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THE NATURE OF LAST GLACIAL PERIGLACIATION IN THE CHANNEL ISLANDS

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INTRODUCTION

Following the recognition of periglacially induced macro-scale sedimentary structures and fabrics of deposits of Last Glacial age on Alderney, a search for analogous features on Guernsey and Jersey has been undertaken. It has long been known that cold climate related mass wasting deposits (head) and aeolian deposits (loess) are common throughout the Channel Islands. Structures specifically related to frozen ground, however, either seasonal or perennial, have not previously been documented outside Alderney. A number of features including sorted patterned ground, sediment displacement due to ice lensing, tors, frost-thrust boulders and an ice wedge cast, all indicate that the northern and western coastal lowlands of Guernsey were affected by periglacial processes including permafrost during the Last Glacial. Applying the principle of Occam's Razor, all of these features appear to post-date the low Last Interglacial raised beach. Specific evidence relating to the presence of permafrost *per se* was not apparent on Jersey.

BACKGROUND

Finds of palaeoecological material such as basal organic rich deposits in Jersey indicative of former tundra conditions (Coope *et al.*, 1980; 1985) and fossil vertebrate bone, such as the mega-fauna of mammoth - reindeer - woolly rhinoceros and small rodents (lemming) found in the cave sequence at La Cotte de St. Brelade, Jersey (Callow and Cornford, 1986) are consistent with the former existence of cold climates in the Channel Islands. Although there have been descriptions of head and loess (George, 1973; Keen, 1978), which also infer Pleistocene cold environmental conditions, there has hitherto been no discussion of macro-scale evidence relating to frozen ground (seasonal or perennial) or associated active layer phenomena within the Quaternary lithofacies of the Channel Islands until recent work by James and Worsley (1997). Micromorphological features interpreted as being indicative of freeze-thaw processes, however, have been recorded from the cave sediments from La Cotte de St. Brelade (van Vliet-Lanoë, 1986).

In south-west England, detailed reconstruction of former periglacial environments for west Cornwall appeared to have been best achieved through the analysis of secondary periglacial structures within a recognised stratigraphy (c.f. Worsley, 1987). Sedimentary structures possibly related to former ground ice are very common in the slaty diamictons of west Cornwall particularly along the north coast, but only at one site on the south coast. In the latter case, involutions and fossil thermal contraction phenomena have been described in the slaty diamicton in coastal sections of Gerrans Bay (James, 1981a; 1981b). Indeed it has been argued by James (1994) that Pleistocene permafrost extent in south-west England was considerably greater than that which was postulated by Williams (1965).

If permafrost extent is a good indicator of the intensity of cold climates, then the ice wedge casts and sand and gravel wedges found in northern France, particularly in Brittany, demonstrate former Pleistocene cold environmental conditions having extended into that region (van Vliet-Lanë, 1996; van Vliet-Lanoë *et al*., 1997). The chronology for such periglacial conditions in Brittany, however, suggests a rather earlier date than for southwest England and the Channel Islands. For example, Loyer *et al*. (1995) indicate that during Marine Oxygen Isotope Stage (OIS) 6, permafrost extension was rather limited, compared with the much more intensive cold conditions indicated for the region during the preceding cold stages (OIS 8 and 10).

The map of former permafrost extent presented in van VlietLanoë (1996, page 464, Figure 1) places the limit of continuous permafrost very close to the Channel Islands (just to the east), indicating that from existing evidence in France there is good reason to expect evidence of periglacial structures, indicative of at least discontinuous permafrost, if not continuous permafrost, in the Channel Islands.

CURRENT WORK

The distribution of Pleistocene sediments in the Channel Islands, including those indicative of cold environmental conditions, were first systematically recorded by D.H. Keen during the period 1972-75 as part of the B.G.S. Channel Islands Sheets 1 and 2 mapping programme (Institute of Geological Sciences, 1982; British Geological Survey, 1986). In addition to the ubiquitous head sediments, loess forms a significant cover inland on both Jersey and Guernsey. This loess cover is much less complete on the Blaye plateau of Alderney.

Undoubtedly the most visible periglacial facies on the Channel Islands is the angular rubbly matrix supported diamict (head) which crops out above bedrock at numerous sites around the coastlines. Significant thicknesses may be observed, for example, at Moulin Huet [WV 328 752] (Guernsey), Bonne Nuit Bay [WV 645 558] (Jersey) and Hannaine Point [WA 557 072] (Alderney). With few exceptions, the preferred orientation of the macro fabric is normal to the respective coastlines of the islands. The head is generally found to overlie the raised beaches in the Channel Islands although at a few sites head derived from bedrock or loess *underlies* the raised beaches such as at Belcroute [WV 606 478] (Jersey) and the west side of Longis Bay [WA 080 596] (Alderney).

In 1996, close examination of both the head and the underlying raised beach extending from Fort Clonque [WA 555 073] in the south-west of Alderney to Fort Tourgis [WA 563 081] in the north of Clonque Bay revealed clear evidence of post-depositional disturbance of the sediments noted above (James and Worsley, 1997). The combined thickness of both the raised beach and overlying diamict ranges between 3 to 4 m and the long axes of greater than gravel sized clasts within both units are vertically oriented, a feature which may extend through the ancient beach sediments to the underlying raised shore platform. One exposure immediately north of Fort Tourgis

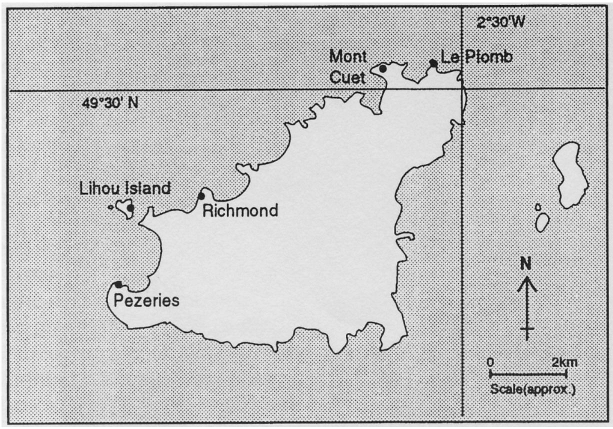

Figure 1: Outline map of Guernsey with the locations of the main localities mentioned in the text.

revealed a vertically aligned boulder of 1.5 m long axis which had become detached by more than 0.2 m from a very low promontory within the bedrock platform. This has been interpreted as a frost-thrust boulder and together with incomplete sections of stone polygons (a form of sorted patterned ground) and the vertically oriented clasts throughout both units suggested significant cryogenic activity presumably taking place within former active layers above a permafrost table in Alderney over sustained permafrost within the Last Glacial (Cold) stage.

In the following year (1997), detailed investigations were made at similar diamict exposures in Jersey and Guernsey. Apart from the normal primary flow structures associated with solifluction processes displayed by the head, for example, Belcroute and Bonne Nuit Bay, no epigenetic periglacial structures within the recognised stratigraphy were identified on the island of Jersey.

Similar primary mass movement structures were found at Moulin Huet, south-east Guernsey (see Figure 1), but close examination of head exposures along the west coast of Guernsey revealed a range of epigenetic structures of periglacial origin. Near Fort Pezeries [WV 237 763] in the south-west of Guernsey, a north-west facing soft-rock deformation feature at the distal end of a diamict terrace was located at the eastern end of a small bay. Further east within Les Pezeries (Bay) [WV 240 763], possible involutions were located in the upper section of the diamict with a thin organic lens 3-4 m below the diamict surface. Additional evidence was also found at the eastern end of Les Pezeries [WV 240 762] with a soft sediment deformation structure believed to have been associated with ice lens growth in the upper section of the diamict (see Figure 2).

The low island of Lihou is largely skirted by a thin (2-3 m) head unit with distinctive disturbed upper layers including at least two examples of frost-thrust boulders (Figure 3) on the eastern side of the island [WV 244 789] and also buried, sorted patterned ground. While the west facing site at L'Eree [WV 248 785] consisted of three small coves each revealing vertically oriented clasts in both the upper section of the raised beach and in the overlying 2-3 m thick head.

Further north, west of Richmond around [WV 267 793] and below the remains of Fort Richmond, lies a coastal terrace backed by a degraded bedrock cliff. The margins of this landform are currently undergoing active erosion by the sea and hence the terrace terminates in a low cliff some 2 m high. Exposures in this low cliff show that the terrace is underlain by an irregular bedrock (granodioritic gneiss) platform with palaeo-gullies, which in turn is overlain by a clast-rich raised beach typically up to 1 m in thickness. This is capped by 1 m of blown sand and silt (Munsell colour 7.5 YR 6/6, reddish yellow).

In one locality at the Fort Richmond site, see Figure 4 (a), (b) and (c), the lower half of the eroding vertical cliff displayed a three dimensional wedge-shaped structure. From the unconformity marking the interface between the aeolian cover and the raised beach material, down to the modern sandy beach, this structure narrowed overall from 0.7 m to 0.45 m. Excavations at the cliff foot showed that the structure extended seawards across the beach zone for a minimum of 2 m, and as the beach level descended the width narrowed to 0.1 m. The axis of the structure trended from 176° to 354° N, see Figure 4 (b). For the most part, the host sediment to the wedge, was a sandy, clast-rich raised beach facies, although towards the base and across the excavated area on the beach, bedrock (here a deeply weathered granodioritic gneiss) contained the structure. The interior of the wedge was characterised by well-sorted sand (Munsell colour 2.5 YR 4/4, reddish brown) and granules derived from a deeply weathered bedrock source with occasional pebble sized clasts, although there was a considerable variety of particle size and shape, within this fill material. The field relationships strongly suggest that this wedge fill was derived from above the unconformity cutting across the raised beach, prior to the deposition of the aeolian sediment cover. The colour, texture and sorting of the fill contrasted markedly with the host material.

As the clasts within the upper part of the raised beach succession lateral to the upper fill displayed vertical macro fabrics, this suggests that it had been affected by a palaeoactive layer. Some of the clast fabric within the host sediment immediately adjacent to the wedge margins suggested some downward movement towards the fill zone. Since the wedge fill truncates this horizon and hence is later in age, it is postulated that the wedge structure owes its primary origin to an ice wedge which progressively grew within permafrost, and that subsequently, during a phase of permafrost decay, the ice was replaced by sand derived from the adjacent land surface. The preservation of evidence for the associated active layer indicates that if the wedge has been truncated after infilling the amount of ensuing erosion was minimal. Assuming that the raised beach is of Last Interglacial (Eemian) age, then the reconstructed permafrost phase probably relates to a time of lower sea level than present during the Weichselian glacial stage.

Whilst being aware of the inherent dangers of interpretations depending upon single structures (Worsley, 1996), the site clearly showed that the wedge structure was a linear three dimensional form. It should be borne in mind, however, that where contemporary ice wedges are encountered in coarse materials such as gravel, or indeed within bedrock, the three dimensional pattern of orthogonal cracking has a much larger scale than that found in finer materials. Hence in such deposits the large scale of the network gives widely spaced features and therefore, one would expect a much lower incidence of preservation upon permafrost decay.

This sedimentary structure is potentially the most significant of those periglacial structures recorded here. There are only two features which can be confidently used to identify the former presence of permafrost *per se* and they are ice wedge casts and relict pingo scars, although it should be mentioned that some believe that rock glaciers should also be included in this list of features diagnostic of permafrost. Therefore, to infer the definite former existence of permafrost within an area, ice wedge casts and/or evidence of relict (collapsed) pingos must be found. The relict forms of both of these permafrost structures have been widely disputed (see Gurney, 1995; Worsley, 1996), particularly where features are believed to have been incorrectly interpreted and thus permafrost erroneously inferred.

At Fort Hommet [WV 283 805] clasts within the raised beach, particularly within the upper 30-40 cm of the unit, were seen to display a vertical fabric as they were at Richmond to the south. The vertical orientation of the clasts in this section and in numerous other sections in Guernsey and Alderney are believed to result from periglacial modification of the sediments (c.f. Fitzpatrick, 1987). The re-orientation processes which lead to the formation of vertical clast fabrics are numerous depending upon the exact circumstance (for example, in an active layer over permafrost or simply within seasonally frozen ground). One of the most important processes is frost heaving (or 'up-freezing') which pushes (or pulls) clasts towards the surface, during which time they rotate and align their long axes with the vertical. Clasts with their long axes oriented at angles higher than 50° are generally only observed in areas with very low slope

Figure 2: Soft sediment deformation due to ice lensing at Les Pezeries. The ruler used for scale is 10 cm in length.

Figure 3: Frost-thrust boulder on the coast of Lihou Island. Note that the heave of the boulder has displaced the overlying gravels. The ruler used for scale is 10 cm in length.

angles since on higher angle slopes mass wasting processes disturb the vertical orientation. The other mechanism believed to be responsible for the vertically oriented clasts in these deposits has been described by James and Worsley (1997) for Last Glacial deposits in Alderney. Here it was postulated that high pore water pressures build up during autumnal freeze-back of the active layer, when the active layer may be freezing both from the surface downwards and also from the permafrost table upwards. The pressure is released through water escaping to the surface (the line of least resistance). During this escape, clasts in the vicinity are rotated in the still unfrozen matrix. Care should be exercised with some interpretations of vertical fabric, however, since frost shattering of bedrock, patterned ground formation (see Hallet and Waddington, 1991) and the processes forming involutions can also create fabrics involving vertically oriented clasts and hence in this respect they are in many senses, polygenetic.

Turning to landforms with a probable periglacial origin, a few examples of tors were investigated on Guernsey, for example, at the Fort Richmond locality discussed earlier, see Figure 4 (b), where they were developed in schist. In the coastal area between Saline Bay and Cobo Bay tors have formed in the granite bedrock. Whilst these are currently in a coastal location, during the Last Glacial Maximum when sea levels would have been of the order of 100 m or more lower than at present (Lambeck, 1997) these features would have occupied a prominent location on the irregular rock platform. Even though there are various hypotheses proposed for tor genesis it seems probable that under a periglacial climatic regime a combination of frost shattering and fluvial removal of deeply weathered granite would have promoted tor formation during the Last Glacial. It should be borne in mind, however, that the existence of periglacially influenced tors does not prove the former existence of permafrost.

DISCUSSION

The range of possible/probable frozen ground phenomena overlying former discontinuous or continuous permafrost in Guernsey suggests a south-westerly extension of the zone of epigenetic periglacial structures found in Alderney (James and Worsley, 1997). Thus the relatively low western coastlines of Alderney and Guernsey reveal cumulative evidence of frozen ground phenomena associated with at least widespread discontinuous permafrost. Indeed, if further ice wedge casts are discovered this would support the case for continuous permafrost. In many instances, these low areas appear to be the low coast sections of solifluction terraces that would have extended from the upland massifs of each island across a formerly extensive land surface which is presently submerged by a higher sea level. As the underlying raised beaches are possibly the equivalent of the Marine OI sub-stage 5e interglacial beach at 8 m elevation and dated in Jersey at La Belle Houghe Cave to *circa* 121 Ka BP (Keen *et al.,* 1981), the overlying periglacial head units are assumed to be Last Cold Stage (Weichselian) in age.

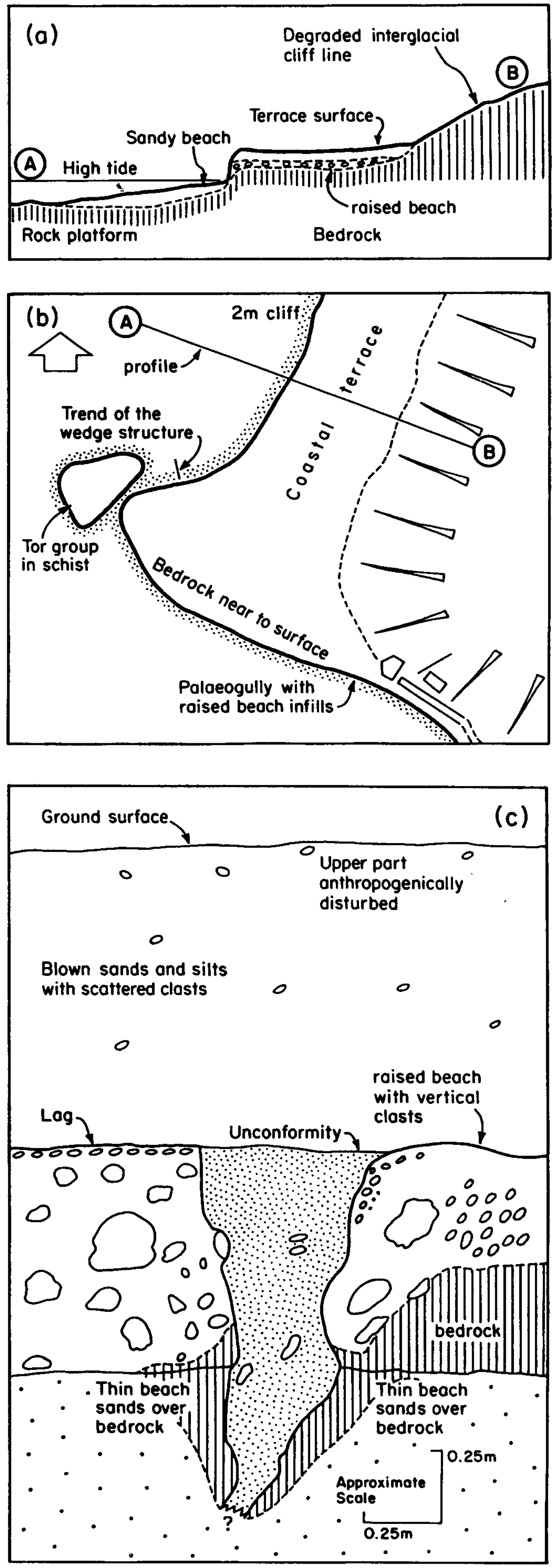

***Figure** 4: (a) Schematic section of the context of the Fort Richmond ice wedge cast. The line of the section (A-B) is shown in (b).*

(b) Plan view of the location, trend and context of the Fort Richmond ice wedge cast. Note the line of section (A-B).

(c) Section of the exposed the ice wedge cast. The section is comprised of three units. Uppermost is 1 m of blown sands and silts, beneath this are the raised beach deposits with vertical clasts which directly overlies the bedrock. The upper two units are seen in true section (i.e. they are vertical), whereas the unit described as thin beach sands over bedrock is viewed obliquely since it forms the low angled beach. The wedge structure is found within the raised beach deposits and the deeply weathered bedrock beneath. The fill of the wedge is variable although it is predominantly well sorted sand.

CONCLUSIONS

The discovery of epigenetic periglacial structures in Alderney (James and Worsley, 1997) and Guernsey indicate the former presence of significantly more severe cold conditions during the Last Glacial in the region than demonstrated previously. Indeed on the basis of data from within the British Isles the southern limit of such conditions had previously been thought to be much further north in mainland Britain (Williams, 1965), but the recent work by James (1994) and James and Worsley (1997) suggest that the southern permafrost limit needs to be redrawn to include west Cornwall and at least some of the Channel Islands. This conclusion is consistent with the conclusions derived from recent investigations in France (Lebret *et al.,* 1994; van Vliet-Lanoë, 1996).

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