Biuletyn Peryglacjalny, no. 38, 1999.

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Reading

ICE-WEDGE CAST INVESTIGATIONS IN THE BRITISH ISLES 1849–1949.

A b s t r a c t

Although 1949 was the start of international periglacial research collaboration, during the preceding century, important observations of permafrost related structures were made in the British Isles. Probably the oldest published figure featuring an ice-wedge cast dates from 1848. Later in 1877 a lithograph of an ice-wedge cast in the Fenland area of eastern England was published and from northern Ireland came the first account of gravel dykes' genetically related to freezing. Subsequently, a subterranean erosion mechanism was proposed to explain large wedge-shaped structures at Cambridge. The benchmark study was that of T. T. PATERSON who in 1940 made a comparative study of ice-wedges in Baffin Island and the same Cambridge wedge structures. Concurrently, a glacial sedimentological debate stimulated discussion of the first known Scottish ice-wedge casts. Finally relict ice wedge polygons were identified on air photographs.

INTRODUCTION.

This paper documents the early history of relict permafrost science in the British Isles. The notion of cold climate processes independent of glaciation per se has prevailed since at least the 1830's when Sir HENRY DE LA BECHE, the founder of the Geological Survey, first introduced the old Cornish miners term 'head' to describe the facies related to relict sheets of solifluction materials which draped much of the landscape in south west England. Palaeopermafrost related sedimentary structures have been periodically reported in the literature by geological field workers for some one hundred and fifty years. Here we shall focus upon the findings and interpretations made of such structures during the first century prior to the formal internationalisation of periglacial research in 1949. Most of the sources to be considered were overlooked in the earlier review by FITZPATRICK (1956). The locations of the sites mentioned in the text may be found in figure 1.

Unsurprisingly, the prevailing 'conventional wisdom' at the time of publication influenced the interpretation of the sedimentary structures

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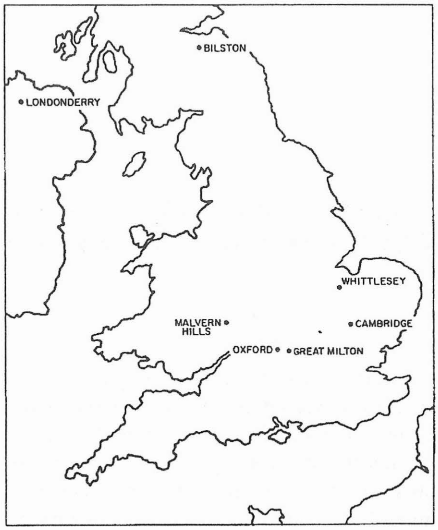


Fig. 1. Location map of the various wedge sites discussed in the text

which are now considered to be indices of relict permafrost. Not until the twentieth century was ground freezing proposed as a causal factor in the formation of wedge structures. The major breakthrough in understanding came in 1940 when T. T. PATERSON published the first comparisons, based upon personal experience, between ice-wedges in a contemporary permafrost environment and relict phenomena of Pleistocene age.

PIONEERING OBSERVATIONS

JOHN PHILLIPS was a nephew of WILLIAM SMITH the founder of stratigraphy, and a major advocate of marine erosion as the principle agency of landscape formation. For a time he worked for the embryonic Geological Survey and under the survey's auspices authored an account (PHILLIPS, 1848) of the Geology of the Malvern Hills in the West Midlands of England. In the current context this volume is of importance in that it contains a sketched section which appears to show an ice-wedge cast although the structure per se was not commented upon (see Fig. 2). This may be the oldest published record of such a relict structure in the world.

S. B. J. SKERTCHLEY was another early geologist who probably unwittingly observed true ice-wedge casts in eastern England. In a lithograph (SKERTCHLEY, 1877, Fig. 20) he illustrated a section in the Whittlesey Gravels which are typically around 3 m thick over the Jurassic bedrock. These gravels form a capping to an outlier rising some 9 m above the

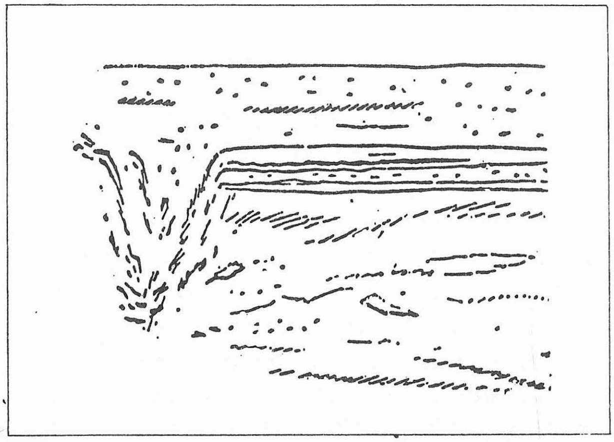


Fig. 2. A possible ice-wedge cast as originally figured by JOHN PHILLIPS in 1848

surrounding Fenlands. In the drawn face below a capping of 'loes--likeloam', a narrow but convincing epigenetic ice-wedge cast descends through a gravel succession and in all probability terminates in the underlying Jurassic Oxford Clay (see Fig. 3). Much more recently, CASTLEDEN (1980) has identified intraformational ice-wedge casts in very close proximity to SKERTCHLEY'S original site, thus giving confidence in the interpretation of the original structure. These observations are of significance as the exposed gravels form part of a widespread dissected formation of sandy gravels which occur extensively along the western margins of the Fenland in eastern England. These sediments appear to date from the Last Cold Stage (Devensian/Vistulian) and the cold stage

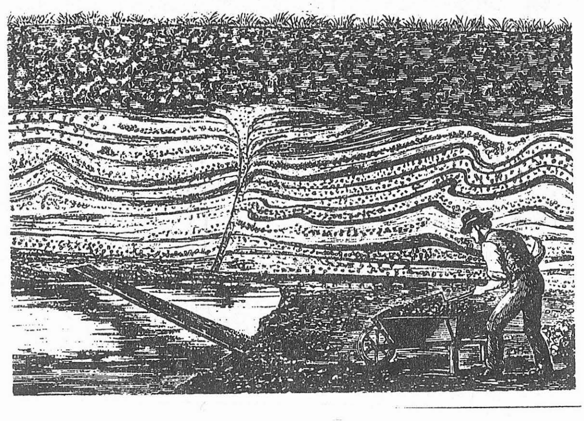
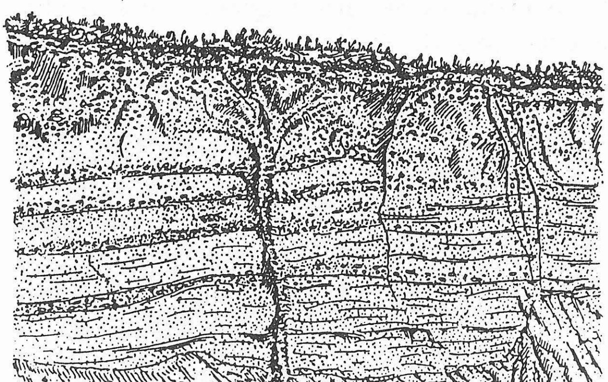


Fig. 3. An epigenetic ice-wedge cast descending into the Whittlesey Gravels. This was a lithograph in SIDNEY SKERTCHLEY's 1877 Geological Survey memoir on the Geology of Fenland

preceding the Last Interglacial (Ipswichian) when they formed a complex of aggrading low angle alluvial fans which extended into what is now the Fenlands during times of low global sea level. These palaeofans currently provide the best exposures of ice-wedge casts and related structures in Britain, as numerous aggregate quarries provide several kilometres of constantly changing exposures (WORSLEY, 1987).

CONCEPT OF FROZEN GROUND

A member of the Irish Geological Survey, J. R. KILROE (1908) described what he termed a 'dyke' (fissure) in a pit excavated into the side of a kettle hole within an area of hummocky dead-ice terrain related to the Last Cold Stage. The significance of the description of this structure in the context of the historical development of glaciology has been highlighted by COLHOUN (1970). The pit exposed unconsolidated cross stratified near horizontally bedded glaciofluvial sand and gravel. He was particularly struck by the clean contact between the infilled fissure structure and the surrounding host sediments. To understand this he felt obliged to suggest that the host materials must have behaved in a solid manner when the infilling of the fissure occurred. This necessitated the host sediments being frozen. His drawing made from a photograph (see Fig. 4) shows that the fissure opens out just below the land surface and lateral to this the sediments appear disturbed in a similar fashion to those of relict active layers. This hints that the fissure was epigenetic and a true ice wedge cast rather than a soft sediment deformation structure.



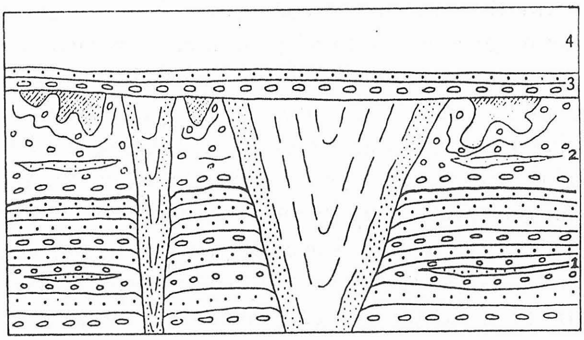
Dyke of gravel in stratified sand and gravel, Caw (from a photograph.)

Fig. 4. The postulated 'frost crack' in glaciofluvial sediments near Londonderry, northern Ireland described by J. R. KILROE in 1908

THE CAMBRIDGE WEDGE CONUNDRUM

J. E. MARR, Professor of Geology at the University of Cambridge, had a particular interest in Quaternary geology and physiography, although he is mainly associated with research in the English Lake District. Nevertheless he promoted studies of his own neighbourhood and MARR (1919) gives the results of a 10 year long investigation of the Pleistocene deposits of the immediate vicinity of Cambridge. In this he recognised an 'ancient channel' at the elevation of the interfluve between the River Camb and the adjacent tributary valley to the west. The surface of the channel infill corresponded with the highest terrace surface and the base was cut into Cretaceous bedrock. The sediments associated with the channel were named the Observatory Gravels and at a number of locations they were worked as an aggregate resource. Some 2 km north west of the city centre behind a public house called the 'Travellers Rest' were several actively worked pits which MARR was able to monitor as the exposed faces were progressively extended.

He classified the Observatory Gravel succession into five lithostratigraphic sub-units (see Fig. 5). The two lowermost were regarded as fluvial in origin and these formed the bulk of the sequence with the



1 = Lower evenly-bedded series. 3 = Upper evenly-bedded series.
2 = Unevenly-bedded series. 4 = 'Soil and 'warp.'

Fig. 5. The schematic stratigraphy of the Cambridge 'Observatory Gravels' as seen in the 'Travellers Rest' pits (after J. E. MARR, 1919)

oldest and younger respectively described as 'evenly-bedded' and 'unevenlly-bedded'. These two units were separated by an erosional unconformity which in places displayed clear palaeochannel forms in cross section. A third unit, occurred as the infill of downward tapering structures which originated at the top of the unevenly bedded unit and often penetrated through both the sandy gravel units and entered the solid Gault Clay (Cretaceous) beneath. The fill was described as a sandy loam with scattered flint clasts and occasional seams of gravel. The upper part of the 'unevenlly bedded' unit lateral to the wedge tops was disturbed and consisted of what were referred to as loam rich ferruginous pockets or pipes which were apparently folded into the subjacent sediments (see Fig. 5). Unconformably across the tops of the wedges and the 'unevenlly bedded' unit lay a further 'uniformably bedded' unit of sheet-like form. Finally, above this forth unit, extending up to the modern land surface was a unit described as 'soil and warp' which may well have included some loess.

MARR was clearly perplexed over the genetic significance of the wedge structures. It is probable that he had no appreciation of ice wedges and the structures produced by their decay for he does not cite the then recently published paper by LEFFINGWELL (1915). Rather he had to rely upon his own geological intuition. He was aware that the sedimentary relationships suggested that the sediment within the wedges was sourced from above. Four factors were emphasised: (a) the sides in unconsolidated sediments were too steep for open channels, (b) the immediately adjacent gravel host displayed down folding (c) a 'dragged' fabric lining associated with the outer limits of the wedge infill, and (d) the size range of the wedges from thin zones of disturbance through to fully developed wide features. To account for these characteristics he argued that a subsurface void must be created prior to infill. Thus, he invoked the former operation of a subterranean erosional process which produced cavities into which the overlying material progressively collapsed. Accordingly, he referred to the wedge structures as channels. This hypothesis was probably influenced by his observation that ground water flows were concentrated into the toes of the wedges especially where they penetrated the impervious Gault Clay.

A final notable observation by MARR was the presence of rare wedges (channels) which did not extend above the unconformity between the two lowest fluvial units. Significantly when these were traced horizontally they were seen to eventually cross each other i.e. they formed an element of a polygonal ground pattern. This suggests that two generations of 'channels' (wedges) were present, the first ante dating the erosional phase and was then separated by a phase of sedimentation represented by the 'unevenlly bedded' unit from a second one which post dates both units. This may be the first recognition of evidence which can now be interpreted in terms of recurrent permafrost development.

THE CONUNDRUM SOLVED

T. T. PATERSON'S (1940) paper probably still ranks as being the most significant in the context of publications relating to the reconstruction of past permafrost environments in the British Isles. For the first time the classic monograph by LEFFINGWELL (1919) is cited although curiously not his earlier paper (LEFFINGWELL, 1915). PATERSON had the benefit of participating in 1934 in one of the many Arctic expeditions which emanated from Cambridge during the 1930's. In addition he was able to discuss permafrost environments with experienced polar explorers such as N. E. ODELL and J. M. WORDIE.

No doubt strengthened by his own observations on ice-wedge polygons on the east coast of Baffin Island and Melville Bay, PATTERSON was able to appreciate that the wedges, exposed in the pits close to the 'Travellers Rest' public house mentioned above, were related in the first instance to frost cracking processes. Hence he appreciated that MARR's subterranean erosion mechanism was not plausible when the sedimentary evidence was reappraised in terms of a palaeopermafrost model. Prior to discussion of the 'Travellers Rest' wedge structures, PATERSON illustrated aspects of ice wedges developed on raised beaches and deltas at Eglinton Fjord in Baffin Island (see Fig. 6). In particular, having cut a trench across the top of a degraded ice-wedge he was able to describe the structural deformation and sedimentary character.

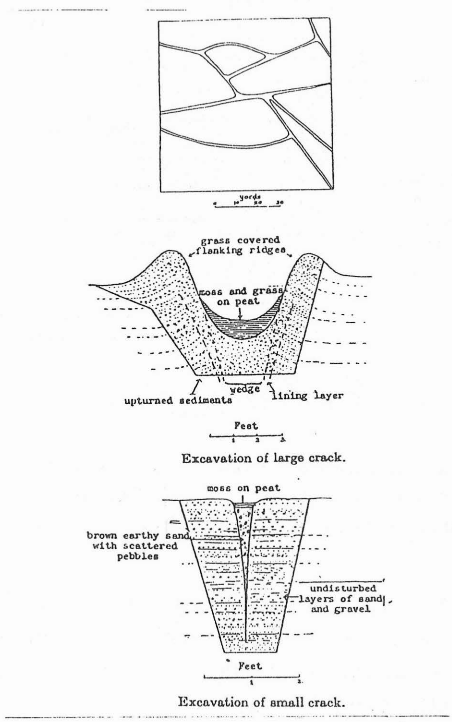


Fig. 6. Field sketches of ice-wedge related features made by T. T. PATERSON in a modern permafrost environment on Baffin Island, Canada

Also in 1934, the ice-wedge casts exposed behind the 'Travellers Rest' had a maximum widths and depths of respectively almost 2 m and 3.6 m but as before a spectrum of sizes were present down to incipient cracks less than 1 m deep. An important finding was that when traced through a receding section the small cracks could either increase in size to large structures or vice versa although in part this might be attributable to varying degrees of post formational erosion prior to the deposition of the upper 'evenly bedded' sequence. PATERSON closely examined the nature of the infill material and commented upon the outer material lining having been derived directly from the host sediments and that the clast long axes were parallel to the wedge sides. In contrast, the interior material was unstratified sandy loam and seen to have been derived from the surface rather than the sides (see Fig. 7). Finally, he noted that in the horizontal plane at the exhumed unconformity at the base of the Pleistocene succession where the wedges had penetrated into the Gault Clay, a random cross cutting wedge network was present.

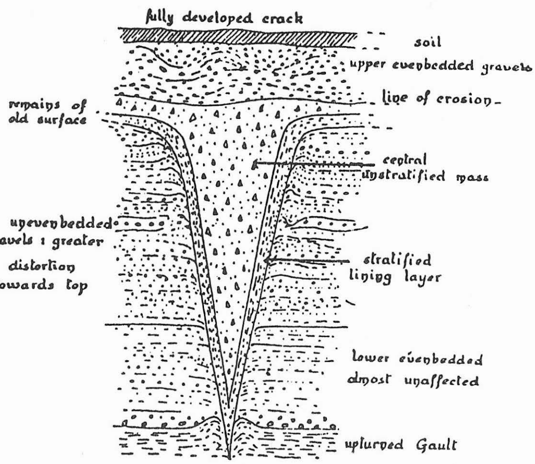


Fig. 7. Detailed drawn two-dimensional section of an ice-wedge cast as exposed in the 'Travellers Rest' pits Cambridge in 1934 (after T. T. PATERSON, 1940). Note the vertical fabric forming the outer limits of the wedge

PATTERSON analysed the significance of the stratified linings to the wedge infills and drew a perceptive insight into the sequential development stages occurring during ice-wedge casting, a topic which has received relatively little attention. He saw that it was not a simple matter of the wedge ice ablating en mass, rather he suggested that the ice melt would have initially been along the outer margins of the ice wedge as the ice would be in contact with a host material possessing a greater thermal conductivity. Hence, along a narrow zone around the ice wedge, water circulation would enhance the melt of the immediately adjacent frozen sandy gravel and this material would then be able to slip downwards into the void to form the stratified lining. A similar mechanism to this was to be subsequently deduced by CHURCH *et al* (1965) in their interpretation of Alaskan ice-wedge casts. At a later stage, lowering of the ice wedge tops would have permitted the disordered collapse of surface derived material to form the largely unbedded fill core. It is remarkable that this pioneering sedimentological analysis of ice wedge casting processes has not been given the attention it fully deserves yet if PATERSON's example had been followed many of the dubious claims of ice-wedge cast identification could have been avoided.

A SCOTTISH DISPUTE.

During the year 1939 there was a major debate at the Geological Society of London following a very controversial paper by R. G. CARRUTHERS who argued that the glacial successions of northern England could be best explained by a hypothesis of 'undermelt' progressively releasing the debris contained within a stagnant ice sheet (CARRUTHERS, 1940). This was essentially the glacial depositional process of 'meltout'. So intense was the debate that a precedent was set for another meeting had to be convened specially to continue the discussion! This is the background to a minor controversy concerning ice-wedge casts.

South of Edinburgh in Scotland a surface glacial till overlies glaciofluvial sediments which in turn overlie a further till. This succession relates to the wastage of the Last Glacial ice sheet some 15 ka BP. In the light of the debate just mentioned, sequences of this character were then particularly topical. Thus ANDERSON (1940) contributed a short description of the relationships exposed in a number of sand pits working the succession just mentioned. In a pit at Bidston (see Fig. 1), he described a till (Roslin Till) some 1–1.5 m thick overlying sands. The latter contained 'a vertical fissure .... about 6 feet deep, and 2.5 feet wide at the top, tapering downwards' i.e. a wedge structure infilled by till. Further, he noted that the stratification of the host sands displayed contortion close to the fissure walls and faulting 'as if the sands had been slipping slightly at one time into the crack'. There were other fissures present but of a lesser depth. ANDERSON attributed the surface till to a conventional glacial readvance rather than by the 'undermelt' process just proposed by CARRUTHERS. He suggested that the glacier had moved over *frozen* sands and gravels in order to explain why open fissures were apparently able to withstand being over-ridden by advancing ice.

This report drew comment by CARRUTHERS (1941) who claimed that the vertical wedges of till penetrating the sands actually extended to the top of the overlying Roslin Till. Hence he postulated that the wedges were temporally 'postglacial' in age. This also implied that the total wedge depth was twice that recorded by ANDERSON. He rejected the notion that wide open fissures could have withstood being over-ridden by a glacier and asserted that they were 'frost wedges', citing the just published paper of PATERSON (1940) in support. CARRUTHERS was anxious to argue that the field relationships were consistent with his controversial 'undermelt' glacial depositional mechanism. In response, ANDERSON (1941) stated that he was unaware of any instances where 'frost wedges' penetrated till but was careful not to reject this possibility. However, he stressed that he had not observed any evidence for the wedges within the Roslin Till sheet. In further comment, CARRUTHERS (1942), was mainly concerned with the validity of his 'undermelt' hypothesis but nevertheless gave some additional data on the 'frost wedges'. In the company of ANDERSON he had apparently revisited the Bidston pits and although the original structure had by then been destroyed other wedges of varying sizes were exposed. One of these he described as a 'trough fault' analogous to the infills of decayed tundra frost wedges. Surprisingly he did not further address the dispute as to whether the wedges originated from the surface of the Roslin Till sheet and the reader is left to infer that this was likely to be the case.

In 1965 the second meeting of the 'Quaternary Field Study Group' was held in Edinburgh. Two years later this group became the 'Quaternary Research Association' (WORSLEY, 1989). The Edinburgh meeting programme included a visit to a pit near Roslin working the same till/sand succession discussed by ANDERSON and CARRUTHERS. A very convincing 3 m deep ice-wedge cast was seen to penetrate the sands. The lower fill of this wedge consisted of down faulted sands and gravels derived from the host materials but the upper part was infilled by Roslin Till. This observation would appear to vindicate CARRUTHER's interpretation of the wedges. Unfortunately the section had had its original till cap removed prior to excavation so the critical relationship of the structure to the till was not seen.

AIR PHOTOGRAPH DATA

In the last decade of the review period in the 1940's, air photographs started to become available to the general public for the first time. RILEY (1944) first drew attention to the presence on such photographs of crop features which sometimes corresponded with polygonal ground patterns although the potential confusion with archaeological features was and indeed continues to be a problem. It was the doyen Jurassic stratigrapher W. J. ARKELL who suggested to RILEY (p 83), that the linear patterns which crop out near to Great Milton on an oblique air photograph (Plate 12), were probably 'frost cracks'. This interpretation was repeated in ARKELL (1947) in his book synthesizing the geology of the Oxford area. Citing PATERSON (1940), he interpreted the large scale polygons apparent on river terraces in the upper River Thames catchment was relict permafrost features. He also commented that they were most common on those terraces which ante dated the terrace associated with the Last Cold Stage. It is now known that ice-wedge casts are also plentiful within the low terrace gravels dating from the Last Cold Stage terrace in the Oxford region but as they are invariably capped by a Holocene silty loam, moisture differences in the sub-surface at times of water deficit are not reflected by the surface vegetation.

ARKELL was also familiar with the tapering wedge-shaped structures up to 4 m deep, associated with the gravels of the Handborough Terrace which is one of the highest in the Oxford area. These structures have the appearance of convincing ice-wedge casts when seen in a two-dimensional exposure as the host gravel fabric immediately adjacent to the wedge margin is up-turned. However, excavation of these wedges reveals that they are cylindrical rather than linear in plan form and hence have a carrot-like morphology. This is probably the first occasion when an investigator consciously contrasted relict three dimensional forms with modern ice wedges. Sadly this early example was not to be followed by many subsequent recorders of Pleistocene aged wedge structures and as a result many unsound claims for ice-wedge casts are present in the literature. This issue as a whole has been discussed previously (WORSLEY, 1996).

CONCLUSION

From the foregoing it can be seen that considerable progress had been achieved in the interpretation of relict permafrost related phenomena during the century long review period. Indeed, taking the subsequent British palaeopermafrost literature as a whole it is reasonable to suggest that subsequent further progress has in some respects been comparatively limited. It is remarkable how few later workers have followed the lead of PATERSON and undertaken studies of both modern and relict permafrost features. The sedimentology of ice-wedge casting remains a topic for further research.

ACKNOWLEDGEMENTS

ALAN BRANDON is thanked for bringing PHILLIPS' work to my attention.

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