and extended into the sands to a depth greater than 2 m. Over the exposed section the infill maintained a transverse width of 25 cm. in the upper part, narrowing to 15 cm. towards its base. The base was not seen. Despite the wedge depth and width, no trace of stratification disturbance within the adjacent sediment was detected. Migrating solutions precipitating limonite had moved along the wedge margins, giving it greater cohesion when weathered.

Conclusions

It is essential to appreciate that the Quaternary sequence examined has suffered little diagenetic change and that the sediments are essentially very incoherent. This results in few natural exposures; an observer must therefore resort to quarry sections which are necessarily of a temporary character. The finding of fossil frost wedges is determined by chance, the degree of weathering and, above all, the ability to recognise the structure as such. Many have without doubt been seen previously, but it is likely that they have gone unrecognised. As the sections change rapidly, any list of localities displaying these features must relate to the time of observation only. For the present it can be concluded that, within the Quaternary sequence of East Cheshire, there is good evidence for identifying recurring phases of permafrost by the recognition of the attendant development of frozen ground phenomena. All the sediments described are considered by the writer to be Weichselian in age, and it follows that this duration of time must have witnessed several climatic oscillations on this sedimentary stratigraphic evidence alone.

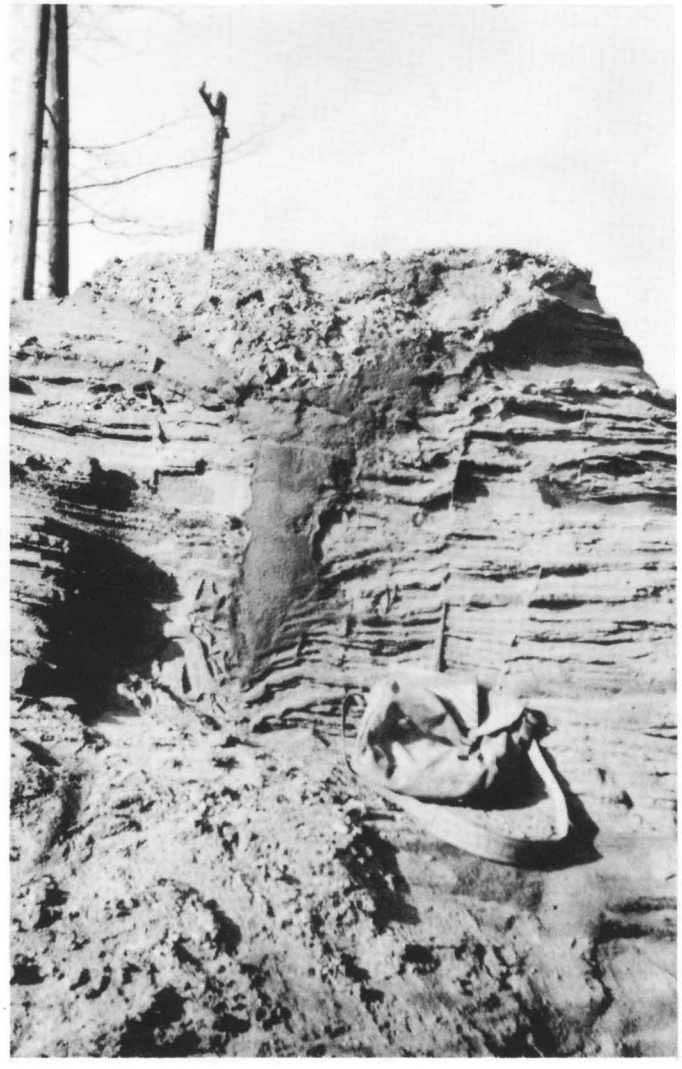


Fig 1. Inter-formational fossil frost wedge, Farm Wood Quarry, Chelford. The overlying sediment has been removed.

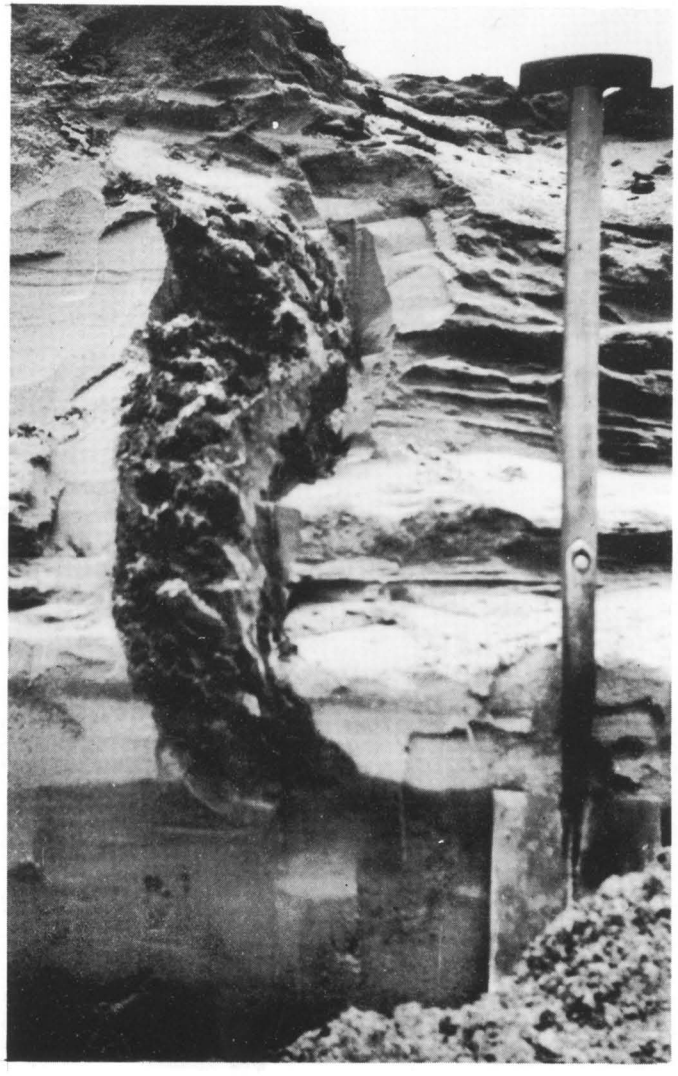


Fig 2. Inter-formational till fossil frost wedge, Taxmere Quarry, Arclid.

Acknowledgements

The field work was done whilst the writer was a recipient of a Science Research Council Research Studentship, which is acknowledged gratefully. Thanks are also due to the various quarry owners for readily permitting access to their property.

Peter Worsley, B.A., F.G.S.,
Quaternary Research Unit,
Department of Geography,
The University,
Reading

REFERENCES

BRÜNING, H. 1964. Kinematische Phasen und Denudationsvorgänge bei der Fossilisation von Eiskeilen. Z. Geomorph. new. ser., vol. 8, pp. 343-50.

BLACK, R.F., and BERG, T.E. 1964. Glacial fluctuations recorded by patterned ground, Victoria Land. Int. Symp. Antarctic Geol., vol. 1, pp. 107-22 (Adie, R.J. editor) Amsterdam. (North Holland Pub. Co.)

BOULTON, G.S. and WORSLEY, P. 1965. Late Weichselian Glaciation in the Cheshire-Shropshire Basin. Nature, Lond., vol. 207, pp. 704-6.

HORBERG, L. 1949. A possible fossil ice wedge in Bureau County, Illinois. J. Geol., vol. 57, pp. 132-6.

POSER, H. 1947. Dauerfrostboden und Temperaturverhältnisse während der Würm-Eiszeit im nicht vereisten Mittelund Westeuropa. Naturwissenschaften, vol. 34, pp. 1 - 8.

RETTGER, R.E. 1935. Experiments on soft-rock deformation. Bull. Amer. Assoc. Petrol. Geol., vol. 19, pp. 271-92.

WORSLEY, P. 1966. A proposed nomenclature for Pleistocene diamictite litho-stratigraphic units in the north east Cheshire Plain. (in press)

1967. Fossil sand wedge polygons at Congleton, England. Geogr. Annlr. (in press).

Manuscript received 6th April, 1966