Evidence for the extent of permafrost activity in south-west England during the last cold stage

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Previous evidence for former last cold stage permafrost distribution in south west England has been largely limited to the most northerly parts and possibly upland areas of the region. However, a number of coastal sites in both north and south Cornwall contain clear evidence for the former existence of ground-ice bodies based on the presence of ice wedge pseudomorphs and associated vertically inclined clasts. These features are taken to be linked to the former presence of permafrost, hence it is concluded that the southern and western extent of palaeo-permafrost distribution in South West England during the last cold stage should be redrawn.

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Introduction

The presence of former periglacial activity in SW England is largely based on the presumed origin of the angular matrix and clast-supported diamicton commonly referred to as "head" in a periglacial environment. A variety of processes are known to have contributed to the formation of head and work on this and some of the resulting palaeoenvironmental implications were described by Te Punga (1956, 1957). In addition he described altiplanation surfaces on Dartmoor, while relict thurfur or earth hummocks at various locations on Dartmoor were described by Gerrard (1983). Waters (1965) and Stephens (1970) also produced summaries of periglacial activity in south west England. Increasingly expertise gained in contemporary periglacial environments has been brought to bear on the interpretation of the processes responsible for the relict periglacial landforms found in south west England and elsewhere in the UK, for example, Harris (1987). One of the more important conclusions at that time was that the processes leading to the formation of head are indicative of a cold climate but do not necessarily imply permafrost conditions; the presence of a range of other features is required, for example, relict (collapsed) pingos.

Sedimentary structures possibly related to former ground-ice are not uncommon in the diamictons of Cornwall particularly along the north coast, for example, at Godrevy (Stephens, 1970), Trebetherick (Clarke, 1973) and Tregunna (Scourse, 1987). Until recently only one occurrence in "head" derived from slaty rocks had been recorded from the south coast of Cornwall (James, 1981a, 1981b). The apparent absence of cryogenic structures in granitic and coarse arenaceous derived diamictons may reflect sedimentological and hydrological differences between their granulometry compared to that originating from slaty rocks. Diamictons vary in response to primary frost-heave processes because of differing susceptibility to ground-ice growth, and so the products of their initial weathering from contrasting bedrocks will produce different solifluction responses. The granites break down into large boulders, weathered granules and coarse sand, while the fissile slates form discoid clasts and a silty matrix. These granulometric differences in the derived sediments affect rates of gelifluction and frost creep (cryoreptation) and the nature of ground-ice processes. An understanding of the susceptibility of periglacial sediments to freeze/thaw events as shown by Taber (1930) and Beskow (1935) is essential as Harris (1981) later demonstrated, showing that the variations between the granulometric and geotechnical properties of the sediment types were a key feature in interpretation.

Involutions and fossil thermal contraction phenomena have been described in the slaty diamicton forming significant proportions of the coastal sections of Gerrans Bay (James, 1981a, 1981b) (Figure 1). Such structures are best preserved in sequences of contrasting sediments. A distinctive, 1 m-thick lithofacies of well-comminuted local slaty diamicton forms the middle section of the head at Towan Beach (NGR SW 869 328). It is in planar contact with the underlying loamy diamicton but has a markedly convolute contact with the overlying silty diamicton. A number of apparent fossil thermal contraction phenomena intersect the comminuted slaty head unit and terminate at the planar contact at the base of the unit. The largest feature is a wedge cast >0.5 m deep with a maximum width of 10 cm extending at least 10 cm into the section and measured at right angles to the axial plane of the wedge. The small slate clasts are vertically aligned along each side of the wedge cast which is filled with sediment from the above overlying silty diamicton.

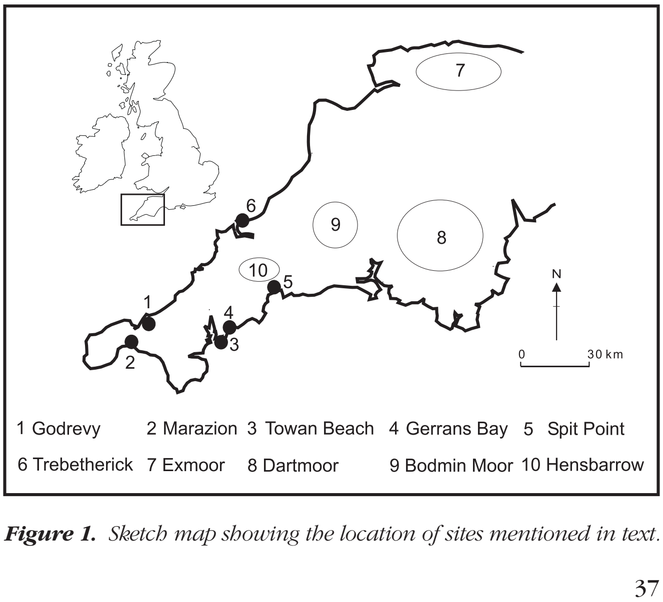

Figure 1. *Sketch map showing the location of sites mentioned in text.*

Clarke (1973) described wedges penetrating the Trebetherick Boulder Bed and the underlying slaty breccia at Tregunna (NGR SW 963 739). The two wedges are >1 m in depth and have a maximum width of 0.5 m terminating at the junction with the present shore platform. Scourse (1987, fig. 21.5, p. 228) shows one of the wedges filled with sediments from the overlying unit with vertically aligned slate clasts at the margins. Whilst the wedges at Tregunna, like those at Towan Beach, are almost certainly thermal contraction crack features, they have most recently been interpreted as active layer soil wedges (Scourse, 1996; Scourse and Furze, 1999) but the debate still continues as to whether they were formed in permafrost, the active layer, or in deep seasonal frost.

Recent work

Additional field evidence suggesting the former presence of permafrost in Cornwall consists of large involutions extending vertically upwards for 2 m from planar surfaces at Godrevy on the north coast and at Marazion and Spit Head on the south coast. In a review of permafrost distribution in Europe, Isarin (1997) states that "according to Vandenberghe (1988), cryoturbations larger than 0.6 m indicate former continuous permafrost conditions,…." (p. 316). Similarly, Van Vliet-Lanoë (1988) also agrees that large involutions extending from a planar base may be indicative of permafrost. Vertically disposed clasts of mainly vein quartz in the upper sections of head at Godrevy occur near the centre of the 800 m lateral section. Recent discoveries of similar phenomena some 100 m further south consist of similar size involutions circa 2 m apart. They cover a 50 m wide section, again above a planar surface, and merge to form "plumes" of vertically inclined clasts extending 2 m below the base of the overlying anthropogenic sand layer (Figure 2). Similar, but smaller, features can be found near the top of a 20 m wide section within head in a cove east of Marazion (NGR SW 522 304). On its own, the putative relationship of the size of involutions and/or the possession of a flat base to the presence of permafrost must remain uncertain. Involutions more than 0.6 m in height are known to form in subaqueous settings quite independent of permafrost and involutions with flat planar bases can form outside the periglacial environment, for example, "pseudo-nodules" (see Allen, 1970). However, in this study the large involutions were formed neither in a sub-aqueous setting nor in that of the "pseudo-nodules" but in a recognized stratigraphy, namely in head indicative of a periglacial environment.

Near Spit Beach (NGR SX 072 524), east of Carlyon Bay Beach along the south coast of Cornwall, a 2-3 m thick raised beach is overlain by a thin 1 m-thick head unit at the low-angle distal end of a head terrace. It reveals sub-rounded clasts which display a macrofabric distinctly inclined towards the vertical and similar to that previously recorded in Alderney (James and Worsley, 1997), Guernsey (Gurney *et al.*, 1998) and northern Brittany (Renouf and James, 2001). On the east side of Spit Beach (NGR SX 076 525) a low cliff with a much thinner raised beach (circa 10-15 cm) is covered by 3-4 m of head and loess. Although not particularly clast rich, the flat clasts, where present, tend to be vertically disposed and occasionally assume plume like forms. Between the above two exposures, an ice wedge pseudomorph (NGR SX 074 525) with dimensions of 0.8 m at its greatest true width and more than 0.75 m in depth and with upturned clasts on each side of the wedge has been recently recorded by Bristow and James (2002) (Figure 3). The base of the Spit Point ice wedge pseudomorph was not reached but it is estimated that it penetrates 1.5 m into the underlying units. This is similar in size to those recorded at Tregunna (Clarke, 1973; Scourse, 1987). As with the wedge structures at Tregunna and Towan Beach, exactly comparable features have not been described from contemporary cold regions and whilst all the Cornish examples are probably thermal contraction crack phenomena there would still be some debate of their association with permafrost.

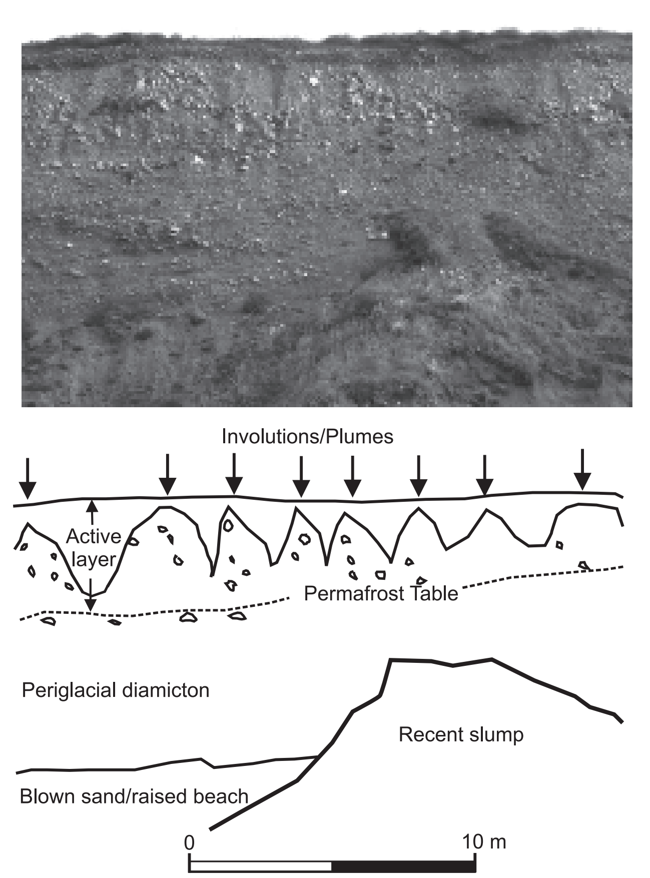

Figure 2. Field photograph and sketch showing the involutions forming "plumes" at Godrevy.

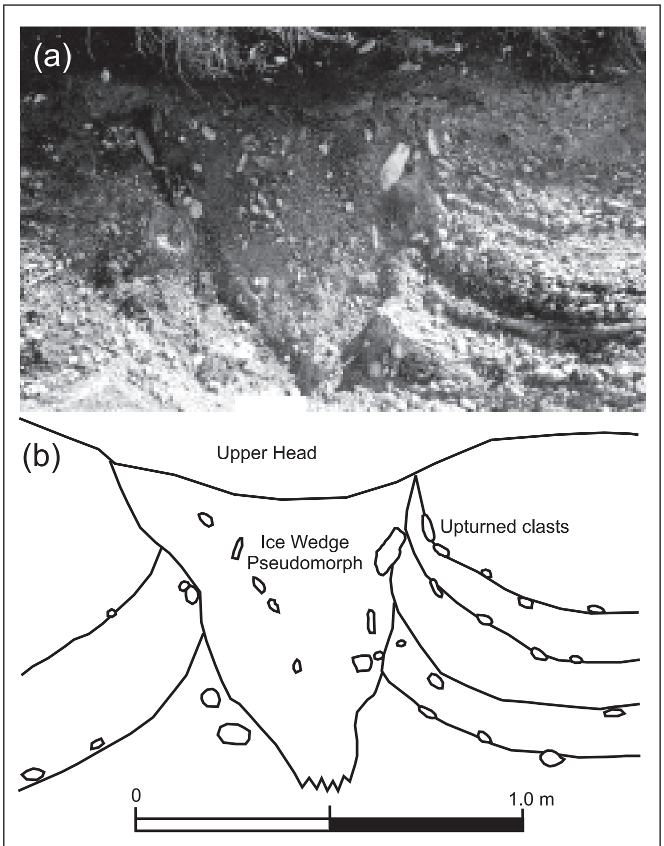

Figure 3. Possible ice-wedge pseudomorph, Spit Beach, South Cornwall. A. Field photograph and B. interpreted line diagram.

Discussion

The above descriptions pose a number of specific points for discussion. The reconstruction of palaeo-permafrost environments appears to be best achieved through the identification and analysis of secondary periglacial structures. Worsley (1996) cautioned those seeking to prove the presence and former extent of former permafrost in the UK. He suggested that acceptable field evidence be restricted to undisputed ground-ice phenomena within a recognized stratigraphy, ice/sand wedges, relict (collapsed) pingos and soft sediment deformation structures (believed to be associated with ice-lens growth).

These limitations proposed by Worsley (1996) were strictly adhered to in subsequent investigations in the Channel Islands (James and Worsley, 1997; Gurney *et al*., 1998) and subsequently at Toul ar Roussin in Northern France (Renouf and James, 2001). Also found in association with ice wedge pseudomorphs at the above sites were frost thrust boulders and merging involutions ("plumes") of vertically disposed clasts. These plumes have been identified at Toul ar Roussin (northern Brittany), Spit Beach (South Cornwall) and Godrevy (North Cornwall). At Toul ar Roussin and Spit Beach they extend for more than 2 m in depth through the head and even into the underlying raised beach at Toul ar Roussin and Spit Beach. The plumes may represent sections through stone polygons indicative of patterned ground phenomena. However, while it has not been possible to excavate beyond the vertical sections to expose cross sections through the structures, the very low angle surface of the head terraces suggests that they represent polygons rather than stripes and circles. Whilst there is some discussion concerning the relationship between polygons and permafrost, for example, Vandenberghe and Pissart (1993), who do not believe that the presence of permafrost is necessary, others, for example, Waltham (1995), describe them within permafrost in Alaska.

It is therefore proposed that such plumes be included as indicative of palaeo-permafrost environments through their association with other generally accepted ground-ice phenomena. The presence of a planar contact at the base to the plumes matches Pissart's (1987) view that where merging involutions (plumes) have a flat base in permeable substrate then this probably corresponds to a former permafrost table. Whilst involutions do not necessarily require permafrost for their formation (Maarleveld, 1981), large involutions (0.6 m) stratigraphically related to the tops of ice wedge casts, can be used as indicators for former permafrost (Karte, 1987). The topographic conditions at each of the above locations associated with proposed palaeo-permafrost environments are almost identical, that is, shallow gradient, poorly drained ground at the distal extremities of Late Quaternary soliflucted local diamicton (head) terraces. Such distal head sediments tend to be finer grained, representing a possible origin as solifluction lobes, resulting from frost creep, sheet flow and surface wash under waterlogged conditions. Similar situations associated with contemporary ground-ice conditions may be found in northern Canada, Alaska and Siberia, (S.D. Gurney *pers. comm.* 2004).

Where slope angles increase towards the proximal positions of the prisms of head accumulation (towards the back of coastal head terraces), the evidence for former permafrost conditions in the forms described in this paper is likely to have been destroyed by processes operating on the steeper proximal slopes that prevailed both at the time of deposition and subsequently during the Holocene. A possible example of one process is at L'Eree, western Guernsey, where the (originally) vertically inclined clasts tend to tilt forward. The apparent paucity of ice wedge pseudomorphs and other associated ground-ice phenomena in any number within the study area probably reflects the limited preservation of suitable former distal head terraces in coastal areas. This lack of preservation results from post last cold stage (Holocene/Flandrian) sea level rise leading to the erosion of many of the distal sections of formerly extensive head terraces. It is also noticeable that the so far identified surviving palaeo-permafrost phenomena are limited to less exposed areas within embayments, estuaries and sites protected by offshore reefs. Such phenomena are described within river floodplains, for example, in Lincolnshire (Briant *et al*. 2004). Future investigations within similar environments in SW England may help to determine their frequency in the region. With the possible exception of the reported wedges at Tregunna within the Camel Estuary, there appears to be no report of such features in south west England apart from within the coastal head terraces noted above.

Conclusions

Hutchinson and Thomas-Betts (1990) and Croot and Griffiths (2001) suggested that it was unlikely that permafrost conditions prevailed in either Devon or Cornwall during the Late Quaternary. The proposed evidence for this, followed earlier work by Manley (1951, 1953), and relates to moderation of the Pleistocene climate in the southwest leading to fluctuations in the mean annual air temperature (MAAT) as well as changing precipitation patterns. In addition, Hutchinson and Thomas-Betts (1990) pointed out a possible coincidence with areas of high heat flow within the two counties thereby reducing the likelihood of permafrost being present during the Pleistocene (see their figs. 1b and 1c, p. 388).

In contrast, Croot and Griffiths (2001, p. 270, fig.1) illustrated periglacial features in south west England and South Wales and refer to a range of phenomena including relict pingos, ice-wedge casts, polygons and stripes. Although the sources of the included information are not clear, the authors state "the evidence on the ground in Devon and Cornwall does not support the southwestern extention of permafrost into either county" (Croot and Griffiths, 2001 p. 269). However, there appears to be a contradiction in that relict pingos and ice wedge pseudomorphs are, at the very least, generally accepted as evidence for the presence of permafrost (e.g. Worsley, 1996). Evidence has also been presented elsewhere for relict pingos at Brent Tor, west Dartmoor (Miller, 1990; Ballantyne and Harris, 1993). If, as proposed above, the plumes of vertically inclined clasts taken to represent vertical sections through patterned ground, are found in association with other previously accepted ground-ice phenomena, all within a recognized periglacial stratigraphy, then some of the numerous polygons indicated by Croot and Griffiths (2001), could also substantiate the former presence of permafrost in SW England.

All of the suggested palaeo-permafrost phenomena described in this paper, for example, ice wedge pseudomorphs, the soft sediment deformation features and frost thrust boulders which may not alone indicate permafrost but which are most readily explained by its presence, along with the "plumes" of vertically disposed clasts, are found in sediments above, and occasionally within, low-level raised beach deposits. These are possibly, even likely in most cases to be of Ipswichian (Marine Oxygen Isotope substage 5e) (Last Interglacial) age, (Figure 4). In their summary of the Pleistocene marine and periglacial deposits of the English Channel, Bates *et al*. (2003) conclude

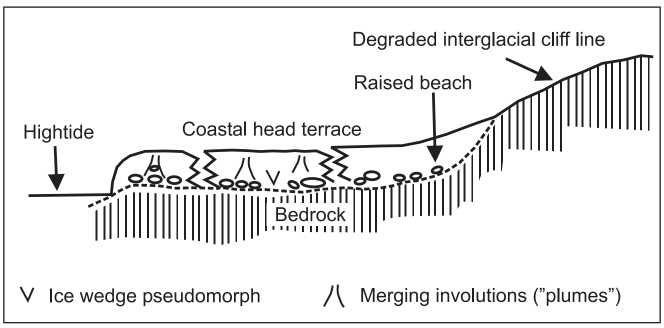

Figure 4. *Schematic model for the possible locations of ice-wedge pseudomorphs and plumes.*

that although a variety of dating schemes have been developed to date the overlying head and loess, a complete chronological framework still remains to be produced. However, published thermoluminescence (TL) dates for the overlying loess (Wintle, 1981) constrain the upper head to probable Mid-Late Devensian (last cold stage) supporting the contention that the considered head units in this paper are probably of Marine Oxygen Isotope stages 4 and 2 in age. Thus it is assumed that the proposed palaeo-permafrost features found in the upper head units in coastal localities in south west England are last cold stage (Devensian) in age.

In conclusion, it is suggested that the various publications (for example, Hutchinson and Thomas-Betts, 1990; Croot and Griffiths, 2001) showing the limits for palaeo-permafrost conditions for south west England, largely based on original work by Williams (1965), may need to be redrawn to show an extension of these limits as far west as St Ives Bay on the north coast of Cornwall and Mounts Bay on the south coast. Apart from William's (1965) earlier work which suggests that permafrost was largely absent from south west England with the exception of the Dartmoor and Exmoor massifs, subsequent attempts to determine the boundaries of permafrost in the region have either followed a north-south zonation or more specifically, an approximate northwest-southeast boundary separating continuous and discontinuous permafrost near the Devon-Cornwall border. Huijzer and Vandenberghe (1998) favoured the north-south zonation and produced maps which included south west England covering the 27-20 ka interval during the Late Devensian (figs. 15 and 16, p. 407 and 408) based upon estimates of the mean annual temperature and mean temperature of the coldest month. Data estimated for north Cornwall seems to indicate that SW England fell within the climatic limits for permafrost at that period.

The approximate northwest-southeast boundary separating continuous from discontinuous permafrost proposed by Van Vliet-Llanoë (1996, 2000), follows the western coastline of the Cotentin Peninsula in northern France before traversing the English Channel and reappearing near Start Point in south Devon. It is considered that this paper provides further evidence to be considered in the still problematic reconstruction of Devensian permafrost boundaries in south west England (see Murton and Lautridou, 2003) and that the evidence discussed above suggests the presence of at least sporadic permafrost and probably discontinuous permafrost in the region at times during the Devensian Stage.

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