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Late Pleistocene Stratigraphy and Palaeobotany of the Isles of Scilly

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Late Pleistocene stratigraphy and palaeobotany of the Isles of Scilly

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SUMMARY

A re-evaluation of the Pleistocene stratigraphy of the Isles of Scilly has enabled the formal definition of eight lithostratigraphic units of member status grouped into two formations. A chronology of events has been provided by radiocarbon (^{14}C) determinations, optical and thermoluminescence (TL) dates. Inter-site correlations have been strengthened by palynology, which has aided palaeoenvironmental reconstruction. The defined units have been incorporated into two lithostratigraphic models, one for the 'northern' (glacial) Scillies and one for the 'southern' (extra-glacial) Scillies.

Raised beach sediments of the Watermill Sands and Gravel in the southern Scillies are overlain by the Porthloo Breccia, a unit of soliflucted material derived exclusively from the weathering of local granite. Organic sequences at Carn Morval, Watermill Cove, Porth Askin, Porth Seal and Bread and Cheese Cove occur within the Porthloo Breccia, and are interpreted as the infillings of ponds associated with active solifluction. Radiocarbon determinations from these organic sediments are critical because they pre-date units associated with a glacial event. The ^{14}C determinations indicate deposition of the organic material between $34\,500^{+885}_{-800}$ (Q-2410) and $21\,500^{+890}_{-800}$ (Q-2358) years BP and provide a maximum age for the glacial event and the first radiometric dates for the coastal 'head' sediments of southwest England. The pollen assemblages from these organic sites all record open grassland vegetation, and represent the

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earliest vegetational record for the Scillies. High *Pinus* values are interpreted as evidence of climatic deterioration.

In the southern Scillies, the Porthloo Breccia is overlain by the Old Man Sandloess, a coarse aeolian silt with subdominant fine sand, TL-dated to 18600^{+3700}_{-3700} years (QTL-1d and 1f; Wintle 1981) and optically dated to 20000^{+7000}_{-7000} and 26000^{+10000}_{-9000} years (two samples; 738al and 741al; Smith *et al.* 1990). This material occurs in a variety of facies related to different modes of reworking. In the northern Scillies, the Porthloo Breccia is overlain by three units that are all related to a single glacial event. The Scilly Till, a massive, poorly sorted, clay-rich pale brown diamicton containing abundant striated and faceted erratics of northern derivation, occurs at Bread and Cheese Cove, and Pernagie and White Island Bars. This sediment is of uncertain depositional facies, although the available data suggest that it may be a lodgement till. At Bread and Cheese Cove the Scilly Till occurs in association with a matrix-supported sandy gravel, the Tregarthen Gravel, which has an erratic assemblage consistent with the underlying Till. The distributional relation between the glacially derived sediments, marine bars and morphological varieties of granite tors suggest that some of the bars may be remnant moraines, and that the glacier was erosive in the northern Scillies.

Aeolian loessic processes in association with the glacial advance resulted in the deposition of the Old Man Sandloess in the southern Scillies. The relative coarseness of this material is interpreted as a function of its proximity to glacially derived source material. The mineralogy of the Scilly Till is sufficiently similar to the Old Man Sandloess to suggest a genetic link between the two units.

Overlying the Scilly Till and Tregarthen Gravel in the northern Scillies is the Hell Bay Gravel, an extremely widespread matrix-supported gravel containing a similar assemblage of striated and faceted erratics to the underlying Till, but alongside a considerable proportion of locally derived granitic material. The matrix of the Hell Bay Gravel is identical to colluvially reworked facies of the Old Man Sandloess. This material represents an initial phase of solifluction, post-dating the glacial event in which the Scilly Till, Tregarthen Gravel and Old Man Sandloess were mixed and transported downslope. In situations where these sediments were stripped from the land surface, weathered granite once again became the dominant raw material for solifluction, this subsequent phase being represented by the Bread and Cheese Breccia in the northern Scillies and the upper Porthloo Breccia in the southern Scillies.

The evidence therefore suggests that ice advanced at least as far as the northern Isles of Scilly during the Dimlington Stadial of the late Devensian Substage. This conflicts with previous interpretations which place the glacial deposits within the Wolstonian Stage. However, the late Devensian event was probably not the first glacial event to have influenced the Islands because erratics are widespread in some exposures of the Watermill Sands and Gravel; the age of this earlier event remains uncertain.

1. INTRODUCTION

The Isles of Scilly lie 45 km west-south-west of Land's End (figure 1). Assuming sea level at Ordnance Datum (O.D.), there are well over 100 islands in the group, but the vast majority of these are devoid of soil and terrestrial vegetation. Evidence from the five largest, and permanently inhabited, islands of St Mary's, St Martin's, St Agnes, Tresco and Bryher, and the uninhabited islands of Samson, St Helen's, Northwethel, Tean, Nornour, Great Ganilly, Great Arthur, Little Arthur and Annet, forms the basis of this study.

The solid geology of the islands is dominated by granite, a unifying influence that has assisted in the identification of foreign material (figure 2). Barrow (1906) divided the granite into coarse and fine-grained facies, and believed the only existing exposure of country rock to be the highly tourmalinized slates, 'killas', of White Island, St Martin's. Although recent workers have reinterpreted this material as either sheared or greisened granite (J. R. Hawkes, personal communication, 1985), one small exposure of phyllitic country rock containing sporadic perthite mergacrysts does occur on Shipman Head, Bryher (J. R. Hawkes, personal communication, 1985).

No *in situ* Mesozoic sediments occur on the Islands, but Barrow (1906) identified Eocene(?) gravel, consisting largely of flint and greensand chert, on the summit of Chapel Down, St Martin's. This he correlated with the Eocene fluvial gravels capping the Haldon Hills in Devon. In 1957, Dollar attributed the St Martin's gravel to the Pliocene, and Mitchell (1960) attributed it to Lower Pleistocene fluvial aggradation. However, Mitchell & Orme (1967) later reinterpreted this gravel as glacial outwash material.

The occurrence of foreign pebbles on the northern Isles of Scilly has been known for more than a century. Smith (1858) first recorded the existence of such pebbles, making a collection of chalk-flints and greensand from Castle Down, Tresco; Whitley (1882) later interpreted these as glacial in origin. Barrow exhibited a striated boulder from the islands to the Geological Society of London in 1904, and was later (1906) able to place their occurrence within a stratigraphic framework. He observed that in cliff section the erratics were usually set within a fine silty matrix, often cemented by iron oxides, and that this 'glacial deposit' was both underlain and overlain by head deposits, the whole resting on a raised beach. Barrow accepted Whitley's (1882) glacial hypothesis, but preferred deposition from 'floe-ice'.

Mitchell & Orme (1965, 1967) re-examined the Pleistocene stratigraphy of the Islands, identifying the following sequence:

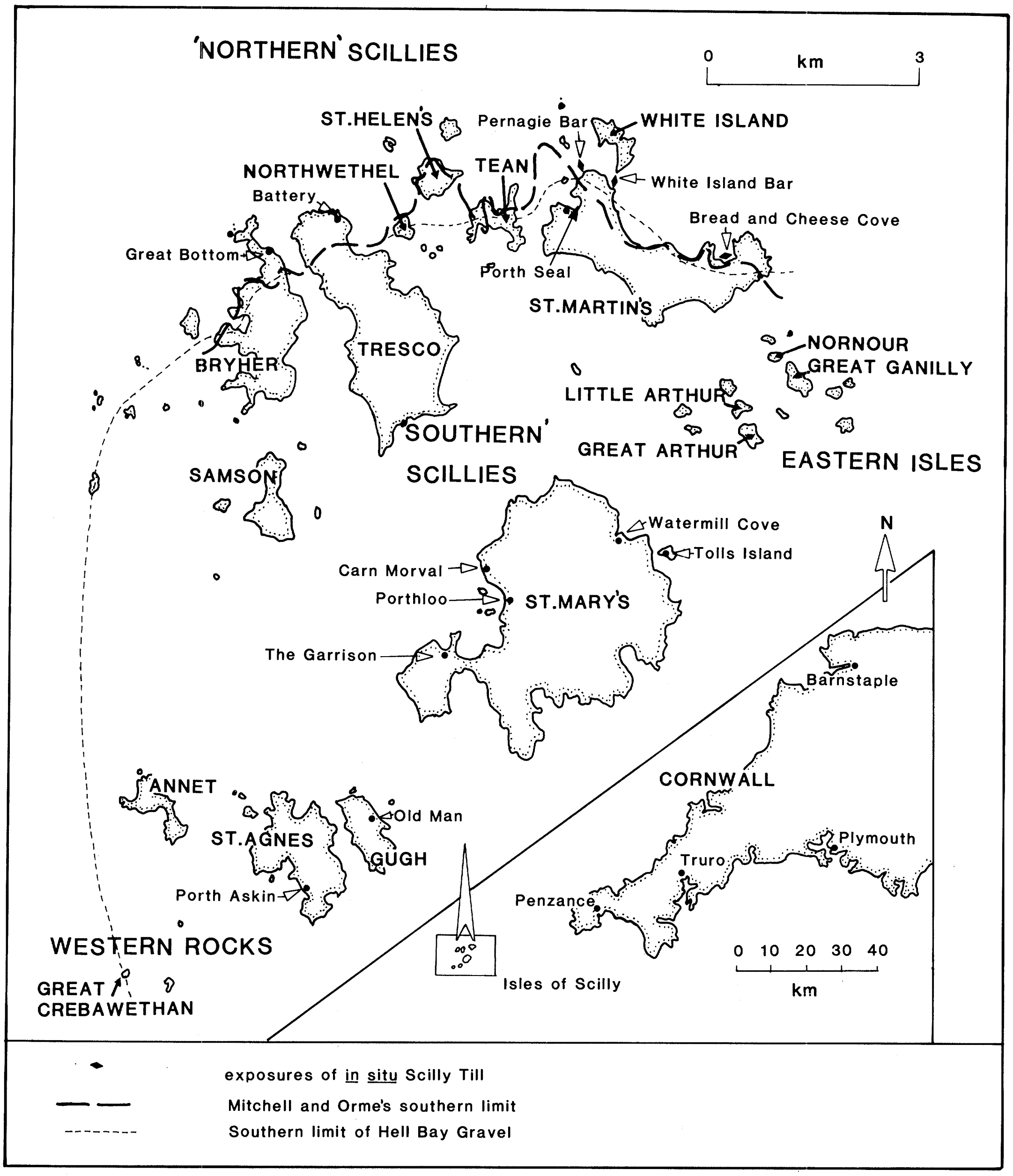

Figure 1. The Isles of Scilly: location map, critical sites, exposures of the Scilly Till, the southern limit of the Hell Bay Gravel and Mitchell & Orme's (1967) glacial limit.

Upper Head	Weichselian (= Devensian)
Raised Beach (Porth Seal)	Eemian (= Ipswichian)
Glacial Deposit	Gipping (= Wolstonian)
Raised Beach (Chad Girt)	Hoxnian
Shore platform	

(revised stage names from Mitchell *et al.* (1973)).

They divided Barrow's (1906) 'glacial deposit' into two facies, till and outwash gravel, and identified an ice limit running through the northern islands based on the distribution of these sediments (figure 1). By comparing their stratigraphy with similar sequences in southwest England and in Ireland, Mitchell & Orme suggested a Gipping (= Wolstonian) age for the glacial event. This interpretation is largely based on the suggestion that the erratic-free Chad Girt Raised Beach is Hoxnian in age by correlation with other raised beaches of supposed Hoxnian age at similar elevations elsewhere, e.g. the Courtmacsherry Raised Beach in southern Ireland. Direct correlation of lithostratigraphic units with chronostratigraphic stages on a one-to-one basis then dictated that the Porth Seal Raised Beach should be Eemian (= Ipswichian) in age. The Wolstonian glacial limit on the islands has become firmly established in the literature (cf. Catt 1981; Lowe & Walker 1984), despite some speculation that the glacial material on the Scillies might be younger in age (John 1971; Synge 1977, 1985).

Bowen (1969, 1973) questioned Mitchell & Orme's interpretations, proposing that the lenticular mode of the glacial material and its geomorphic association

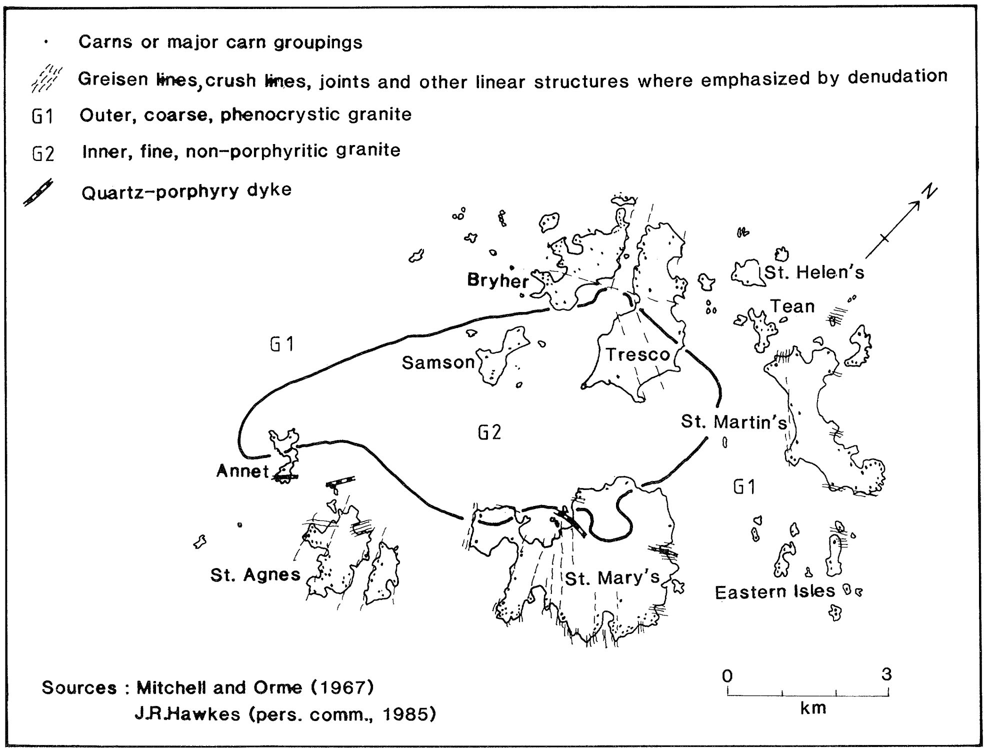

Figure 2. The Isles of Scilly: solid geology and structural geomorphology. 'Carn' is the local term for tor, and 'greisen lines' represent light-coloured linear structures produced by pneumatolysis of the granite by fluids rich in fluorine and lithium.

with coastal valleys was more consistent with a solifluction origin causing re-deposition of till. He later suggested (1981) that the critical stratigraphy identified by Mitchell & Orme (1967) at the Porth Seal site was 'inferred, and superposed, and granite corestones have been interpreted as a marine deposit'. Bowen (1973) regarded the single raised beach as Ipswichian in age, the soliflucted glacial sediments having been originally emplaced during the Wolstonian.

The dating of the glacial material on the Scillies by both Mitchell & Orme (1967) and Bowen (1973) is heavily dependent on the number and age of stratigraphically juxtaposed raised beach units, and correlation with neighbouring regions.

Coque-Delhuille & Veyret (1984, 1989) proposed a much more southerly ice limit on the islands. They concur with Mitchell & Orme (1967) and Bowen (1973) that the glaciation concerned was Wolstonian in age, but provide no new evidence to support this claim.

This account describes the results of a re-examination of exposed Pleistocene sections on the 16 largest islands between 1979 and 1985. A revised local stratigraphy is proposed, independent of the stratigraphies erected in the neighbouring regions, and formal lithostratigraphic units are defined. The detailed results of palaeobotanical investigations of hitherto unreported organic sequences are described and incorporated into the lithostratigraphic schemes. Radiocarbon determinations from these organic sequences, and thermoluminescence (TL) (Wintle 1981) and optical dates (Smith *et al.* 1990) provide a detailed chronology.

2. STRATIGRAPHY

(*a*) *Stratigraphic models*

Mapping of over 150 sites has enabled the identification of the major sedimentary units and the construction of two model sequences for the islands (figure 3), one for an area that can be described as the 'southern Scillies' and one for the 'northern Scillies'; these areas can be regarded as 'extra-glacial' and 'glacial' respectively. The boundary between these two areas is defined by the southern limit of the Hell Bay Gravel; apart from a few minor details, this corresponds closely with Mitchell & Orme's (1967) ice limit (figure 1). The southern Scillies cover about 90% of the total land area of the islands. The mapped sites consist almost entirely of coastal sections at the heads of bays and coves. The Pleistocene sediments, therefore, occur as discrete sedimentary bodies filling small basins separated from each other by positive relief features, such as headlands, in the solid granite. The stratigraphic models (figure 3) represent composite sequences built up from analysis of these discrete basins, and lateral continuity should not be assumed. The maximum number of units recorded in vertical succession at one site is five, at Bread and Cheese Cove, St Martin's. Only the most complicated and critical sites are discussed in detail here, but all the individual basins are described in Scourse (1985).

(*b*) *Lithostratigraphic definition*

The members and formations indicated in figure 3, and the Garrison Boulder Bed, are formally defined in

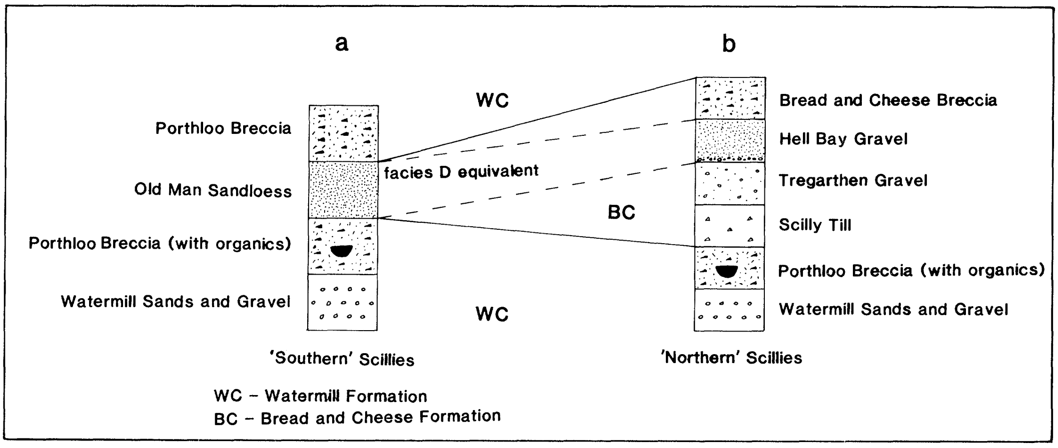

Figure 3. Lithostratigraphic models for the southern and northern Scillies, and their correlation. Eight units of member status are grouped into two formations. The Bread and Cheese Formation consists of members containing foreign materials derived from the late Devensian glaciation, but the Watermill Formation is totally dominated by locally derived granitic material and devoid of foreign material introduced during the late Devensian glaciation.

Table 1. *A synonymy of lithostratigraphic terminology for the Pleistocene of the Isles of Scilly*

(The table is not in stratigraphic order.)

Lithological unit	Existing terms	Member	Formation
granite breccia without erratics	Upper Head (Mitchell & Orme 1967)	Porthloo Breccia	Watermill
granite breccia with erratics	Upper Head (Mitchell & Orme 1967)	Bread and Cheese Breccia	Bread and Cheese
sandy silt	Iron-cement (Barrow 1906) Outwash gravel: Scilly Till (Mitchell & Orme 1967)	Old Man Sandloess	Bread and Cheese
sandy gravel	Outwash gravel (Mitchell & Orme 1967)	Tregarthen Gravel	Bread and Cheese
stony clay	Scilly Till (Mitchell & Orme 1967)	Scilly Till	Bread and Cheese
erratic gravel in sandy silt matrix	Scilly Till: Outwash gravel (Mitchell & Orme 1967)	Hell Bay Gravel	Bread and Cheese
granite breccia containing organic beds	Main Head (Mitchell & Orme 1967)	Porthloo Breccia	Watermill
beach sands and cobbles	Chad Girt Raised Beach (Barrow 1906; Mitchell & Orme 1967)	Watermill Sands and Gravel	Watermill
beach cobbles	—	Garrison Boulder Bed	Garrison

Appendix 1 according to Hedberg (1976) and Holland *et al.* (1978). A synonymy of the defined units is given in table 1.

(*i*) *Watermill Sands and Gravel Member*

The rounded nature of the cobbles and boulders, their clast-supported structure, the well-sorted and leptokurtic character of the grain-size distribution, and the restricted altitudinal range of this unit, support its interpretation as a raised beach. Two sites have been identified where the upper Porth Seal Raised Beach can be observed directly overlying the lower Chad Girt Raised Beach: at Porth Seal itself (Mitchell & Orme 1967) and at Northward Bight, St Martin's (Mitchell 1986). At both these sites, beach sediment has been reworked by solifluction into the overlying Porthloo Breccia (Scourse 1987). All the exposures of raised beach between about 4 m and 8 m O.D. have been correlated with the Watermill Sands and Gravel Member. At some sites this unit contains 100 % granite clasts, at others a considerable proportion of erratic clasts. This lithological difference may or may not have chronostratigraphical significance, and is in any case difficult to quantify because of the wide size range of the contained clasts.

(*ii*) *Porthloo Breccia Member*

Barrow (1906) cited the exposure of the 'Main Head' at Porthloo as typical, and therefore it is formally defined here as the type-site for the Porthloo Breccia, with which the Main Head is synonymous.

The early geological surveyors, including Barrow, were particularly impressed by the effects of former mass movements that had produced a surficial capping to many Pleistocene exposures (Worsley 1977). This points to the origin of the term 'head' as the uppermost unit of the geological record. Such colluvial or solifluction deposits in the Isles of Scilly are often not

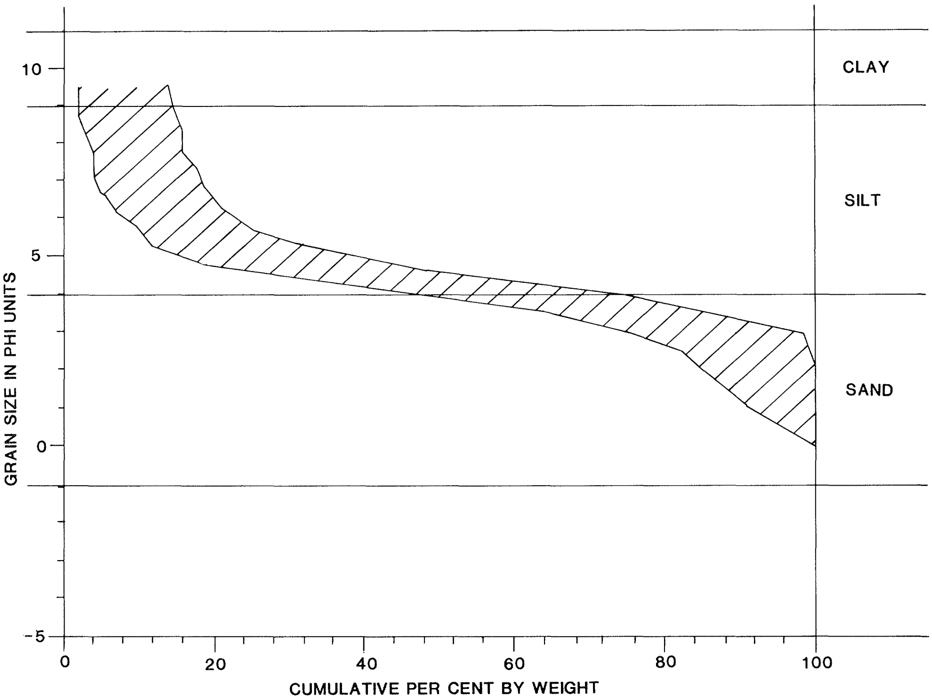

Figure 4. Grain-size envelope for facies A, B and C of the Old Man Sandloess.

found in this stratigraphical position, so the alternative term 'breccia' is used in this study. Most 'head' deposits in the islands constitute coarse granitic breccias, and the term 'breccia' is also preferable to 'head' in that it is purely lithological and has no genetic connotation. A periglacial origin is thought likely, but not assumed, for these breccia deposits. Henry (1984) also adopts this terminology.

The two units of Porthloo Breccia (figure 3) were previously defined as the 'Upper' and 'Lower or Main Head' (table 1). The upper and lower units are lithologically identical; where the Old Man Sandloess is absent it is not possible to separate the two units, justifying the use of the single term 'Porthloo Breccia'. It is quite clear from the stratigraphy, however, that the deposition of this material has taken place on two occasions separated by a period of sandloess deposition in the southern Scillies.

The Porthloo Breccia is by far the most ubiquitous Pleistocene unit in the islands, most of the other units being interbedded within it, or underlain or overlain by it.

The angular nature and exclusively local derivation of the clasts within the Porthloo Breccia, their downslope orientation and characteristic dip into the flow direction (French 1976; Harris 1987), the association of the unit with terrace-like features and granite tors, and the granitic derivation of the matrix mineralogy, are all indicative of a soliflual origin. The Porthloo Breccia is characterized by considerable lateral and vertical facies variations, discussed in Scourse (1987). The material is commonly stratified, and occasionally displays lobate structures with clast concentrations along the margins of the lobes.

(*iii*) *Scilly Till Member*

This material is discussed in §4*a*.

(*iv*) *Tregarthen Gravel Member*

This material is discussed in §4*c*.

(*v*) *Old Man Sandloess Member*

In an examination of loessic sediments from Cornwall and the Isles of Scilly, Catt & Staines (1982) observed that although many of the samples resembled undoubted loess from Kent and Belgium, the sand content of some of the samples ranged from 6.5 % to 33.1 % which 'exceeds the amounts normally found in loess' (Catt & Staines 1982, p. 370). They concluded that many of the samples were not purely loessic in origin, and that, although some may contain a little loess, this is probably mixed with sand from other sources.

The loessic sediments examined by Catt & Staines are formally defined here as the Old Man Sandloess. Additional grain-size analyses as part of this study confirm that this material contains consistently more sand than clay (figure 4), including samples interpreted as '*in situ*' (not colluvially reworked). Most of the samples contain dominant modal classes in the sand grade. In general, the material is too coarse to be defined as true loess, but too fine to be defined as coversand. It contains a dominant modal class either in the coarse silt or very fine sand fraction, with total sand usually more than 25 % and total clay less than 10 %.

The distribution of loess and coversand has been mapped in Belgium and the Netherlands and related to source areas, usually associated with sandur and outwash plains. In Belgium, material defined as 'sandloess' forms a transitional belt between coversand and loess (Mellors 1977). For example, at Alphen in the southern Netherlands, Vandenburghe & Krook (1981) have described a deposit, loam bed C2, which has a dominant modal class in the coarse silt fraction, low clay content, and sand values that are too high for typical loess: 'this can be readily explained by the fact that in transitional regions between coversand and loess areas pure loess is not common but is usually mixed with coversand' (Vandeburghe & Krook 1981, p. 423). This transitional material is identical with the Old Man Sandloess, so the term 'sandloess' has been adopted for this unit as the most precise term available.

Four facies of the Old Man Sandloess have been identified, based on granulometric and structural data. Facies A ('homogeneous sandloess') possesses the columnar structure and pin-hole voids characteristic of *in situ* loess (Mellors 1977). It contains around 53% silt, 35% sand and 12% clay, and is characterized by a leptokurtic distribution. This facies is interpreted as an *in situ* sandloess. It has been observed at Porth Cressa, St Mary's (SV905105), the Garrison, St Mary's (SV898105), Gimble Porth, Tresco (SV890160), Porth Killier, St Agnes (SV882087), Samson Hill, Bryher (SV881142) and Stoneship Porth, Bryher (SV872143).

Facies B ('waterlain sandloess') is horizontally stratified with small-scale fining-upwards sequences not exceeding 5 cm in thickness, the contacts being conformable. At Carn Morval, St Mary's, this material contains 49% sand, 37% silt and 14% clay. This material is interpreted as a waterlain sediment, sandloess having settled through a standing water body.

Sub-horizontal stratification and incipient ripple structures characterize facies C. Fining-upwards sequences up to 15 cm thick with erosional lower contacts grade into occasional cross-beds and incipient ripples. Occasional quartz granule stringers occur parallel with the stratification. This facies contains slightly less clay and fine silt than facies A, and has a more platykurtic distribution. This material is interpreted as 'fluviatile sandloess', depletion of clay and fine silt being effected by the fluvial reworking of *in situ* sandloess. Facies C sites are relatively common, e.g. Perpitch, St Martin's (SV940155).

Facies D is characterized by large-scale, and often chaotic, slump and flow structures, which frequently interdigitate with juxtaposed units, primarily the Porthloo Breccia. The material is mixed with large granite clasts and finer material of granitic derivation. Clasts are often found towards the base of individual flow structures. This material is quite variable granulometrically (figure 5). The facies is interpreted as a 'mass-flow' or 'colluvial' sandloess. It contains structures indicative of both strictly geliflucted as well as 'wetter' mudflow material. The Old Man Sandloess most commonly occurs as facies D, e.g. at Woolpack Point on the Garrison, St Mary's (SV898099).

All the described facies represent stages along a continuum from *in situ* sandloess to sandloess intermixed to such an extent with other material that its identity is only barely recognizable. The Old Man Sandloess is very variable both vertically and laterally. In section, however, a number of facies relationships are consistent (figure 6). The basal facies is usually D; this implies sandloess deposition with penecontemporaneous colluvial reworking. This passes upwards into facies A, resulting from a reduction in the efficacy of the reworking processes and possibly desiccation. This inferred desiccation ceases with the overlying facies C involving fluvial reworking of the underlying *in situ* material. Finally, facies D returns, suggesting the renewed importance of colluvial and soliflual processes. These vertical facies relations can only be observed in the southern Scillies (figure 1), where the thickest sequences of Old Man Sandloess are found. As facies B occurs only sporadically it cannot be included within this typical sequence.

(*vi*) *Hell Bay Gravel Member*

The Hell Bay Gravel consists of material of glacigenic derivation (Scilly Till, Tregarthen Gravel) thoroughly mixed with Old Man Sandloess and subsequently reworked downslope, probably by solifluction. The affinity of the matrix of the Hell Bay Gravel with the Old Man Sandloess can be seen from figure 5. A large number of erratics collected from the Hell Bay Gravel have been identified by Dr J. R. Hawkes (British Geological Survey); his identifications are listed in Appendix 2.

(*vii*) *Bread and Cheese Breccia Member*

This material is discussed in §4*a*.

(*viii*) *Garrison Boulder Bed Member*

The Garrison Boulder Bed is isolated stratigraphically from all other units, and occurs at an elevation well above the other raised beach exposures which have been correlated with the Watermill Sands and Gravel; it has therefore been defined separately.

(*ix*) *Additional comments on the defined units*

Barrow (1906) defined one unit which he regarded as being glacial in origin, his 'glacial deposit', whereas Mitchell & Orme (1967) defined two units which contained erratics of glacial derivation, the 'Scilly Till' and 'Outwash Gravel'. In this study, all erratics of glacial derivation occur within the Bread and Cheese Formation. This is divided into six members as defined above and in table 1; the erratics on Scilly therefore occur within a wide range of sedimentary contexts. Apart from the erratics contained within some exposures of the Watermill Sands and Gravel, the Watermill Formation is erratic-free. It is clear from the descriptions given by Mitchell & Orme (1967) that they would regard the Hell Bay Gravel either as 'Outwash Gravel', or as a sandy facies of the 'Scilly Till'. The Hell Bay Gravel is neither till nor outwash gravel but a slope deposit, either solifluction or mudflow, derived from the Scilly Till or Tregarthen Gravel, and intermixed with the Old Man Sandloess. The reason for these differences is their interpretation of loessic material, the Old Man Sandloess, as glacifluvial in origin; it is this material that forms the matrix of the Hell Bay Gravel.

3. CRITICAL SITES: SOUTHERN SCILLIES

(*a*) *Carn Morval*

(*i*) *Stratigraphy*

A succession of organic deposits occurs at the head of a small gully cut into the solid granite to the south of

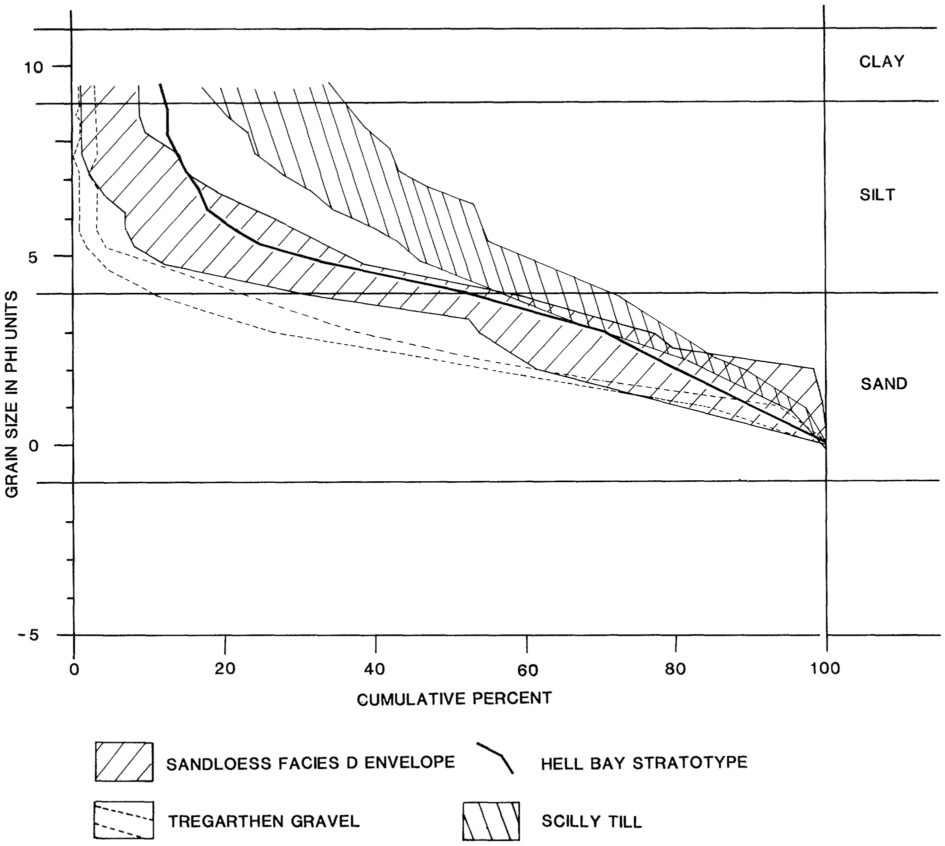

Figure 5. Grain-size envelopes for the Old Man Sandloess (facies D), Scilly Till and Tregarthen Gravel. The grainsize distribution of the matrix of the stratotype of the Hell Bay Gravel is superimposed on the grain-size envelope of facies D of the Old Man Sandloess.

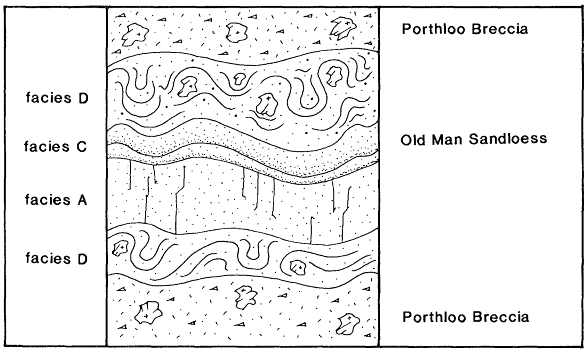

Figure 6. Facies model of the Old Man Sandloess illustrating the most commonly observed sequential relationships.

Carn Morval headland (SV905118). The gully is oriented roughly parallel with the local slope dip towards the southwest. Four sedimentary units can be identified in this locality (figure 7). To both the northwest and southeast of the gully the lowermost unit (unit 1) of raised beach, consisting of rounded clast-supported pebbles, boulders and cobbles in a matrix of well-sorted sand, occurs between 4 m and 5 m O.D. as two separate exposures. The base of the exposure to the northwest lies at 4.52 m O.D.; it is never more than 0.5 m in thickness, and its upper parts interdigitate with unit 3 (organic sequence). This exposure thins against the rising surface of the solid granite to the southwest. The exposure to the southwest consists of a coarser facies, but its base lies at the similar altitude of 4.73 m O.D.

Unit 3, an angular granitic breccia with an extremely poorly sorted matrix, interpreted as a solifluction deposit, clearly overlies both raised beach exposures, but the precise stratigraphic relation of the organic sequence to these raised beach exposures is less clear, lacking direct superposition or lateral extension (figure 7). However, lenses of the breccia clearly interdigitate with the organic sediments, so it seems likely that the raised beaches lie below the organic sequence.

This site was first investigated by Wintle (1981) as part of a programme of research calibrating TL with ^{14}C dates. Traced laterally towards the southwest, the breccia is overlain by a well-sorted sandy silt, interpreted by Wintle as being loessic in origin. For this material she obtained a date of 18600^{+3700}_{-3700} (QTL-1f) by using the TL method (Wintle 1981), whereas the underlying organic beds were ^{14}C-dated to 26550^{+700}_{-650} (Q-2176; 'lowest layer') and 20630^{+480}_{-450} (Q-2177; 'middle layer'). The grain-size distribution for this loessic material falls within the envelope shown in figure 4.

In terms of the proposed stratigraphy (figure 3; southern Scillies), unit 1 is correlated with the Watermill Sands and Gravel, and units 2 and 3 with the lower Porthloo Breccia of the southern Scillies. The uppermost loessic unit forms part of the Old Man Sandloess.

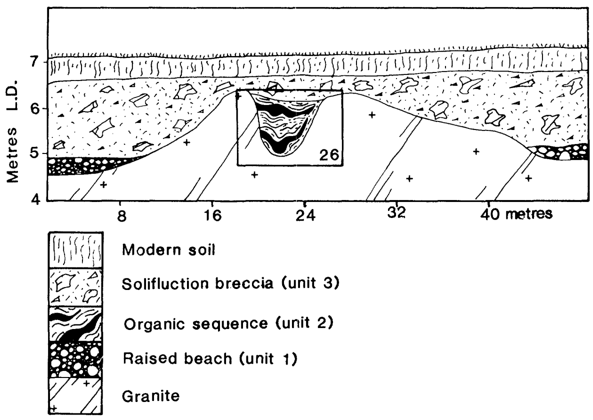

Figure 7. Carn Morval: site stratigraphy.

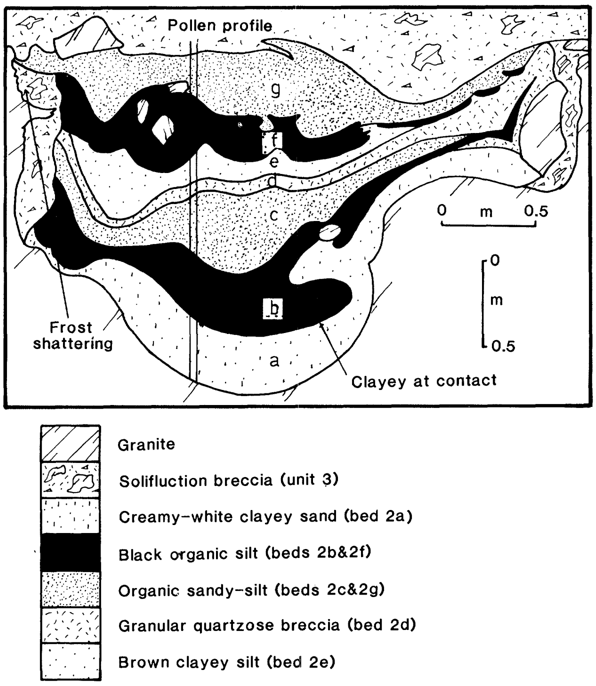

Figure 8. Carn Morval: stratigraphy of the organic sequence.

(*ii*) *The organic sequence: stratigraphy and sediments*

The organic deposits are black in colour, contain abundant micaceous silt and sand, and form two distinct beds within the sequence (beds 2b and 2f; figure 9), each overlain by a less organic dark, brown sandy silt (beds 2c and 2g). Bed 2b is underlain by a cream-white sand with some clay, bed 2a, which on contact with 2b is enriched in clay; 2a rests on granite. Above 2c is a thin layer of granite breccia, 2d, which is continuous with unit 3 on both sides of the gully, and this in turn is overlain by a bed of brown silty clay, 2e. Bed 2f, like 2b, is underlain by a cream-white sand with clay. The top of 2g interdigitates with the overlying unit 3. Although post-depositional contortion and slumping has taken place, the original stratigraphical relationships between the beds have been retained. Granite clasts are found throughout the sequence, and all the contacts are gradational.

The sediments are interpreted as having accumulated in a small pool ponded within the rock gully in the solid granite, the base of which lies at 4.5 m O.D. The presence of water at this site in the past may be explained by the spring which rises today in the gully a few metres towards the west. The sediments themselves and the pollen suggest deposition during a cold stage, and under these conditions the gully may have been closed by an icing or naled to form a basin in which the sediments accumulated. Alternatively, the ponding may simply have been effected by contemporaneous solifluction lobes and sheets.

The beds forming the sequence are distinct, and each has a specific origin (figure 9). Granulometric analysis of bed 2a shows that it contains 66 % sand, 31 % silt and 3 % clay. It is rich in quartz and mica, suggesting derivation from the granite, and probably represents the initial fairly rapid deposition of poorly sorted minerogenic material into the basin at a time of active solifluction.

Amorphous humus is estimated to contribute up to 90 % of the organic content of beds 2b and 2f on the basis of the examination of smear slides, the remaining 10 % being made up by unidentifiable macroscopic carbonized plant and animal detritus, pollen and spores. Two hypotheses can be invoked to explain this high concentration of humus:

(1) Slow accumulation rates, in the same way that recurrence surfaces occur in peat bogs (Aaby & Tauber 1975). As the accumulation rate is partly dependent on hydrological conditions, beds 2b and 2f may relate to periods of drying, exposure and therefore pedogenesis. Such humus can be described as 'autochthonous'.

2. Inwashing of mor humus from surrounding slopes. The erosion of mor humus from podsol profiles and blanket bog on British uplands produces a deposit strikingly similar to beds 2b and 2f. Such humus can be regarded as 'allochthonous'.

Beds 2c and 2g are less humified, and may therefore represent either faster accumulation rates or reduced inwash of mor humus. Bed 2f is less organic than 2b (figure 9) and contains much greater amounts of coarse inorganic detritus, which suggests a greater degree of inwashing, and therefore a greater contribution of allochthonous humus. Bed 2d represents a period of solifluction from the surrounding slopes directly into the pool. Bed 2e has a dominant modal class in the very fine sand fraction, and consists of 50 % sand, 37 % silt and 13 % clay. This suggests an aeolian origin, but, compared with the Old Man Sandloess facies A, it contains a fairly high clay percentage and is relatively poorly sorted; this may perhaps be explained in terms of deposition of sandloess through standing water i.e. waterlain sandloess.

The main features to note from figure 9 are the occurrence of unidentifiable carbonized organic detritus in beds 2b and 2f, and the high organic content of these two beds, 30 % and 22 %, respectively. Organic content minima of 1 % are recorded in beds 2a and 2d. The loss at 950 °C results are surprisingly high, reaching a maximum of 10 % in bed 2b; the removal of clay lattice water is the most likely explanation for this loss (Dean 1974), perhaps with the additional minor removal of organic material that was not combusted at 550 °C.

The post-depositional contortion and slumping of the sequence can be attributed to solifluction over the

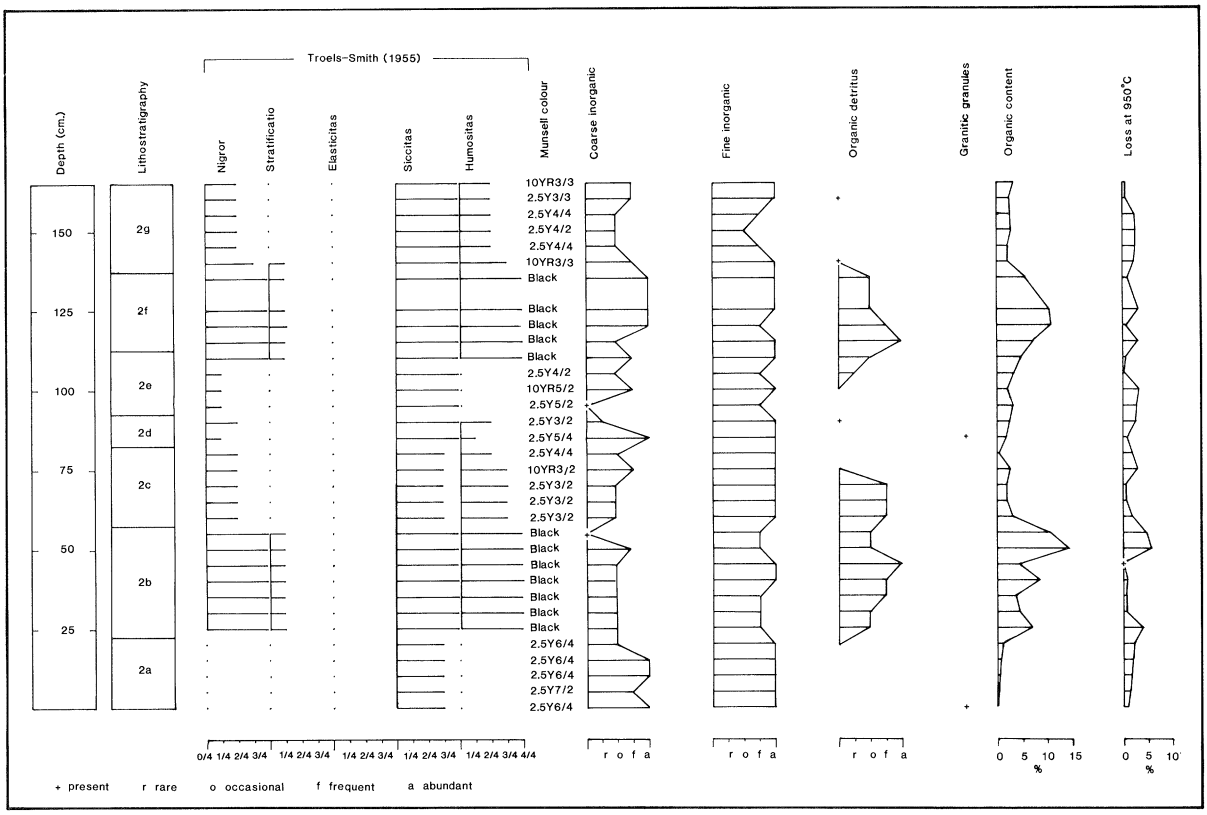

Figure 9. Carn Morval: Troels–Smith (1955) sediment description, Munsell colour, pollen washings and loss-on-ignition data for the organic sequence.

surface of the basin and to loading by this body of material, and perhaps to the melting out of a basal naled as referred to above.

(*iii*) *Pollen analysis*

Serial samples for pollen analysis were taken from the base of bed 2a to the base of unit 3 at 5 cm intervals along the profile indicated in figure 8, and prepared according to the method outlined in Appendix 3. A minimum of 300 grains of pollen of non-obligate aquatic plants were counted at most levels. It was noted during sampling at Carn Morval that the organic sediments had been bored by solitary bees of the genus *Andrena*, and when counting commenced it became apparent that some levels were contaminated. The method used for the separation of fossil from contaminant pollen is explained in Appendix 4.

As far as the taphonomy of the fossil pollen is concerned, in small basins such as this most pollen would have been washed in by small streams draining the immediate slopes, and would therefore represent local vegetation. This local component would be further complemented by aquatic and helophytic vegetation living within, or on the margins of, the pool, but diluted by a small long-distance component. The most important taxon in this context is *Pinus*, and this provides the only change in the diagrams.

In this taphonomic context, it is important to consider the origin of the humus content of beds 2b and 2f. If the humus was autochthonous, and representative of desiccation and pedogenesis, then a decline in aquatic taxa would be expected. The only obligate aquatic taxa recorded in the spectrum are *Sparganium* type, *Potamogeton* and the alga *Botryococcus*. However, the correspondence between these taxa and the stratigraphy is undiagnostic, and the concentration diagram (figure 11) suggests that the changes in these taxa in the percentage diagram (figure 10) are artefacts of the percentage calculations.

Given the possible importance of the inwashing of mor humus into the basin, it is extremely likely that 'penecontemporaneous pollen' (Cushing 1964) forms a significant part of the spectrum. This has been defined as 'redeposition of pollen…over a relatively small time scale, for example, when recently deposited pollen is washed into a sediment from the surrounding soil' (Birks & Birks 1980, p. 191). They also state that penecontemporaneous pollen can be recognized by its corroded nature and its association with fungal debris washed in from the soil. These criteria are likely to be useful in 'temperate' diagrams, where indeterminate totals are low, but in 'cold stage' diagrams, such as Carn Morval, indeterminate totals are consistently high, and sudden influxes of corroded pollen difficult to isolate. Nevertheless, specifically corroded totals are relatively low at the site, and fungal debris not particularly abundant, perhaps supporting an autochthonous origin for the humus.

Just as the different beds can be attributed a specific genesis, so the taphonomy of each bed is different (Table 2). Although local sources predominate throughout the sequence, bed 2e, of probable aeolian origin, may well have a larger regional component than the other beds. Bed 2d probably consists of reworked pollen from lower levels.

The change in the *Pinus* frequencies enables the

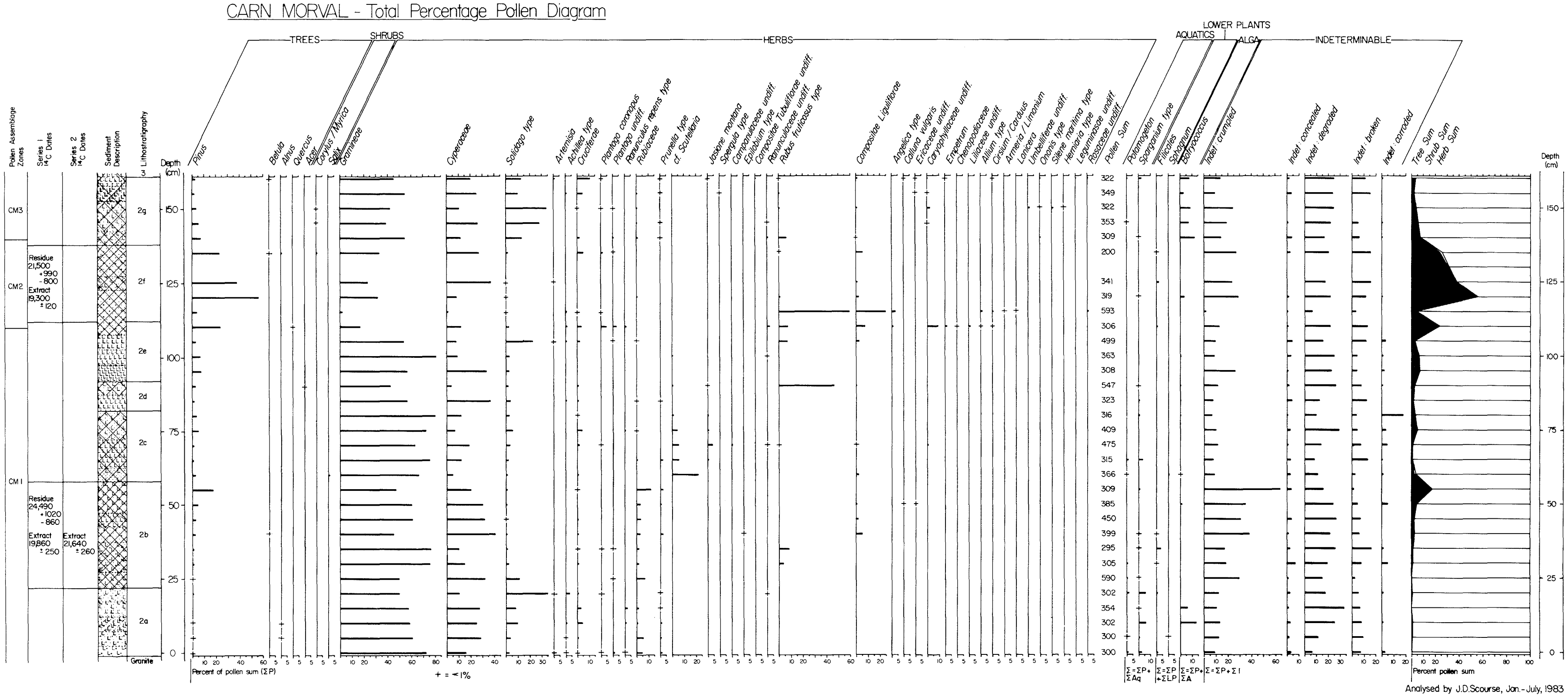

Figure 10. Carn Morval: percentage pollen diagram. Tree, shrub and herb frequencies are expressed as percentages of total non-obligate aquatic pollen (ΣP), aquatics of ΣP+aquatics, lower plants of ΣP+lower plants, algae of ΣP+algae and indeterminable grains of ΣP+indeterminable grains. The summary diagram is calculated from percentages of ΣP. Taxa interpreted as contaminants (Appendix 4) include *Rubus fruticosus*, Compositae Liguliflorae, *Angelica* type, *Bidens* type, Caryophyllaceae, Chenopodiaceae, Ranunculaceae, Liliaceae, *Cirsium–Carduus*, *Allium* type, *Empetrum*, *Armeria–Limonium*, Rosaceae, Leguminosae, *Ononis* type, *Silene maritima* type, *Herniaria* and Umbelliferae. A corrected percentage pollen diagram in which these contaminants have been subtracted from the pollen sum is presented in Scourse (1985).

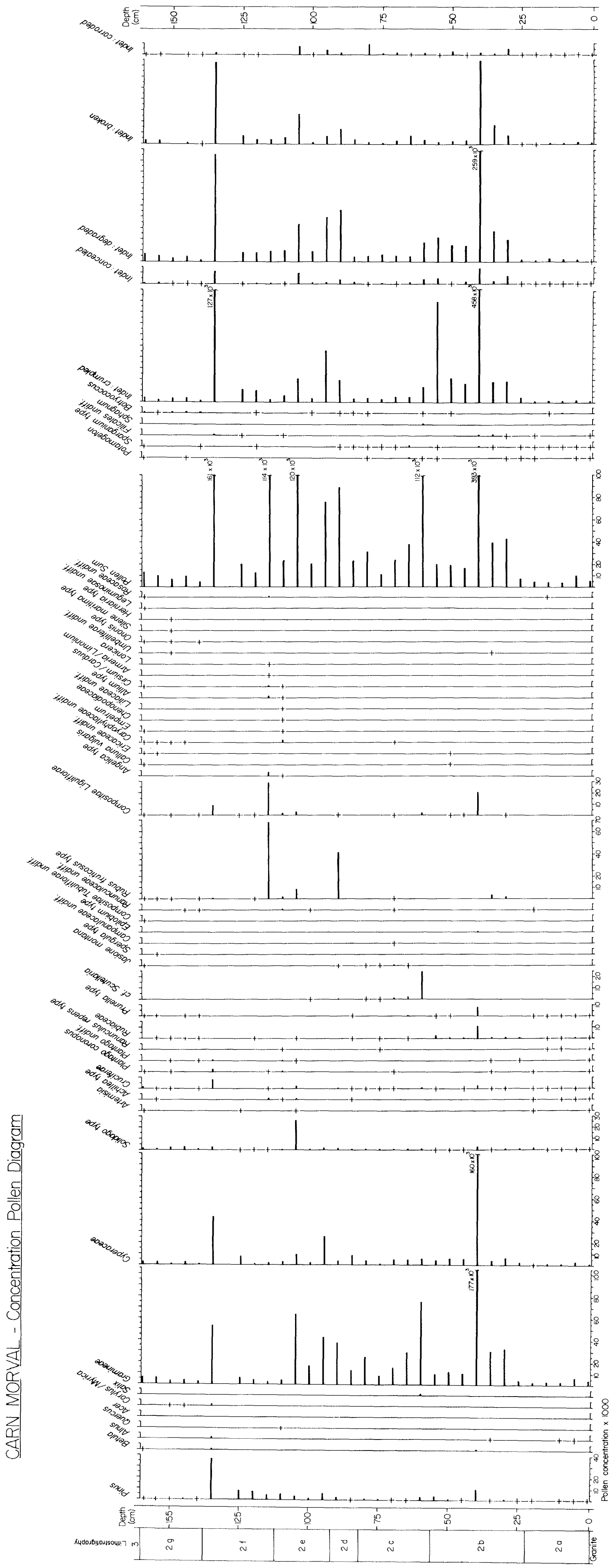

Figure 11. Carn Morval: concentration pollen diagram. A corrected concentration pollen diagram in which the contaminant pollen (see figure 10) has been subtracted is presented in Scourse (1985).

Table 2. *Carn Morval: pollen taphonomy of individual beds in organic sequence*

			pollen taphonomy		
unit	description	genesis	local source; pond itself and slopes	extra-local source	regional source; airborne component
2g	organic sandy silt	lacustrine: fast sedimentation rate	strong	weak	weak
2f	black organic silt	lacustrine: slow sedimentation rate	strong	moderate	weak
2e	brown silty clay	waterlain sandloess	moderate	weak	strong
2d	granular quartz breccia	solifluction	reworking of underlying sediments		
2c	organic sandy silt	lacustrine: fast sedimentation rate	strong	weak	weak
2b	black organic silt	lacustrine: slow sedimentation rate; possible inwashing of pollen	strong	moderate	weak
2a	creame–white sand with clay	fluvial–colluvial, minerogenic inwash	strong	moderate	weak

diagrams to be divided into three pollen assemblage zones (PAZ) (figure 10) by using a numerical ZONATION program (Gordon & Birks 1972).

Zone CM1, 0–110 cm, Gramineae–Cyperaceae PAZ. This zone is totally dominated by herb taxa. Gramineae frequencies are consistently high, from 47 % (55 cm) to 82 % (35 cm); Cyperaceae occur consistently, but at lower frequencies, from 5 % (60 cm) to 42 % (40 cm). Other significant herb taxa include *Solidago* type, which reaches two peaks at 20 and 105 cm, Cruciferae, *Plantago* undiff., Rubiaceae, *Prunella* type, *Jasione montana* and cf. *Scutellaria*. *Pinus* frequencies are very low in the basal sediments, but rise gradually from 20 cm to reach 8 % towards the end of CM1.

Pollen concentrations are very low in 2a, between 8000 and 18000 grains cm^{-3}, rising rapidly to 905000 grains cm^{-3} in the basal level of 2b. Concentrations of this order are very high indeed, even by comparison with temperate limnic sediments (Turner 1985). Percentages of indeterminate pollen are consistently high through CM1, but with an increase in 2b.

Zone CM2, 110–104 cm, Pinus–Cyperaceae PAZ. This PAZ covers 2f and the top of 2e, and is defined by the rise in *Pinus* frequencies, from around 8 % at the top of CM1 to 56 % at 120 cm, and a corresponding decrease in the Gramineae frequencies. Cyperaceae frequencies, however, continue at the same levels as in CM1. Other herb taxa include *Solidago* type, Cruciferae, *Achillea* type, *Plantago* undiff., *P. coronopus* and *Ranunculus repens* type.

Pollen concentrations through this zone are again erratic; the *Pinus* peak appears as a distinct feature, but is less marked than on the percentage diagram. The Gramineae decrease and the stability of Cyperaceae appear not to be artefacts of the percentage calculations.

Zone CM3, 140–160 cm Gramineae–Cyperaceae PAZ. This PAZ covers bed 2g, and is essentially a repeat of CM1, with very low *Pinus*, high Gramineae and a similar array of herb taxa.

Many of the changes in the diagram can be attributed to sedimentary conditions, taphonomic variations, or secondary weathering. In particular, the possible drying of the pool in bed 2b times, inferred from the humification of the sediment, is supported by the increase in physically weathered pollen in 2b. The rapid increase in total pollen concentration at the base of 2b might then be attributed to a dramatic decrease in the sedimentation rate associated with desiccation.

All the herb taxa are characteristic of open grassland vegetation, the grasses dominating, but with sedges in favourable, perhaps wetter, localities. Although there is nothing distinctively Arctic in the Carn Morval assemblages, they are totally different from Flandrian pollen assemblages from the Scillies, which are characterized by significant tree pollen, notably *Quercus*, *Betula*, *Corylus* and *Fraxinus* (Scaife 1984; 1986). This suggests the assemblages represent cold stage conditions, even though a number of the taxa, including *Plantago coronopus*, *Spergula* type and *Herniaria* type, are not known from Arctic or tundra environments at the present day. Much of the grass and sedge pollen may be from helophytic taxa which were living in the pool itself, and thus reflect very local fluctuations. The other herb taxa are commonly recorded in association with the disturbed minerogenic soils of the periglacial zone (Godwin 1975).

Six hypotheses can be invoked to explain the origin of the *Pinus* peak of CM2.

1. Vegetational change: the peak may suggest an actual increase in *Pinus* growing near the site.
2. Change in wind direction: this may have altered the source of the long-distance pollen, introducing large amounts of *Pinus* into the basin.
3. Sedimentation rate: a constant long-distance *Pinus* component, suggested by the stable but low frequencies of *Pinus* in CM1 and CM3, combined with a much lower sedimentation rate, would have the effect of increasing *Pinus* concentrations but not percentage frequencies.
4. Differential weathering: resistant *Pinus* grains are often found in partially oxidized sediment in higher

percentages because other less resistant grains have decayed. There is also a problem of differential recognition, *Pinus* being an easily identified grain even in an advanced state of destruction (Kerney *et al.* 1980).

5. Bee contamination: Faegri (1961) has noted the presence of anemophilous pollen adhering to bumble bees. Given the significance of other bee contaminants at this site, it is possible that the *Pinus* peak is a function of similar contamination.

6. Differential pollen influx rates: a low but consistent long-distance *Pinus* component combined with a reduction in the pollen productivity of the locally growing herbs would have the effect of increasing both *Pinus* percentages and concentrations.

An increase in *Pinus* growing near the site, possibly representing interstadial conditions, is thought unlikely. Other tree taxa, such as *Betula*, show no such increase during CM2. In addition, no macrofossils of *Pinus* have been found at the site, nor were any *Pinus* stomatal guard cells (Bennett 1982; Kerslake 1982) counted in the pollen preparations. The lack of other tree taxa, however, supports the hypothesis of a change of wind direction. Whereas bisaccate *Pinus* grains can be carried thousands of miles by wind, the pollen of other tree taxa is less successful in this respect (Birks & Birks 1980; Nichols *et al.* 1978). However, this hypothesis has the disadvantage of being largely untestable. Although it is possible to demonstrate the likelihood of reduced sedimentation rates in 2b and 2f, the lack of a comcomitant *Pinus* peak in 2b, and the fact that the *Pinus* peak is better developed in the percentage rather than in the concentration diagrams, suggests that this is an unlikely hypothesis. An increase in the concentrations of *Pinus* without an increase in the percentages would support this hypothesis; the opposite is, however, the case.

Two introduced species of pine are the only widespread trees growing on the islands today. *P. radiata* (Monterey Pine), planted since 1900, and *P. contorta* (Lodge Pole Pine), planted from 1964, are used as windbreaks (Lousley 1971). Solitary bees probably pick up pollen from these species, and may well have deposited small numbers in the Carn Morval profile, along with the other recent contaminants. It is extremely unlikely, however, that values as high as 56%, or that the continuous *Pinus* curve over seven levels, could have been produced in this way.

During severe climatic deterioration the pollen productivity of local herbs would be restricted, thus emphasizing any long-distance *Pinus* component in both concentration and percentage frequencies. The overall character of the pollen spectra, the stratigraphy of the site and the radiocarbon determinations (see below) constitute strong evidence in favour of this hypothesis.

These hypotheses are not mutually exclusive. It is probable that two or more of these mechanisms may have operated in conjunction to produce the *Pinus* peak. The favoured explanation is therefore that the feature is the result of a relatively small long-distance *Pinus* component being exaggerated in both percentages and concentrations by the oxidation of other less resistant pollen, combined with a decline in the pollen productivity of local herbaceous plants caused by desiccation of the basin and climatic deterioration. Data that might superficially have been interpreted as evidence of climatic amelioration is therefore almost certainly a product of climatic deterioration. Despite extensive sieving, no identifiable plant macrofossils have been discovered at Carn Morval.

(*iv*) *Coleoptera*

Dr G. R. Coope (Department of Geological Sciences, University of Birmingham) has analysed samples of beds 2b and 2f for Coleoptera, but only recovered decomposed weevils. These are the most resistant of the beetles to chemical decay, adding supporting evidence to likely weathering during 2b and 2f times caused by desiccation of the pool.

(*v*) *Radiocarbon determinations*

Two radiocarbon dates obtained by Wintle (1981) for this site have been quoted above. The precise location of these samples in relation to the stratigraphy identified in figure 8 is unclear, as the samples were simply labelled 'lowest layer' and 'middle layer'. In view of this uncertainty, and the high risks of contamination by modern carbon as suggested by the pollen analyses at this site, additional determinations were obtained.

Three sources of potential contamination by modern carbon can be identified at the Carn Morval site (figure 12): (i) rootlet penetration; (ii) percolation by groundwaters rich in modern humus; and (iii) tunnelling by *Andrena* sp. introducing recent pollen, faeces, dead bees and cocoon secretions.

Andrena sp. at Carn Morval show a marked preference for soft, easily excavatable sediment, beds 2b and 2f therefore having the greatest concentration of bee holes before excavation. Unfortunately these beds are also the richest in organic content (figure 9) and therefore the most suitable for radiocarbon dating.

Contamination by ancient or dead carbon is also a possibility given the likelihood of the deposition of eroded mor humus in the basin. This contamination can, however, be regarded as minimal, as such material would have been only slightly older than any autochthonous carbon in the basin, especially considering the resolution of the radiocarbon method on deposits of this general age.

Beds 2b and 2f were selected for dating because of their high organic content. The radiocarbon dates were completed as two series. For the 'first series', samples were taken from the face of the section after removal of at least the outer 0.5 m of material. After the radiocarbon analysis of these samples, and pollen analysis of the equivalent samples, a number of sources of contamination were identified. Contamination was most severe at the section face, decreasing with distance into the section away from the face. Accordingly, the 'second series' samples were obtained by using a Dutch-type wing auger by penetrating the face of the section horizontally. In this way, core samples from between 1.0 m and 3.5 m into the section through beds 2b and 2f were obtained (figure 12).

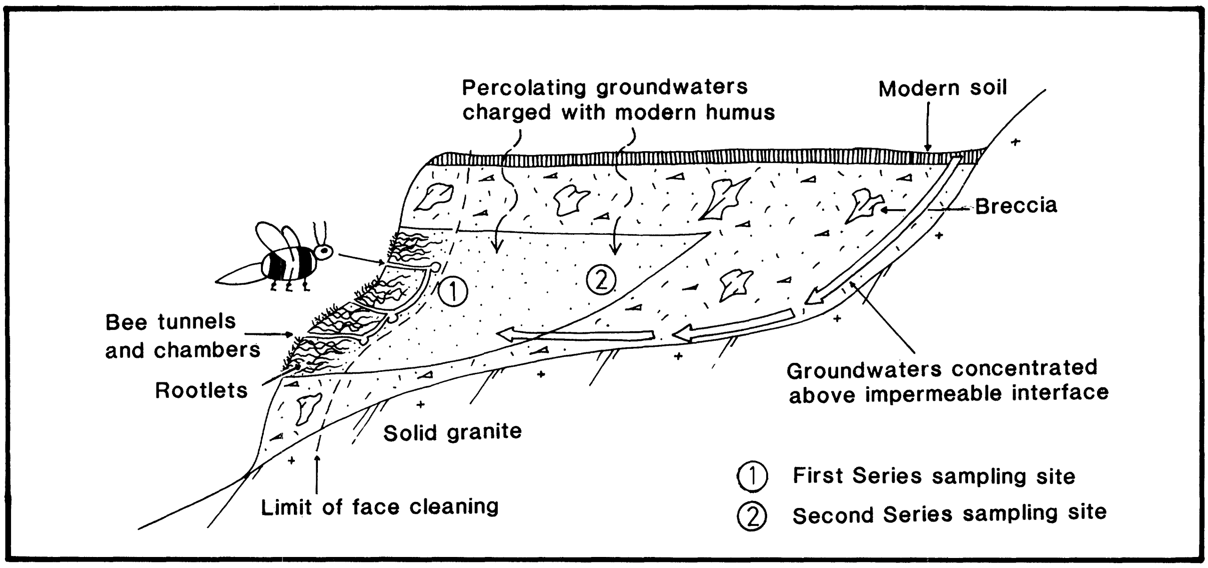

Figure 12. Diagram illustrating potential sources of radiocarbon contamination in coastal organic sequences, and the locations of radiocarbon samples.

Table 3. *Radiocarbon determinations (in years* BP*) for the Carn Morval samples*

	bed	residue	+	−	extract	+	−	lab. no.
first series	2f	21500	890	800	19300	120	120	Q-2358/9
	2b	24490	960	860	19860	220	210	Q-2356/7
second series	2b	—	—	—	21640	270	260	Q-2446

The samples were first broken up and scanned, and visible rootlet material removed. Samples with a major rootlet problem were discarded. Rootlets were only observed in some of the first series samples. Samples were then pre-treated as in Scourse (1985) to give a humic extract and residue, both of which were dated.

The Carn Morval first series determinations (see table 3) are stratigraphically consistent, bed 2f being younger than 2b. The extract dates are younger than the residue dates by between 4630 (2b) and 2200 (2f) years. This suggests that modern humus has been introduced at the face of the section, this contamination being most severe at the base. As not all the humic fraction was extracted from the residues, it is therefore likely that the residue dates are also too young. Humic extract determinations are usually younger than solid residue dates (Olsson 1974; Matthews 1980; de Gans & Cleveringa 1983; Caseldine 1983), and the differences have been consistently interpreted in terms of contamination by groundwaters charged with modern humus.

All the sources of contamination identified were more likely to have penetrated inward from the face of the section than downwards from above, because the overlying breccia is indurated. This clearly necessitated the recovery of a second series of samples. However, bed 2f was found to extend laterally into the section only a few centimetres after its removal for the first series samples, and could not be further sampled. The second series sample of bed 2b was pre-treated but, on combustion, the residue was found to contain insufficient carbon for dating. Therefore, the second series programme at Carn Morval only consists of the determination of the humic fraction of bed 2b (see table 3).

This humic extract determination is older than the first series humic extract determinations by about 2000 years, suggesting that it is less contaminated by modern humus than the first series samples. As no residue determination was possible there is unfortunately no control on the amount of contamination in the first series 2b residue determination. The first series residue determinations are regarded as the most reliable at the site, deposition of the organic material having occurred between about 24490^{+960}_{-860} and 21500^{+890}_{-800} (^{14}C) years BP and the overlying breccia (unit 3) between 21500^{+890}_{-800} (^{14}C) years and 18600^{+3700}_{-3700} (TL) years BP. All seven ^{14}C determinations from the Carn Morval site are well grouped, non-inverted, and the differences between residue and extract dates are explainable.

(*b*) *Watermill Cove*

(*i*) *Stratigraphy*

At SV925123 a section containing organic material occurs immediately to the southeast of Watermill Cove proper on the northeast coast of St Mary's (figure 1). The section (figure 13), which is about 3 m thick at its greatest extent, lies above the modern beach and is transverse to the local slope dip direction towards the northeast. Lying below 1–2 m of coarse granitic solifluction breccia, unit 4, there is a fairly undisturbed unit of black humic material, unit 3, between 1 m and 1.5 m thick, and extending laterally about 20–25 m along the base of the section which lies at around 4.4 m O.D. Underlying the organic deposit, as revealed by

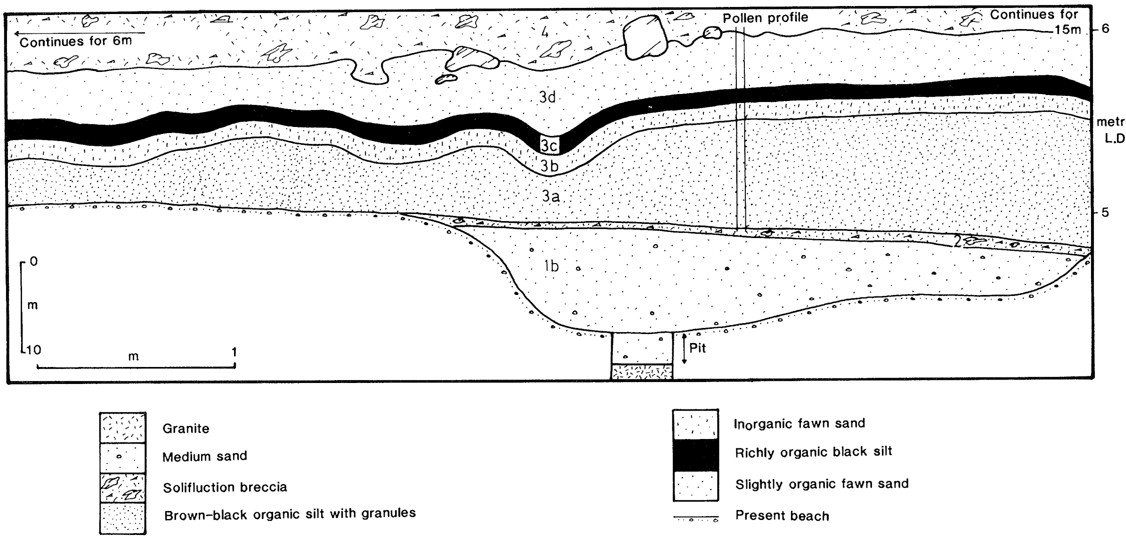

Figure 13. Watermill Cove: site stratigraphy.

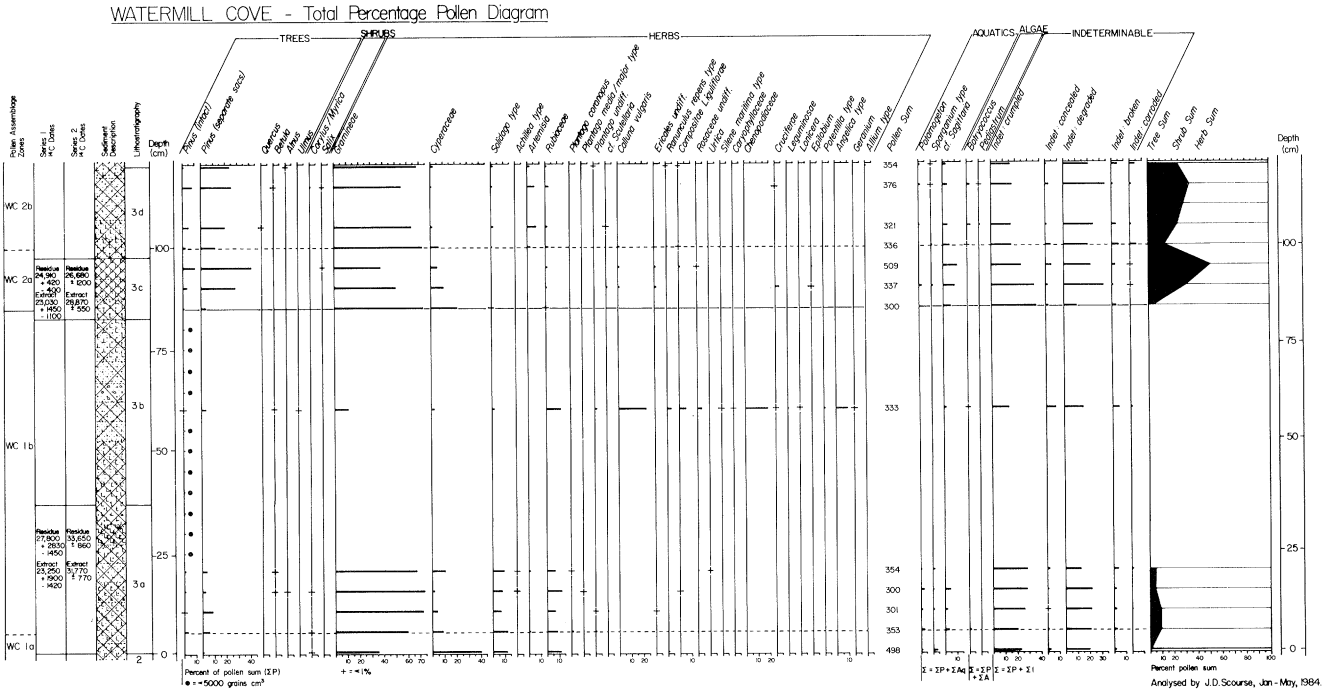

Figure 14. Watermill Cove: total percentage pollen diagram, uncorrected for contaminant pollen at level 60 cm. Pollen sums as in figure 10.

pits, is a homogeneous unit of coarse to medium light brown sand, unit 1b, but immediately between the sand and organics is a thin layer of coarse cemented granite breccia, unit 2; the underlying sands are uncemented, and appear to rest on solid granite. The contact between units 1 and 2 is erosional. Units 2–4 are correlated with the Porthloo Breccia.

Sand, unit 1b, has a dominant mode of 1.0ϕ on the coarse to medium sand boundary, moderate to good sorting, and contains only 1% silt and 1% clay. The sediment resembles modern dune sand but its grain-size distribution lacks the high kurtosis characteristic of such sediments; it may therefore be a backshore sand.

At SV924123, along the southern shore of Watermill Cove itself, a raised beach consisting of both cobbles and sand is exposed at the same elevation. The beach sand, unit 1b, therefore provides a stratigraphic link between the two sections and, as such, forms part of the type-exposure of the Watermill Sands and Gravel.

This sand bed is overlain by a thin granite breccia, interpreted as a solifluction deposit which must have spread over the exposed beach, and this passes upwards into the organic unit. This can be subdivided into four beds, a, b, c and d. Bed 3a is brown to black organic silt, highly humified, containing some quartz granules. Bed 3b is a fawn to light brown sand, largely inorganic compared with 3a, again containing quartz granules; the junction between 3a and 3b is gradational, so that the definition of the contact is somewhat arbitrary. Bed 3c is a black, richly organic, highly humified silt; the contact between 3b and 3c is sharp, although not unconformable. Bed 3d is very similar lithologically to the upper parts of 3b.

The internal stratigraphy of unit 3 is given in the

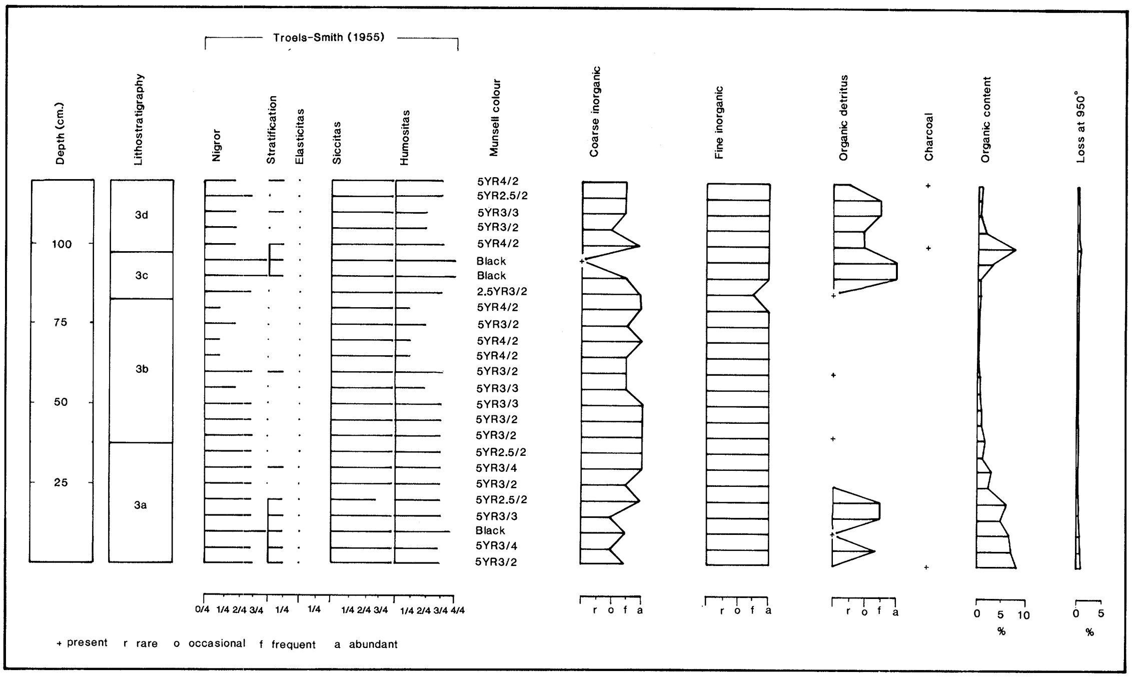

Figure15. Watermill Cove: Troels–Smith (1955) sediment description, Munsell colour, pollen washings and loss-on-ignition data for the organic sequence.

sediment column of the percentage pollen diagram (figure 14) and is supported by the pollen washings/loss-on-ignition diagram (figure 15). Unidentifiable carbonized organic detritus occurs in beds 3a and 3c, and the high organic content of these beds is demonstrated by the loss-on-ignition analysis at 550 °C. Organic content is greatest in the basal level of bed 3a, and in the centre of bed 3c, reaching almost 10% at both levels. Otherwise, the organic content of the profile is very low, falling to less than 1.0% towards the upper part of 3b. There is an abundance of fine inorganic detritus through all beds; coarse inorganic detritus levels are also high, declining only where the organic content reaches its maxima. The organic material is estimated to consist of 90% humus on the basis of smear slide examination, the remainder comprising unidentifiable plant fragments, pollen and spores.

The coarse breccia, unit 4, overlies the entire sequence. Only the very uppermost parts of bed 3d have been deformed by the overlying solifluction. To the northwest of the organic sequence, a quartz–porphyry dyke (elvan) crosses the shore platform from southwest to northeast (figure 2). Clasts derived from this dyke can be found in the breccia, unit 4, suggesting that the dominant direction of solifluction was from the east, northeast or north, in response to the local slope morphology.

(*ii*) *Origin of basin and infill*

Solifluction is considered to be the cause of the accumulation of the organic sequence at Watermill Cove. Solifluction down the slopes of neighbouring headlands would have ponded the small stream that reaches the sea today at the Cove, forming a small lake or large pond into which the sediments accumulated. The varying sediments of unit 3 would therefore represent inwashings of coarse minerogenic sediment, probably associated with active solifluction, contrasting with periods of more organic sedimentation. The hypotheses invoked to explain the origin of the high degree of humification at Carn Morval can also be used here. The main obligate aquatic taxa at Watermill Cove are *Sparganium* type, *Potamogeton*, cf. *Sagittaria*, and the algae *Botryococcus* and *Pediastrum*. These are represented by quite high frequencies in beds 3a and 3c, and it is perhaps significant that two of these taxa, *Pediastrum* and cf. *Sagittaria*, are recorded here and not at Carn Morval. This suggests the increased contribution of allochthonous humus at Watermill Cove in comparison with Carn Morval.

All the sediments in the profile can therefore be regarded as lacustrine, the variations between beds being caused by the influx of different materials within the catchment.

(*iii*) *Pollen analysis*

Pollen samples were taken at 5 cm intervals from the base of bed 3a as far as the base of unit 4 (figure 13). As at Carn Morval, the organic sequence was in a few places penetrated by *Andrena* tunnels, so up to 0.75 m of the face was cleaned before sampling to avoid this source of contamination. Pollen preparation methods and conventions were the same as for Carn Morval, except that a 'concentration threshold' (Scourse 1985) of 5000 grains cm^{-3} was used as an objective method of rejecting levels with pollen concentrations so low (figure 16) as to make analysis unprofitable. The pollen sum for the concentration threshold includes all palynomorphs counted, identifiable and unidentified.

The pollen counts showed that contamination by *Andrena* was minimal, only one level (60 cm) being affected. This level occurs within the most inorganic part of the profile, in bed 3b (figure 13), and is

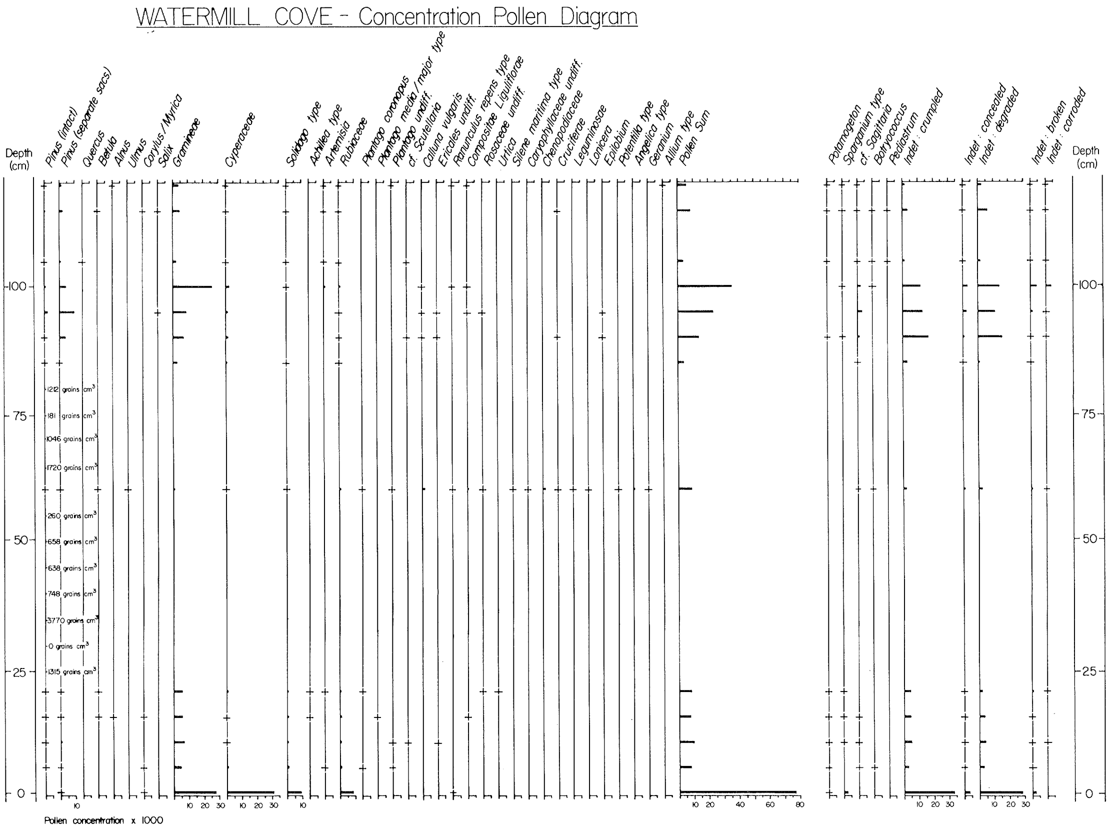

Figure 16. Watermill Cove: concentration pollen diagram uncorrected for contaminant pollen at level 60 cm.

juxtaposed to levels containing pollen well below the concentration threshold (figure 16). Taxa identified as *Andrena* contaminants at this level include *Ranunculus repens* type, Compositae Liguliflorae, *Silene maritima* type, Caryophyllaceae, Chenopodiaceae, Cruciferae, Leguminosae, Rosaceae (cf. *Rubus fruticosus*), *Angelica* type and *Geranium*. Nine of these taxa were identified as contaminants at Carn Morval.

Most pollen reaching this basin would have originated locally, including obligate aquatic and helophytic plants growing within the lake itself. Extra-local and penecontemporaneous pollen would have been introduced through the erosion of the surrounding slopes, complemented by a small regional airborne component.

Of the 24 levels prepared, 13 contained countable pollen, one of these being the contaminated level discussed above. The 11 uncounted levels all contained pollen below the concentration threshold. Level 60 cm would not have contained a countable concentration were it not for the contaminant pollen. The highest concentration occurs in the basal level, with 148000 grains cm^{-3}, with a second maxima of 75000 grains cm^{-3} at 100 cm in bed 3d (figure 16).

As at Carn Morval, the numerical ZONATION (Gordon & Birks 1972) program indicates that it is the change in *Pinus* frequencies that enables the diagram to be divided into two pollen assemblage zones (WC1 and WC2), these both being further subdivided into two subzones (PASZ) (figure 14).

Zone WC1a, 0 cm, Cyperaceae–Gramineae–Solidago–Rubiaceae PA *subzone, and Zone WC1b, 5–20 cm, Gramineae–Solidago–Rubiaceae* PA *subzone.* Zone WC1 is dominated by herb taxa, and occurs within bed 3a. The boundary between subzones WC1a and WC1b is defined by the decline in Cyperaceae upwards from the basal level; WC1a therefore consists of only one level, and WC1b four. WC1a is characterized by high Cyperaceae (40%), relatively low Gramineae (36%), high *Solidago* type (12%) and Rubiaceae (11%), and high *Sparganium* type (3%). WC1a contains the highest frequencies of Cyperaceae, *Solidago* type and *Sparganium* type of the sequence, and *Pinus* contributes less than 1%.

In subzone WC1b, Graminaeae replaces Cyperaceae as the dominant pollen taxon, Cyperaceae dropping to 2% and Gramineae rising to 74% at 15 cm. Comparison with the concentration diagram (figure 16) reveals that changes in the percentage frequencies of a number of other taxa, including *Solidago* type, Rubiaceae, *Potamogeton*, cf. *Sagittaria*, *Sparganium* type and *Botryococcus* are artefacts of the percentage calculations.

The contaminated level (60 cm) is not placed in either PAZ.

Zone WC2a, 85–100 cm, Pinus–Gramineae–cf. Sagittaria PA *subzone and Zone WC2b, 100–120 cm, Pinus–Gramineae–Artemisia* PA *subzone.* WC2 is characterized by much higher *Pinus* frequencies than WC1, with a comcomitant decrease in the frequencies, although not the diversity, of the herb taxa. The boundary between WC2a and WC2b is based on the relative frequencies of cf. *Sagittaria* and *Artemisia*. WC2a coincides with bed 3c, and WC2b with 3d.

WC2a contains the highest *Pinus* frequencies of the profile, rising to 51% at 95 cm from 4% at 85 cm. Intact *Pinus* grains consistently contribute only around 10% of total *Pinus*. Gramineae frequencies are consistently high, reaching 73% in the basal level of the subzone. The decline in the Cyperaceae values through WC2a is an artefact of the percentage calculations. *Sagittaria* (cf.) values are consistently high in both percentage and concentration frequencies, reaching 12% at 95 cm; other obligate aquatic taxa recorded are *Potamogeton* and *Sparganium* type. *Solidago* type and Rubiaceae concentrations are similar to WC1b.

In WC2b, cf. *Sagittaria* frequencies decline to 4% in the uppermost level, *Artemisia* rising to 7% at 105 cm. *Pinus* and Gramineae totals, although erratic, maintain their presence established in WC2a, although Cyperaceae concentrations decline. Along with the decline in cf. *Sagittaria*, pollen of the other obligate aquatic taxa is very sparse, and the apparent rise in *Botryococcus* is an artefact of the percentage calculations. *Solidago* type and Rubiaceae totals remain consistently low.

In both WC1 and WC2, indeterminate levels are high, although physical breakdown (crumpled and degraded) is always dominant over chemical and biological decay (corroded).

The importance of obligate aquatic taxa, and the behaviour of Cyperaceae, lends some support to the evidence of the sediments themselves, and the geomorphological context of the site, that this sequence formed in a small lake, and that the humus represents allochthonous material from within the catchment. The very high values for Cyperaceae and *Sparganium* type in the basal level suggests ponded conditions, the subsequent decline in both perhaps representing the infilling of the basin with minerogenic sediment in bed 3b times; the lack of pollen in 3b supports this interpretation. The renewed importance of the obligate aquatic taxa, and in particular cf. *Sagittaria*, in bed 3d suggest a second phase of ponding. The stratigraphy and pollen record combined therefore suggest two ponding episodes at Watermill Cove.

The similarities between the sedimentological and stratigraphical contexts of the *Pinus* peaks at Carn Morval and Watermill Cove are striking. However, the *Pinus* peak at Watermill Cove is not coincident with highly humified bed 3c, as the feature transcends the lithological boundary between 3c and 3d. A combination of long-distance transport with differential weathering and a decline in the pollen productivity of the local vegetation is once again favoured as the most likely explanation for this feature. The desiccation of the lake in bed 3d times has already been inferred, and this may have coincided with climatic deterioration. It is probable that bed 3d contains a large proportion of reworked *Pinus* pollen from 3c below.

No identifiable macrofossils have been discovered at Watermill Cove.

(*iv*) *Radiocarbon determinations*

Page (1972), in this paper on radiocarbon dating of interglacial deposits in Britain, reports two dates on samples of the organic material at Watermill Cove. Page interpreted the organic material (unit 3 of this study) as Hoxnian, as it lies above a raised beach which was correlated with the lower 'Chad Girt' beach of Mitchell and Orme (1967), and uses the radiocarbon evidence to 'date' the Hoxnian interglacial. Shotton (1973) points out that there is no evidence to justify Page's assumption that the material is Hoxnian, therefore rejecting Page's conclusions. The ^{14}C determinations obtained by Page were $21\,200^{+900}_{-600}$ years BP (GaK-2471) and $22\,200^{+400}_{-400}$ years BP (T-833). Page does not record the stratigraphy in detail, and it is not possible to identify where these samples came from in terms of the stratigraphy described here. The most organic beds 3b and 3d (figure 15) were therefore resampled and pre-treated for radiocarbon analysis (see table 4).

The samples with large standard deviations had very low carbon yields on combustion (V. R. Switsur, personal communication). The first series humic extract determinations are between 4550 (3a) and 1870 (3c) years younger than the residue dates, but with very large standard deviations. This suggests that contamination by modern humus is occurring at the face of the section, contamination being most severe towards the base (bed 3a). The second series are all considerably older than the first series, the differences ranging from 8520 (3a extract determinations) to 1780 years (3c residue determinations). This confirms the expected greater contamination of the first series samples, and suggests that contamination is greatest at the base of the section. It is significant that the largest differences are between the 3a extract determinations, and the smallest between the 3c residue determinations. This implies that the most unreliable determinations are the extracts, particularly the basal samples, and the most reliable are the residue determinations, particularly the upper samples.

However, the differences between the second series residue and extract determinations also have to be explained. Whereas the 3a determinations resemble the equivalent first series determinations in that the extract is 1280 years younger than the residue, the 3c extract date is older than the residue by 2190 years. These differences imply that contamination by modern humus is a problem at the base of the profile up to 3 m into the section, but that this contamination has ceased to be significant higher up the profile, and that contamination at the base may not be originating

Table 4. *Radiocarbon determinations (in years* BP*) for the Watermill Cove samples*

	bed	residue	+	−	extract	+	−	lab. no.
first series	3c	24900	430	410	23030	1275	1100	Q-2362/3
	3a	27800	1770	1450	23250	1720	1420	Q-2360/1
second series	3c	26680	1410	1200	28870	590	550	Q-2407/6
	3a	33050	960	860	31770	850	770	Q-2408/2447

solely at the face of the section. It is probable that the cemented breccia, unit 2, acts as an impermeable layer, and that groundwater charged with modern material is percolating through bed 3a, which acts as an aquifer, along the contact with unit 2, some modern humus being deposited in the process (figure 12). Bed 3c, by contrast, is freely drained.

The older second series 3c extract determination can be explained in terms of the inwashing of older mor humus into the lake; the likelihood of such allochthonous humus being present is supported by the interpretation of the pollen diagrams.

The large gross differences between the first and second series samples show that contamination by humus is not the only source of modern carbon at the face of the section; if it were, then the second series determinations should approximate to, or be only slightly older than, the first series residue determinations. The extra contamination is almost certainly the result of rootlets and *Andrena* burrows at the face of the section.

It is therefore suggested that the most reliable determination for bed 3a is $33\,050^{+960}_{-860}$ years BP, and for 3c, $26\,680^{+1410}_{-1200}$ years BP.

(*c*) *Porth Askin*

(*i*) *Stratigraphy*

Organic sediments are exposed in a section on the southern side of Little Porth Askin on St Agnes (SV882074; figure 1), overlain by granitic solifluction breccia (figure 17) which is in turn overlain by a sandy silt deposit. The organic material (unit 1) and the breccia (unit 2) are correlated with the lower Porthloo Breccia of the southern Scillies, the sandy silt (unit 3) with the Old Man Sandloess (figure 3). Pits dug at the base of the section ascertained that the organic material rests directly on the granite bedrock at 3.08 m O.D.; this contact can be observed directly at the western end of the section.

The organic sequence is highly distorted, and although the contact with the overlying breccia is complex, it appears gradational. Although structures within the organic material suggest that it has been disturbed by the overlying solifluction, it is nevertheless possible to define distinct beds within the organic unit. Resting directly on the granite is a highly organic black silty sand, bed 1a, overlain by a well-cemented brown largely inorganic quartzose sand, 1b. Beds 1c and 1e resemble bed 1a, and beds 1d and 1f resemble 1b. The structures in the deposit suggest that beds 1e and 1f are simply soliflucted beds 1c and 1d. The organic sediments are extremely similar to those described from Carn Morval and Watermill Cove, and they probably have a similar origin.

(*ii*) *Pollen analysis*

A sample of the organic material was prepared for pollen analysis, and yielded countable pollen (see Appendix 5). The assemblage is dominated by Gramineae, Cyperaceae and an assemblage of open habitat herbs similar to those recorded at Carn Morval and Watermill Cove, including *Achillea* type, *Solidago* type, *Plantago* undiff. and Rubiaceae. A number of the taxa,

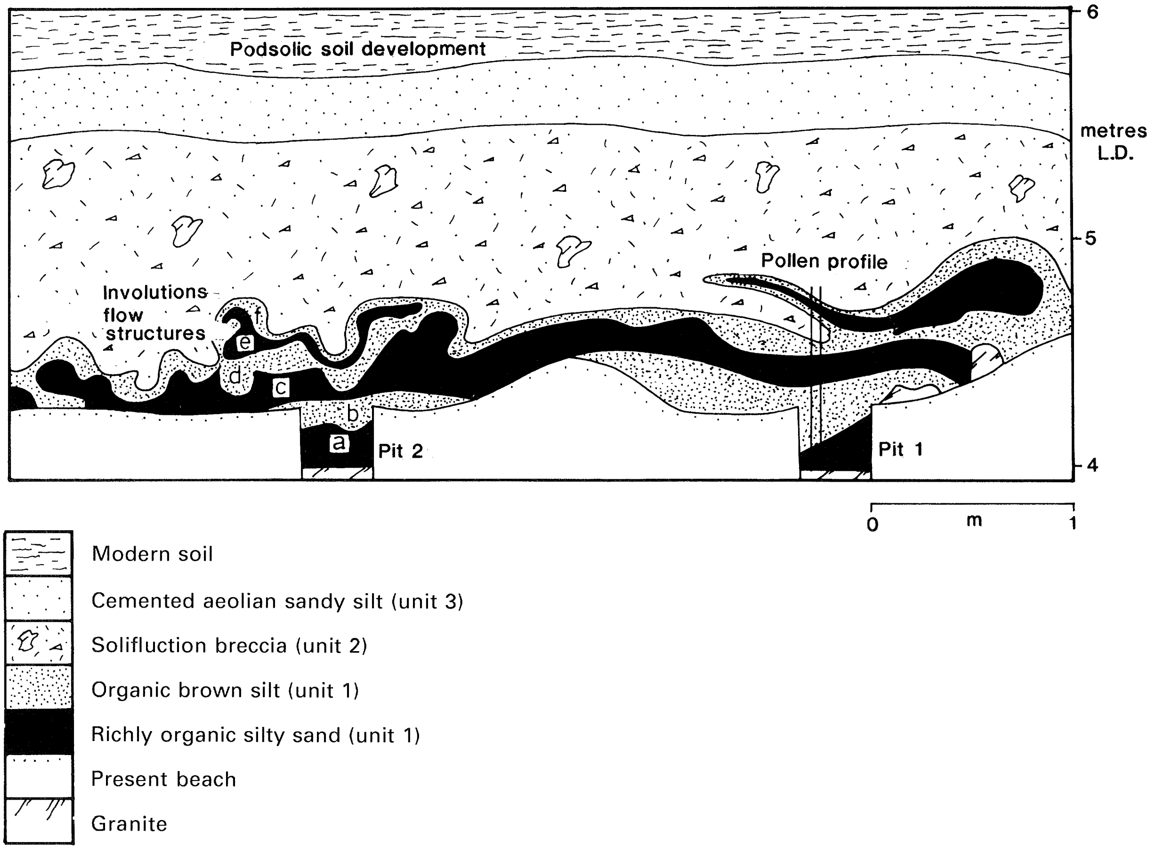

Figure 17. Porth Askin: site stratigraphy.

Table 5. *Radiocarbon determinations (in years* BP*) for Porth Askin samples*

	residue	+	−	extract	+	−	lab. no.
first series	23980	1400	1200	20960	180	180	Q-2370/1
second series	24550	500	470	22960	625	580	Q-2412/3

of the taxa, notably *Rubus fruticosus*, *Helianthemum* and *Hippophaë rhamnoides* were very much better preserved than the other taxa, and this, combined with the presence of solitary digger bee tunnels in the sediment, suggests that contamination by bees is a problem at this site.

The lack of obligate aquatic taxa in the assemblage perhaps suggests that autochthonous humus may be present in the organic material.

No identifiable plant macrofossils have been observed at Porth Askin.

(*iii*) *Radiocarbon determinations*

Wintle (1981) has TL-dated a sample of the Old Man Sandloess at this site to $18600^{+3,700}_{-3,700}$ years BP (QTL-1d). To calibrate this TL date, a sample of the underlying organic material was ^{14}C-dated to 25920^{+325}_{-325} years BP (Q-2176) as part of the same study. As the pollen assemblage shows evidence of contamination by burrowing bees, and as the exact ^{14}C sampling point was not known, it was decided to re-analyse bed 1a. Sampling and pre-treatment procedures were as for Carn Morval.

The difference between the first series determinations (see table 5) of 3020 years suggests contamination by modern humus at the face of the section, and the difference between the second series determinations of 1590 years suggests that this contamination is less of a problem away from the face. However, the difference between the second series determinations suggests that groundwater percolation along the impermeable bed 1a–granite interface is a problem within the section.

The differences between the residue determinations and the extract determinations, 570 and 2000 years respectively, are both relatively small, especially considering the large standard deviations on these measurements, and can be largely accounted for in terms of contamination by solitary bees at the face of the section. Rootlet contamination is not a problem at this site. It is suggested that the second series residue determination is the most reliable for this site, and, with the TL date, it suggests that the breccia, unit 2, was deposited between 24500^{+500}_{-470} and $18600^{+3,700}_{-3,700}$ years BP.

(*d*) *Porth Seal*

(*i*) *Stratigraphy*

Porth Seal, on the northwestern coast of St Martin's (SV918166; figure 1), is one of the most important sites discussed by Mitchell & Orme (1967); it was here they interpreted two raised beaches in section, an observation not recorded elsewhere in the islands until Mitchell (1986) reported a similar sequence at Northward Bight, St Martin's. The most complete sections at Porth Seal occur on the south side of the bay. A number of sequences have been recorded here (Scourse 1985), but only two of these; Porth Seal B and C (figures 18 and 19), are critical. Porth Seal C

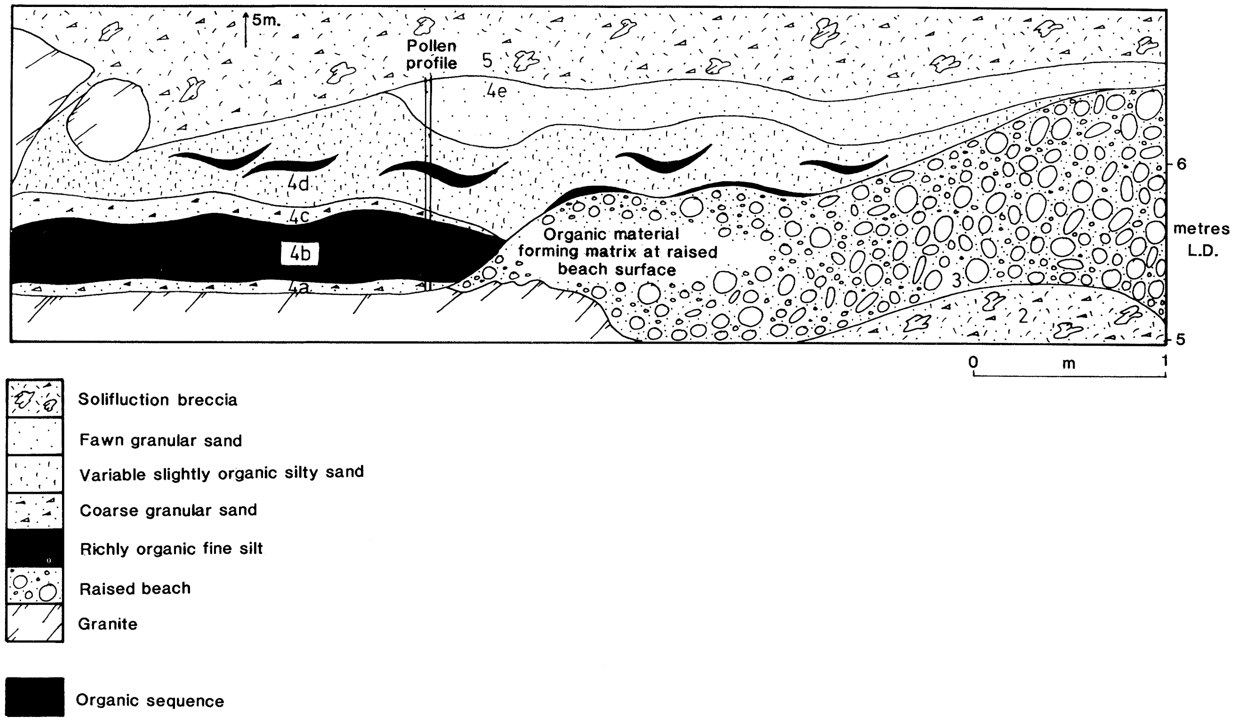

Figure 18. Porth Seal: stratigraphy of organic sequence at Porth Seal B.

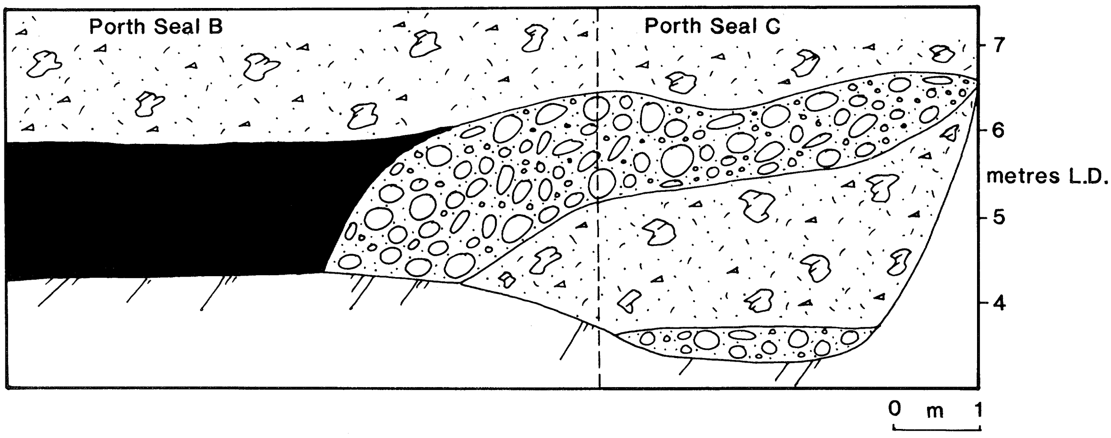

Figure 19. Porth Seal: stratigraphic relations between Porth Seal B and C. For key see figure 18.

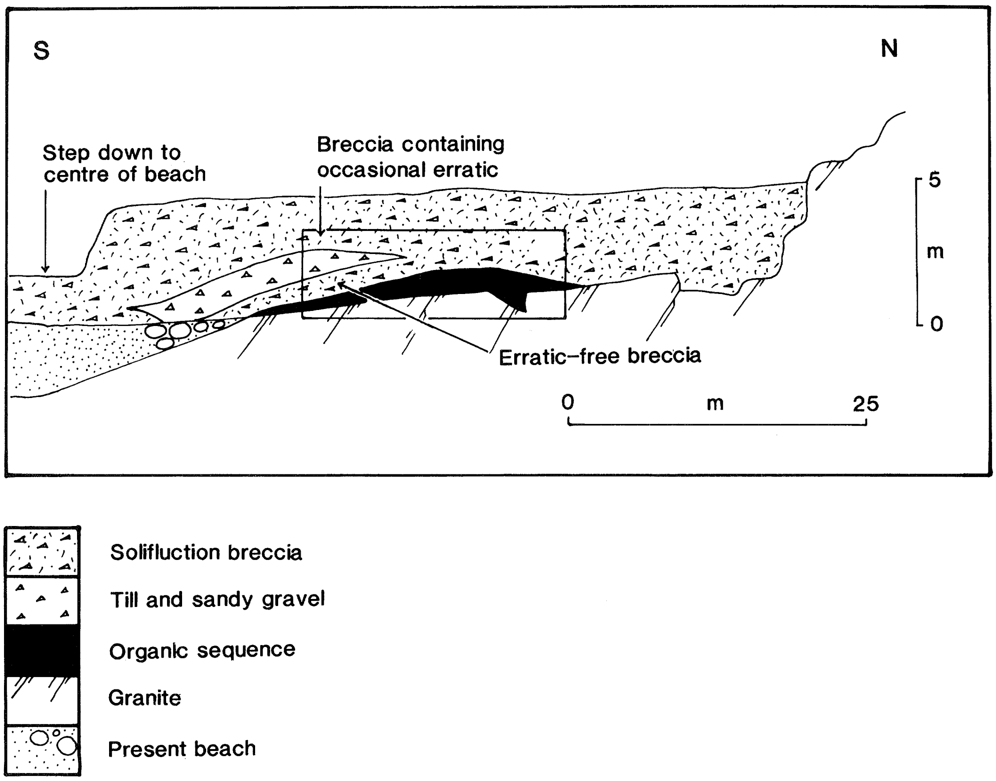

Figure 20. Bread and Cheese Cove: site stratigraphy.

corresponds to the section described by Mitchell & Orme (1967).

Matrix-supported, rounded, raised beach cobbles, unit 3, are exposed at the western end of Porth Seal B (figure 18) overlying a unit of granite solifluction breccia, unit 2. An organic deposit, unit 4, overlies the beach cobbles. This deposit, which is about a metre thick, consists of several distinct beds that are mostly internally stratified. The lowermost bed, 4a, is a thin seam of coarse white granitic sand and granules, which rests directly on the beach cobbles. It lenses out laterally to the west such that the overlying bed, 4b, a black, richly organic fine silt, also rests directly on the beach cobbles at its western limit. In places the matrix of the cobble deposit consists of this organic silt. Bed 4c is similar to bed 4a, and is overlain by 4d, a thick bed of internally variable organic, silty sands with granite clasts and quartz granules. Unit 4 is overlain by up to 5 m of coarse granitic solifluction breccia, unit 5, the base of which lies between 5.7 and 6.5 m O.D.

The lowest unit at Porth Seal B, the granitic solifluction breccia (unit 2), can be traced laterally as unit 2 of Porth Seal C to the west, the Gipping (= Wolstonian) 'head without erratics' of Mitchell & Orme (figure 19). At Porth Seal C this breccia is underlain by another unit of raised beach cobbles, unit 1. This deposit corresponds to the Hoxnian 'Chad Girt Raised Beach' of Mitchell & Orme (1967); the upper unit of raised beach cobbles, unit 3, represents the type-unit for their Eemian (= Ipswichian) 'Porth Seal Raised Beach'. No organic deposits occur at Porth Seal C, and unit 3 is overlain directly by the coarse granitic solifluction breccia, which can be traced laterally as unit 5 at Porth Seal B.

Rather than the direct litho-chronostratigraphical interpretation suggested by Mitchell & Orme (1967), it is suggested that only one *in situ* raised beach, unit 1, occurs at Porth Seal. The upper parts of this deposit have become entrained within the overlying solifluction and appear as an upper, younger, raised beach (unit 3). At almost every site in the Isles of Scilly and West Cornwall where raised beach sediments have been over-ridden by solifluction lobes and sheets, 'tongues' of ingested beach material can be seen in the overlying breccia. These can often appear in two-dimensional sections as stratigraphically distinct raised beach units. Criteria for identifying such soliflually reworked beach sediments are outlined in Scourse (1987); at Porth Seal the upper beach sediments are matrix supported, and the matrix is clearly of soliflual and not beach origin.

In terms of the stratigraphy proposed in figure 3, unit 1 can be correlated with the Watermill Sands and Gravel, with its base at 3.25 m O.D., and units 2–5 can all be correlated with the Porthloo Breccia. Units 2 and 3 are interpreted as facies Aa 'deformation breccia' (Scourse, 1987).

As at the other organic sites, the organic sequence here can be best interpreted as a lacustrine deposit, with variable minerogenic and organic sedimentation into the basin.

(*ii*) *Pollen analysis*

Two samples from this organic material have been analysed for pollen (Appendix 6). Both samples were extremely well humified, and pollen preservation was consistently poor. Important elements include Gramineae, *Solidago* type and Rubiaceae, and consistent minor contributors include Cyperaceae, *Achillea* type and *Plantago* spp. The low percentages for the tree taxa *Pinus*, *Alnus* and *Corylus* can be accounted for as long-distance transport. The low but consistent presence of *Sparganium* type, along with *Potamogeton* and *Typha latifolia* in the lower sample, supports the interpretation of the sequence as lacustrine in origin. The spectra are extremely similar to those recorded from the other organic sequences at Carn Morval, Watermill Cove and Porth Askin.

(*iii*) *Radiocarbon determinations*

Beds 4b and 4d were sampled and pre-treated for radiocarbon analysis (see table 6). The first series determinations, although internally consistent and non-inverted, are considerably younger than those from stratigraphically equivalent material at the other sites, suggesting contamination by modern carbon. The extract determinations are between 2340 (4b) and 4230 (4d) years younger than the equivalent residue determinations, suggesting contamination by modern humus at the face of the section. These samples were contaminated by rootlets.

This contamination is confirmed by the second series samples which were taken 3 m into the section. Low carbon yields on combustion prevented measurements of the 4b residue sample or the 4d extract sample. The first series residue sample of bed 4d is younger than the equivalent second series sample by 10220 years, and the first series extract sample of bed 4b by as much as 18060 years. In the absence of any measurement of the second series 4b residue or 4d extract samples, it is not possible to arrive at any conclusions concerning humus contamination of the second series samples, or the autochthonous–allochthonous status of the humus in the deposit. However, the second series dates, being so much older, do suggest serious contamination of the first series samples; it is unlikely that such large differences could be accounted for solely by the inwashing of recent humus.

Despite this lack of control information, it is suggested that the second series determinations are possibly the most reliable, bed 4b being dated at 34500^{+885}_{-800} and bed 4d at 25670^{+560}_{-530} years BP.

No identifiable macrofossils have been discovered at this site.

4. CRITICAL SITES: NORTHERN SCILLIES

(*a*) ***Bread and Cheese Cove***

(*i*) *Stratigraphy*

The section at Bread and Cheese Cove, on the northern coast of St. Martin's (SV940159; figure 1) was described in detail by Mitchell & Orme (1967). A granite wave-cut platform rises upwards towards the southwest to meet the base of a coarse granitic solifluction breccia, unit 2 (figures 20 and 21). At the base of the section there is a deposit of very coarse granite rubble and boulders, which extends outwards from the modern cliff across the granite platform. Forming the matrix between these boulders, and also a coherent unit towards the base of the section, is a humic horizon, bed 1b, a dark brown silty sand with quartz granules. A number of pits were dug at the base of the section revealing a rich organic sand, bed 1a, resting either on the granite boulders or the wave-cut platform. Bed 1a passes upwards into 1b, which in turn is overlain by the solifluction breccia, unit 2. The base of this unit lies at 5.89 m O.D. and the contact with the organic unit below is sharp. The solifluction breccia is nowhere thicker than 2 m where it is overlain gradationally by unit 3, a clay-rich light brown diamicton containing abundant erratic clasts, which thickens towards the northeast where its base passes

Table 6. *Radiocarbon determinations* (*in years* BP) *for the Porth Seal samples*

	bed	residue	+	−	extract	+	−	lab. no.
first series	4d	15450	120	120	11220	1550	1300	Q-2366/7
	4b	18780	260	250	16440	120	120	Q-2364/5
second series	4d	25670	560	530	—	—	—	Q-2409
	4b	—	—	—	34500	885	800	Q-2410

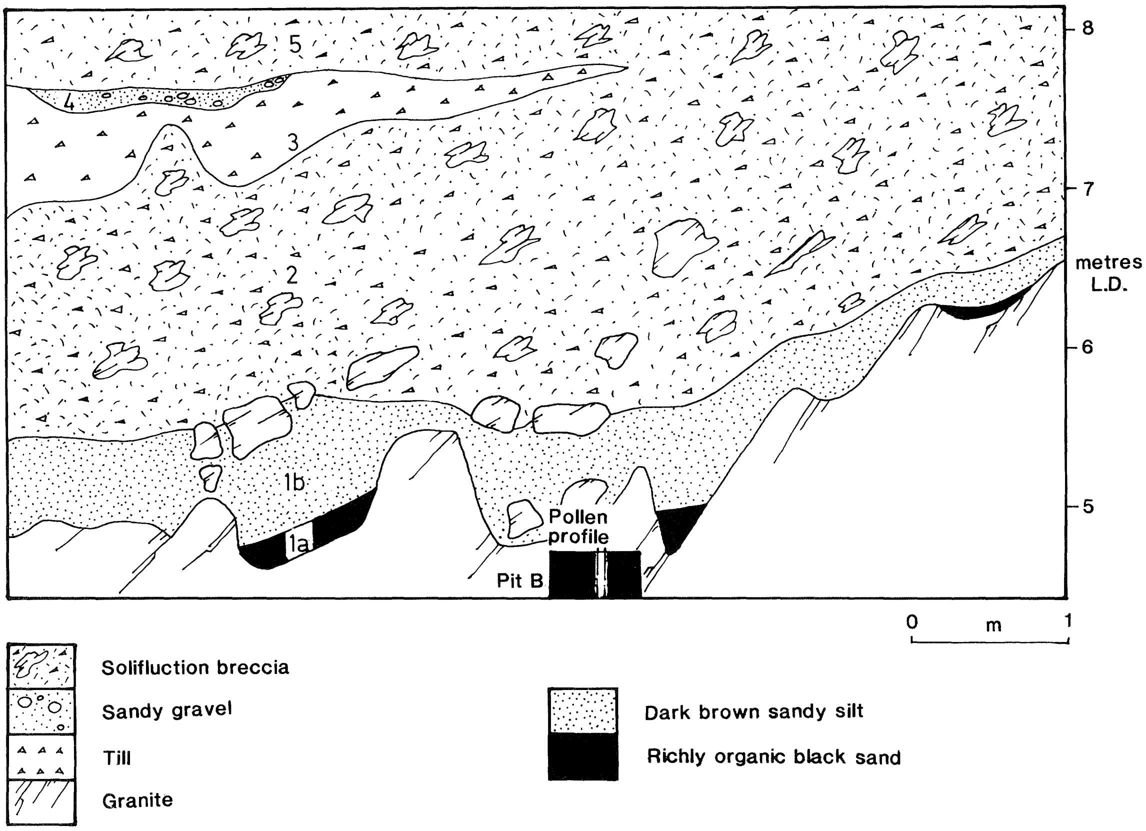

Figure 21. Bread and Cheese Cove: detail of stratigraphy in the centre of the section.

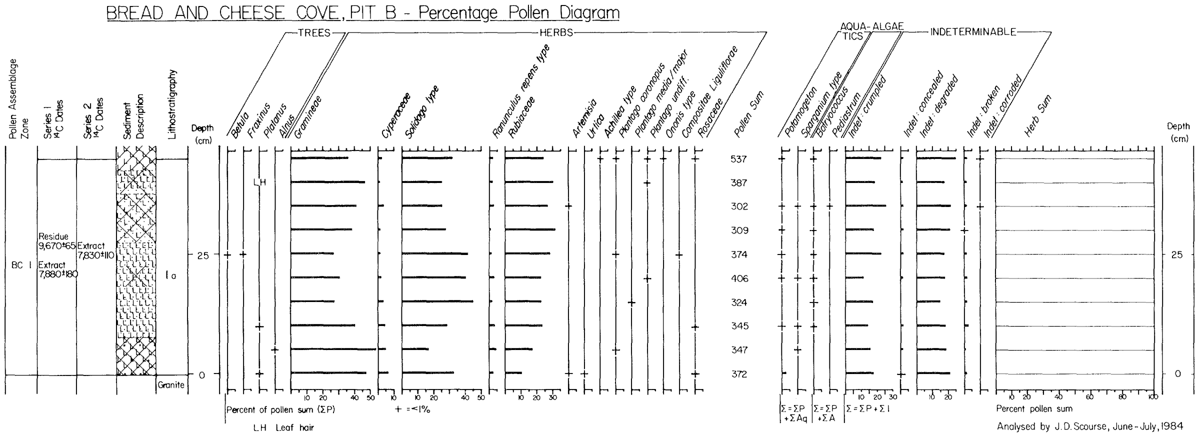

Figure 22. Bread and Cheese Cove: percentage pollen diagram from pit B. Pollen sums as in figure 10.

beneath the modern beach level. This lens is 22 m in length and reaches a maximum thickness of 2 m. At one point (figure 21) unit 3 is overlain by a small lens of iron-cemented sandy gravel, unit 4, which also contains abundant erratic clasts. Both units 3 and 4 are overlain by up to 4 m of coarse, dominantly granitic, breccia, unit 5, which contains occasional erratic clasts. The section is capped by a number of large granite boulders.

Units 1 and 2 are correlated with the Porthloo Breccia, unit 3 represents the stratotype for the Scilly Till, unit 4 is correlated with the Tregarthen Gravel and unit 5 represents the stratotype for the Bread and Cheese Breccia (figure 3).

A profile through one of the pits, B, was sampled for pollen and loss-on-ignition analysis. The stratigraphy of the organic deposit in pit B is shown in the sediment column of the percentage pollen diagram (figure 22). Bed 1a has a generally high organic content, with the highest value of 35 % occurring towards its base (figure 23). These loss-on-ignition results support the sediment description (figure 22), with declining organic content, and reduced humification, upwards (figure 23); inorganic detritus, however, increases upwards.

There is no evidence for breccia deposition and, therefore, solifluction, between the granite platform and the organic sediments. The organic sediments fill the cracks in the surface of the platform, and the interstices of the granite boulders associated with the platform. These boulders probably represent an immature raised beach deposit, organic sedimentation having occurred directly on the surface of the old

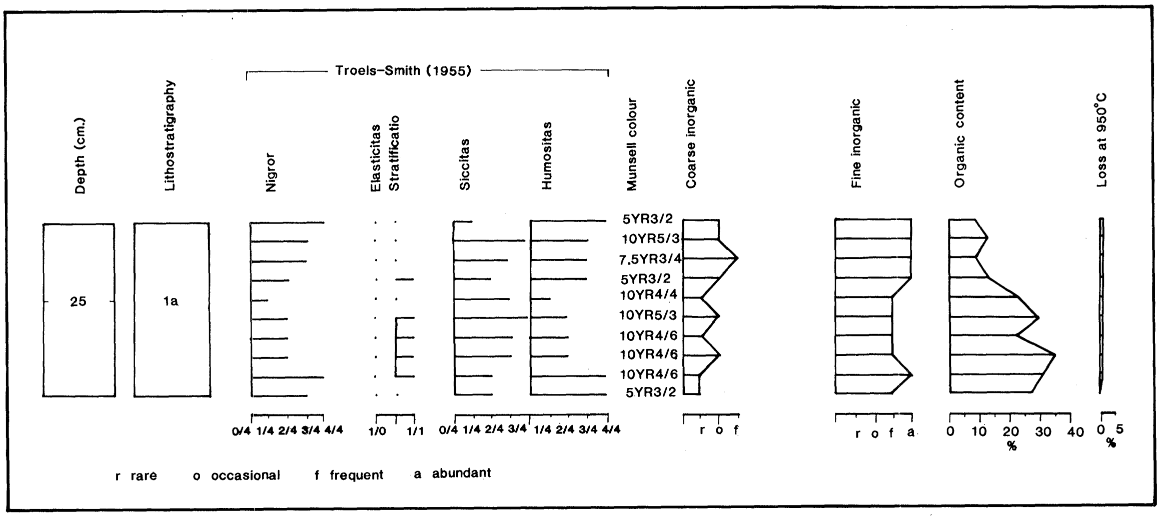

Figure 23. Bread and Cheese Cove: Troels–Smith (1955) sediment description, Munsell colour, pollen washings and loss-on-ignition data for the organic sequence from pit B.

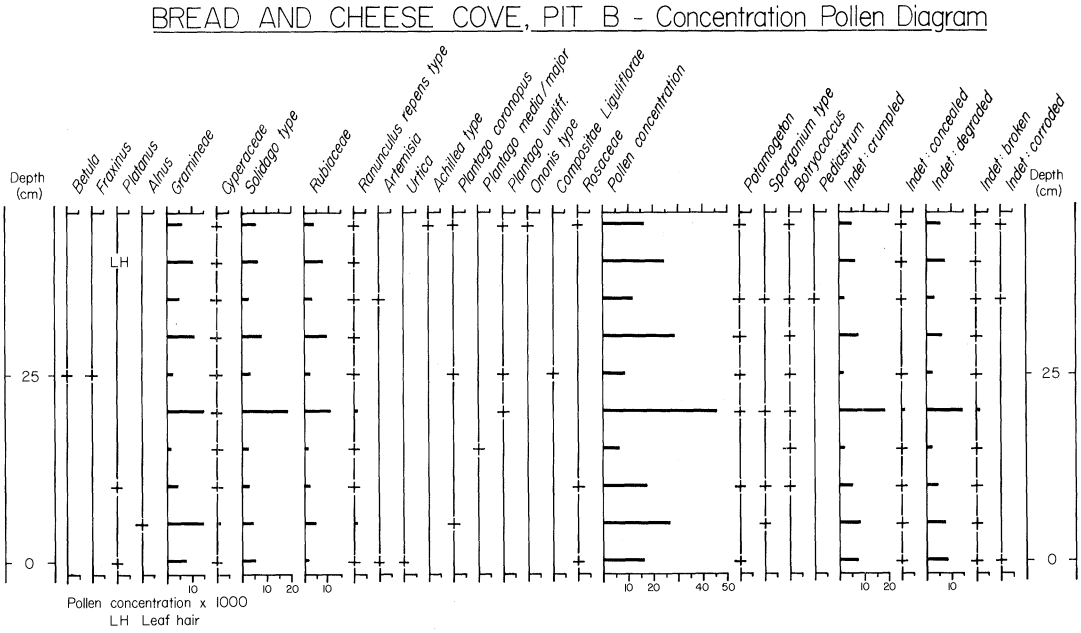

Figure 24. Bread and Cheese Cove: concentration pollen diagram from pit B.

beach. Many of the sand grains and granules found in the pollen washings were extremely well rounded, suggesting a beach origin. The most likely origin for this organic deposit is, as with the other sites, lascustrine, ponding having been effected by contemporaneous local solifluction, and therefore a similar representation of local, rather than regional, pollen expected.

(*ii*) *Pollen analysis*

Both percentage (figure 22) and concentration (figure 24) pollen diagrams show very few changes through the ten levels, and the diagrams have therefore not been zoned. The spectra are totally dominated by herb taxa, in particular Gramineae, which varies between 56% (5 cm) and 27% (25 cm), *Solidago* type, which varies between 49% (15 cm) and 17% (5 cm) and Rubiaceae, which gradually increases from 10% at 0 cm to 31% at 30 cm. Cyperaceae values are low and decline upwards, the highest value of 6% occurring in the basal level; *Potamogeton* behaves similarly with a maximum of 3% in the basal level. The only other herb taxa that occurs with any consistency is *Ranunculus repens* type, reaching 4% at 5 cm. Not one *Pinus* sac or grain was encountered through the entire profile.

Pollen concentrations are extremely variable, ranging between 11000 grains cm^{-3} (15 cm) to 81000 grains cm^{-3} (20 cm). No identifiable macrofossils have been found at this site.

(*iii*) *Sedimentology*

Unit 3, the stratotype of the Scilly Till, is dark yellowish brown (10YR 4/4) drying to light yellowish brown (10YR 6/4). It is largely non-calcareous, but mineralogical data suggest that it is not heavily weathered, containing a number of easily weatherable minerals such as muscovite, glauconite, chlorite,

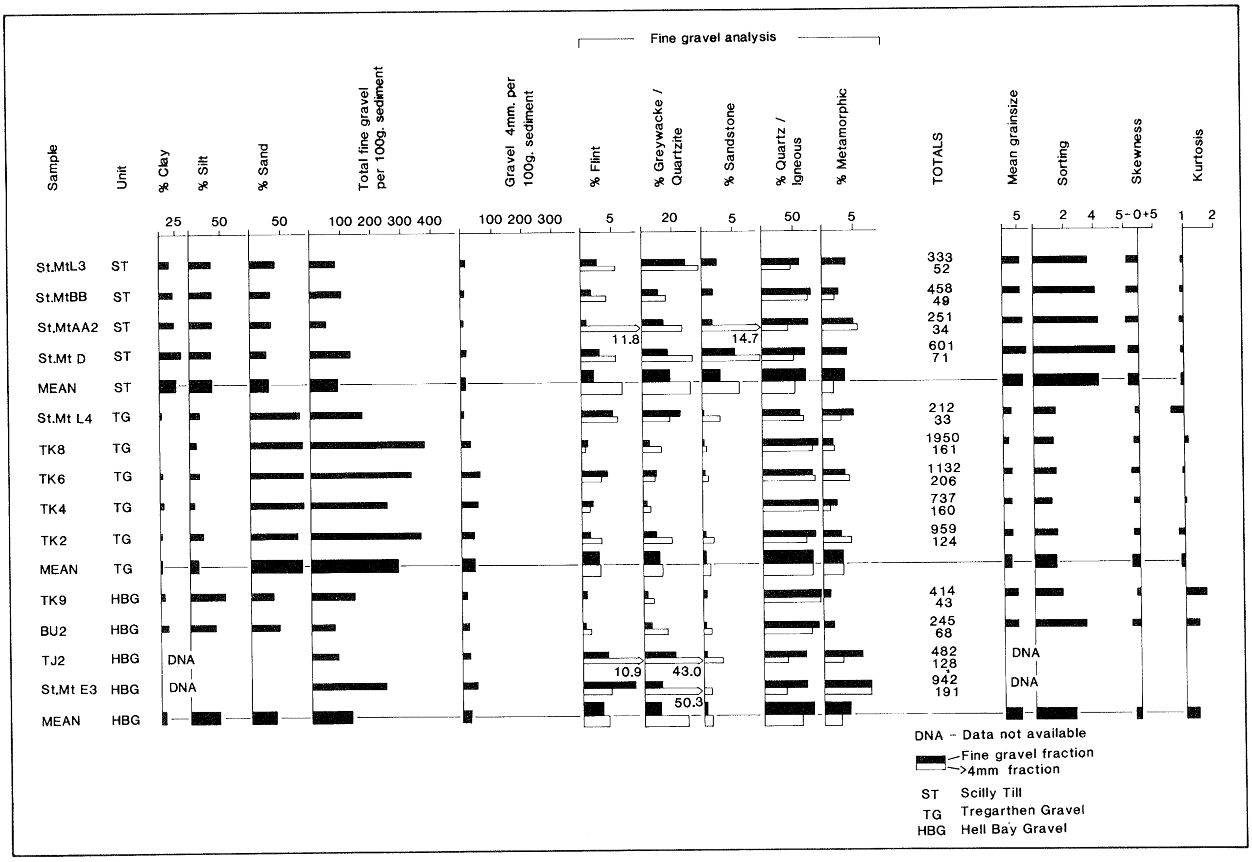

Figure 25. Scilly Till (ST), Tregarthen Gravel (TG) and Hell Bay Gravel (HBG): summary diagram of grainsize and clast lithological data.

biotite, augite, apatite, olivine and calcite (Catt 1986). However, it does not contain any calcareous micro- or macrofossils, although it does contain abundant siliceous sponge spicules (D. A. Jenkins, personal communication, 1986). These data suggest a marine derivation with subsequent partial decalcification.

The Till is crudely stratified with a number of subhorizontal iron-stained sand partings up to 1 mm thick. The contained clasts are very freshly striated and faceted, and consist of a wide variety of lithologies, including Cretaceous flint, Variscan greywackes and quartzites, red sandstones and schistose metamorphic rocks, in addition to local granitic material (figure 25). The Till also contains small specimens of glauconitic micrite, of probable Miocene age, derived from the Jones Formation offshore to the north (Pantin & Evans 1984; A. Morton, personal communication, 1983).

The Till is extremely poorly sorted, containing 43% sand, 38% silt and 19% clay, and is strongly coarse-skewed (figure 5). Three features set the Till apart sharply from the underlying Porthloo Breccia: the high clay content, the lower granule and clast concentrations, and the rich erratic assemblage (figure 26). The abundance of clay and silt, the occurrence of sponge spicules, and the distinctive erratic assemblage are all consistent with derivation from the offshore area to the north of the Scillies.

A coarse lag of angular granite boulders occurs at the base of the Scilly Till at its contact with the Porthloo Breccia. The upper contact with the Bread and Cheese Breccia is clearly soliflucted.

Three clast macrofabric diagrams from the Scilly Till (samples A, B and C), one from the underlying Porthloo Breccia, and one from the overlying Bread and Cheese Breccias are presented in figure 27. These diagrams are constructed from measurements of 50 clasts in accordance with the recommendations in Andrews (1971); eigenvalue and eigenvector calculations are based on Mark (1973). Sample A was from the base of the Scilly Till, sample B from the middle and sample C just beneath the soliflucted upper contact. Sample A shows no strong preferred orientation (eigenvalue 1: 0.4914; eigenvector 1: 3°/175°) but the weak orientation is parallel with the underlying Porthloo Breccia. Sample B, however, has a strong S.W.–N.E. preferred orientation (eigenvalue 1: 0.794; eigenvector 1: 19°/148°), as does sample C (eigenvalue 1: 0.7026; eigenvector 1: 18°/143°). The overlying Bread and Cheese Breccia has a similar fabric signature, with strong (eigenvalue 1: 0.758) N.W.–S.E. preferred orientation (eigenvector 1: 7°/130°). The strong fabrics from the Scilly Till samples B and C and the Bread and Cheese Breccia differ in their orientations from the Porthloo Breccia.

The S1 and S3 eigenvalues (Mark 1973) for all fabrics from the site have been plotted against fabric data from modern glacigenic sediments (Dowdeswell & Sharp, 1986; figure 28). This suggests that, whereas sample B and C plot close to 'melt-out till' and 'undeformed lodgement till', sample A is significantly different in resembling 'glacigenic sediment flow', as does the Bread and Cheese Breccia. The latter might

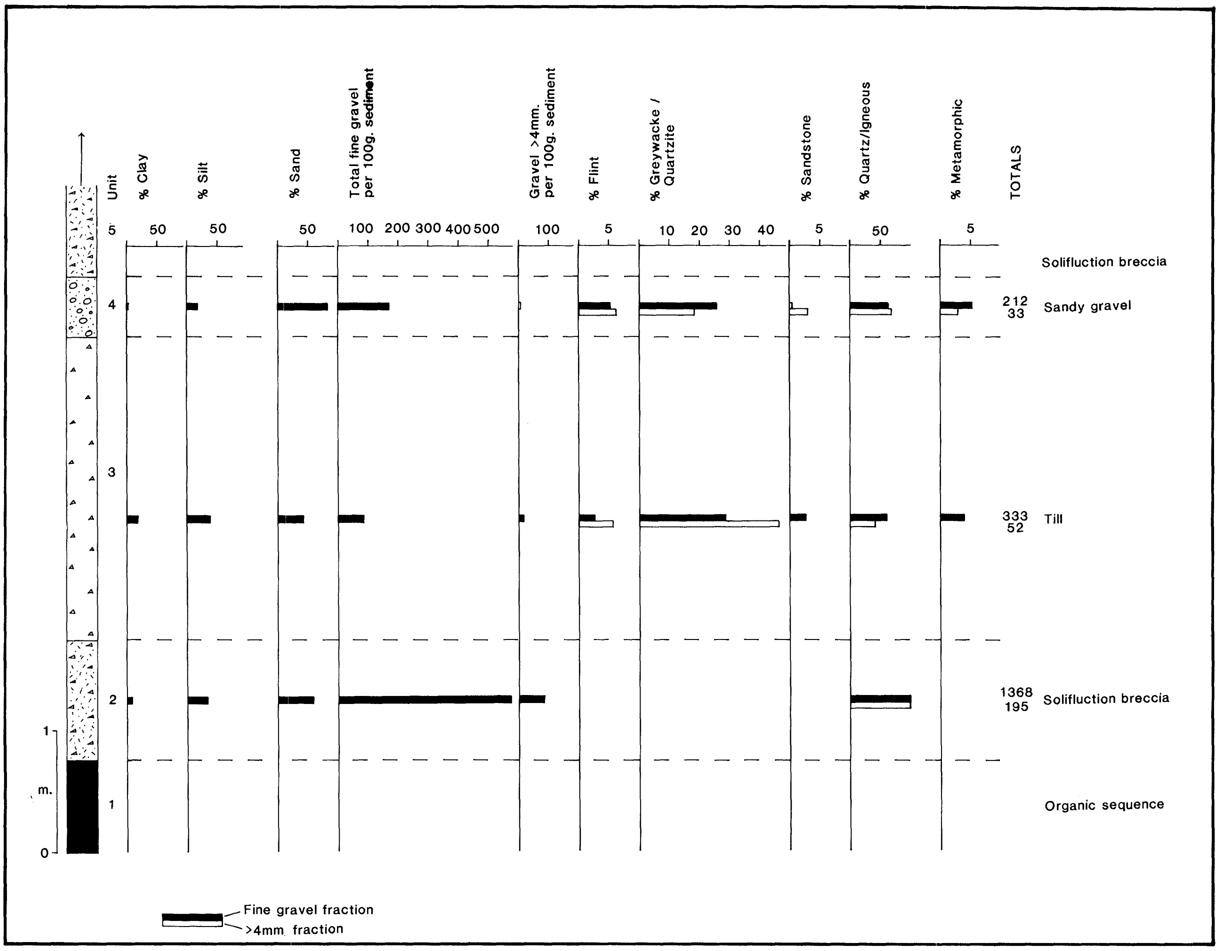

Figure 26. Bread and Cheese Cove: grain-size and clast lithological data in stratigraphic context.

be expected to produce this signature as it is interpreted as a periglacial gravity flow i.e. solifluction. The Scilly Till fabrics have also been plotted against Rose's (1974) data on 'lodgement' and 'slumped' till from Hertford and Hatfield (Dowdeswell & Sharp 1986; figure 29). Samples B and C clearly resemble lodgement till, whereas sample A plots within the slumped till category.

Thus in terms of fabric, samples B and C are typical for lodgement till from both modern and fossil contexts and record ice movements from the northwest. Sample A may well represent soliflucted or slumped till. The strong preferred orientation of the Bread and Cheese Breccia compared with the Porthloo Breccia may represent solifluction in response to a glacial modification of the local slope morphology.

A conclusive interpretation of the precise depositional environment of the Scilly Till is impossible from this one small exposure, and its precise depositional facies must remain an open question. However, it is different in a number of fundamental characteristics from undoubted soliflucted till, as represented by the Hell Bay Gravel, and this suggests that it may well be *in situ*.

Unit 4, although a very small exposure, has been analysed granulometrically and for fine gravel (figures 5 and 25), and these data suggest clear affinities with the stratotype of the Tregarthen Gravel at the Battery section (see §4*c*). This material is interpreted as a waterlain gravel deposited in very close proximity to the Scilly Till.

In its general characteristics the Bread and Cheese Breccia is very similar to the Porthloo Breccia, being dominated by granite clasts, with an abundantly sandy matrix, but it does contain occasional erratic clasts clearly derived from the underlying Tregarthen Gravel and Scilly Till. It cannot, therefore, be correlated with the Porthloo Breccia on lithological grounds, even though it was deposited in a similar environment. It has therefore been formally defined as a separate unit.

(*iv*) *Radiocarbon determinations*

The Bread and Cheese Cove organic sequence is unique because it represents the only datable organic sequence directly underlying the glacigenically derived units of the Bread and Cheese Formation of the northern Scillies. Bed la (figure 20) was sampled and pre-treated for radiocarbon analysis (see table 7).

The second series sampling programme at this site was very unsatisfactory because of the granite boulders and rubble associated with the organic material; wing auger penetration was minimal in comparison with the other organic sites, where samples up to 3 m into the section were achieved. Of 64 wing auger boreholes attempted, only eight penetrated more than 40 cm into the section. The second series sample is therefore

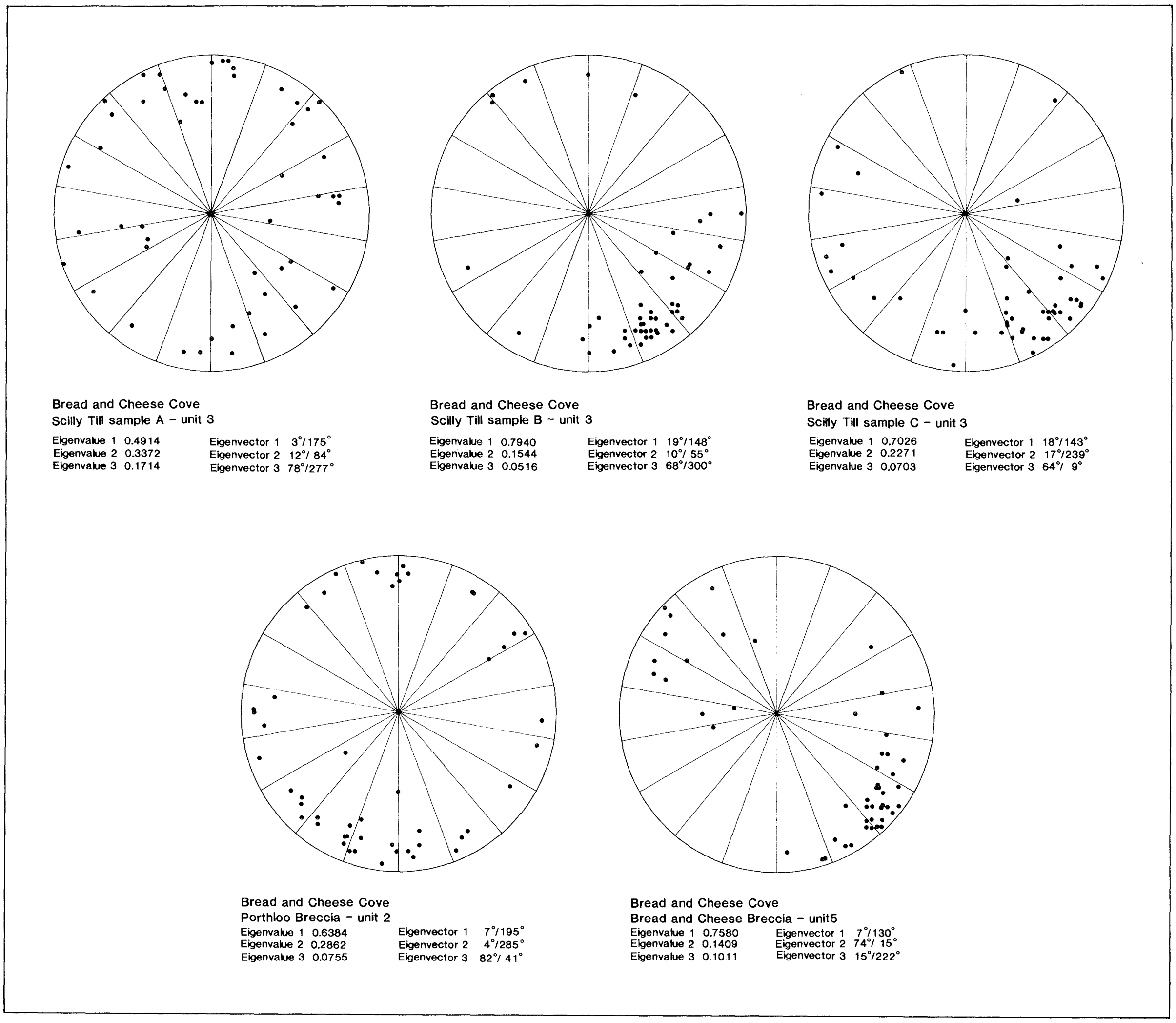

Figure 27. Bread and Cheese Cove: fabric analyses.

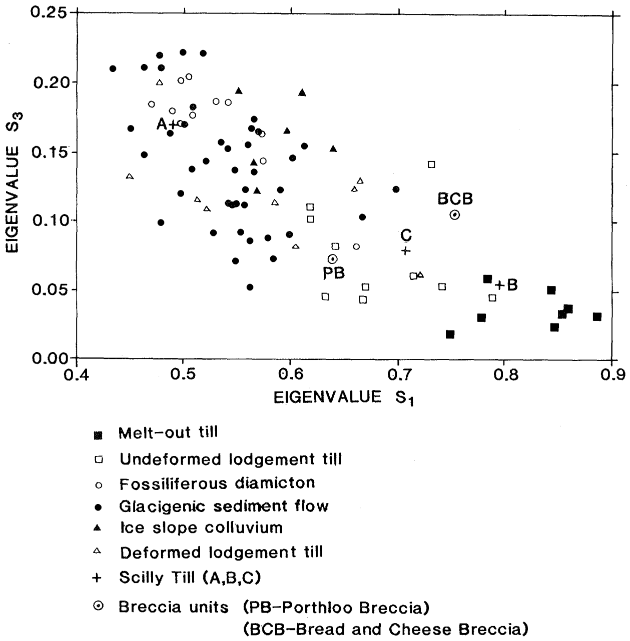

Figure 28. Bread and Cheese Cove: fabric eigenvalue data plotted with eigenvalue data from modern glacigenic sediments as compiled by Dowdeswell & Sharp (1986).

effectively a repeat of the first series sample. On combustion it was found that the second series residue sample contained insufficient carbon for counting.

These radiocarbon determinations are clearly aberrant, with values very much younger than ^{14}C and TL dates on related stratigraphical units on the Islands, and the occurrence of glacigenic and solifluction deposits overlying material yielding Holocene-equivalent radiocarbon determinations clearly suggests that these samples are wholly unreliable. However, the pollen diagrams are clearly consistent with cold-stage conditions, so the origin of the modern carbon in the samples has to be explained.

Of the possible sources of contamination (figure 12), bees can be rejected as no bee holes were observed at the site, and no contamination can be detected in the pollen diagrams. A combination of rootlet penetration with groundwater percolation charged with modern humus are the most likely sources. The solid granite–bed la contact represents an impermeable interface, and detailed radiocarbon analyses of the other organic sites has shown that such situations appear to exacerbate this groundwater contamination source.

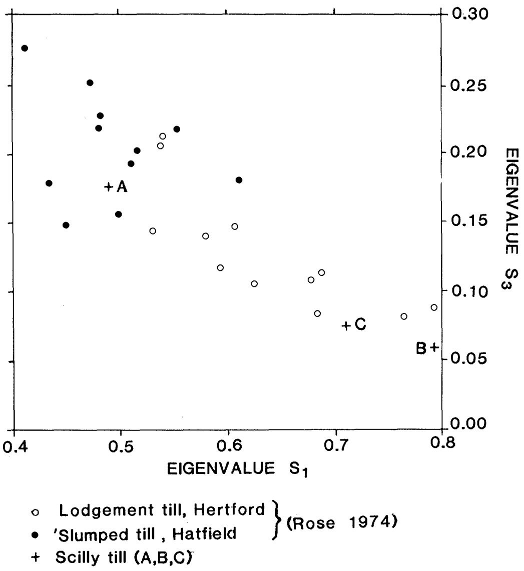

Figure 29. Bread and Cheese Cove: Scilly Till fabric eigenvalue data plotted with eigenvalue data from lodgement and slumped till in S.E. England (Rose 1974) as calculated by Dowdeswell & Sharp (1986).

(*b*) *Additional exposures of the Scilly Till*

Additional material resembling the stratotype of the Scilly Till at Bread and Cheese Cove has only been observed at two sites, both of which occur in the proximity of White Island on the north coast of St Martin's. At other sites where Mitchell & Orme (1967) report 'till', the described material corresponds more closely to the Hell Bay Gravel than it does to the Scilly Till as defined here.

(*i*) *Pernagie Bar*

Pernagie Bar is a marine tombola extending for 0.5 km from Pernagie (SV920171) to Plumb Island (SV918171), Pernagie Brow (SV918173) and Pernagie Isle (SV918175) (figure 1). It consists of large granite boulders that are submerged at high tide, and at its southern end the bar is 'cored' by Scilly Till. This massive stony clay has been observed to extend over an area of more than 10 m^2 underneath the granite boulders, but it may be more extensive. The deposit is of unknown total thickness, but it is greater than 1.2 m.

At this site the Scilly Till is brownish yellow (10YR 6/6) in colour, drying to very pale brown (10YR 7/4). Granulometric, fine gravel and pebble counts confirm its affinity with the Scilly Till (figure 25).

Scilly Till is also exposed in a small section to the south of the bar site where it is underlain by the Porthloo Breccia. Here it appears as a distinctively mottled massive stony clay; analytical data again confirm its affinities with the Scilly Till (figure 25).

(*ii*) *White Island Bar*

Another similar bar links St Martin's with White Island (figure 1) where pebbles, cobbles and boulders of a wide variety of lithological types are again underlain by a 'core' of Scilly Till. During the spring of 1984 the surface of the deposit at the southwestern end of the bar covered an area of around 20 m^2, but it may be more extensive. Using a Dutch-type wing auger, a maximum of 2.6 m of till has been shown to be resting on 19 cm of granitic breccia, devoid of erratics, which passes downwards into an unknown thickness of black to dark brown granular silt. This latter sediment may be organic, but a pollen preparation proved to be barren.

At the surface, the Scilly Till consists of a very stiff, massive stony clay, dark yellowish brown (10YR 4/4) in colour drying to pale brown (10YR 6/3); analytical data confirms its affinities with the Scilly Till (figure 25). A clast macrofabric diagram (figure 30) from the upper part of the Scilly Till sequence suggests strong clast-preferred orientations from northwest to southeast, with predominant clast dips in the 0–30° range oriented towards the northwest. These fabric data correlate well with the Scilly Till B and C samples from the stratotype at Bread and Cheese Cove.

(*c*) *Battery*

(*i*) *Stratigraphy*

The Battery section occurs in the small cove to the south of Piper's Hole on the northeastern coast of Tresco (SV887165) (figure 1). At the extreme northern end of the section a 5.8 m thick complex of sandy gravels and breccias can be seen (figure 31). In all, nine units have been identified, units 1, 3, 5 and 7 representing coarse granitic solifluction breccias, and units 2, 4, 6 and 8 sandy gravels. All the contacts in the centre of the drawn section are erosional, but the units lose their integrity and the contacts between them become confused laterally in both directions. The sandy gravels, especially units 6 and 8, occur as channel-fills with very coarse clast-supported lags at their bases, and they fine and become matrix-supported upwards. The breccia units form lobate, rather than channelized, bodies, most being continuous with the more massive bodies of soliflual sediment on either side of the section. However, breccia unit 7 is a lenticular package which is entirely enclosed by gravel units 6 and 8.

(*ii*) *Sedimentology*

Units 1–8 have been analysed granulometrically and for fine gravel (figure 32). The breccia units are extremely poorly sorted, and contain 48–70 % sand, 24–47 % silt and 6–8 % clay. Unit 7 can be differentiated from the other breccia units in having a

Table 7. *Radiocarbon determinations* (*in years* BP) *for the Bread and Cheese Cove samples*

	residue	+	−	extract	+	−	lab. no.
first series	9670	65	65	7880	180	180	Q-2368/9
second series	—	—	—	7830	110	110	Q-2441

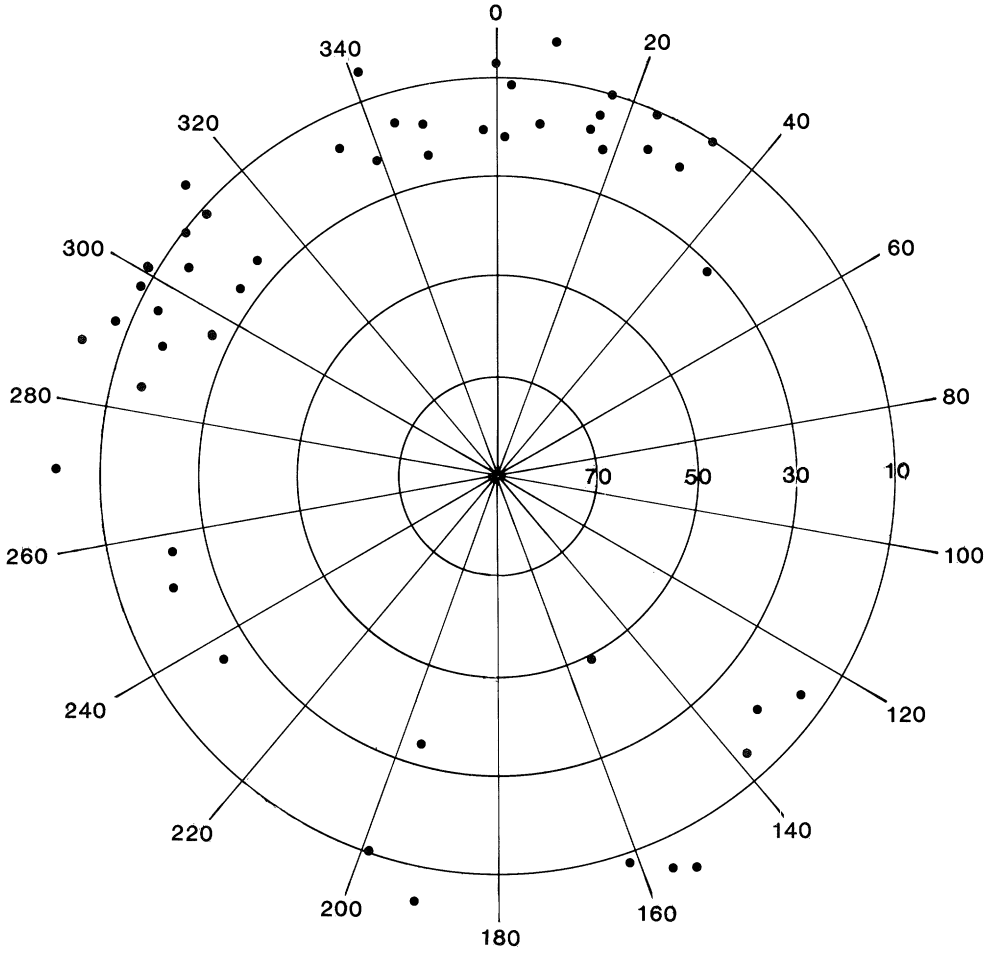

Figure 30. White Island Bar: fabric diagram from the Scilly Till.

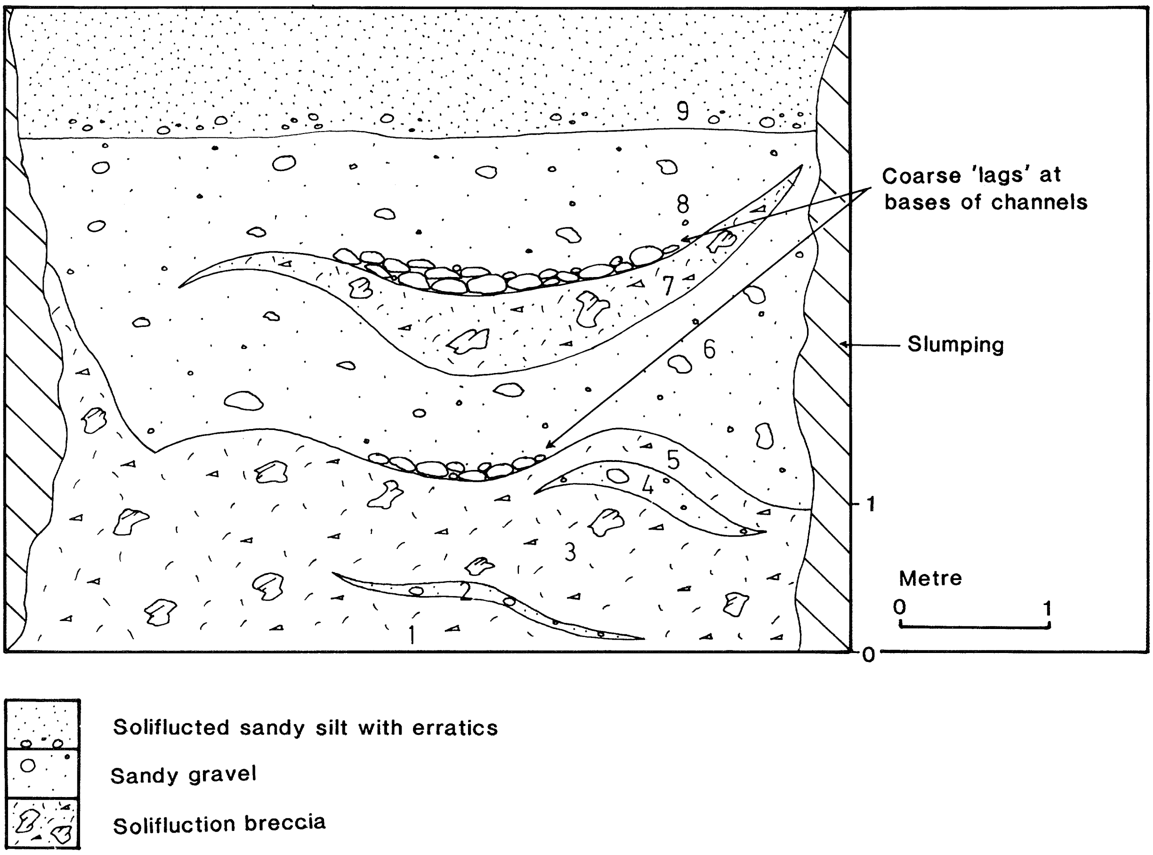

Figure 31. Battery: site stratigraphy.

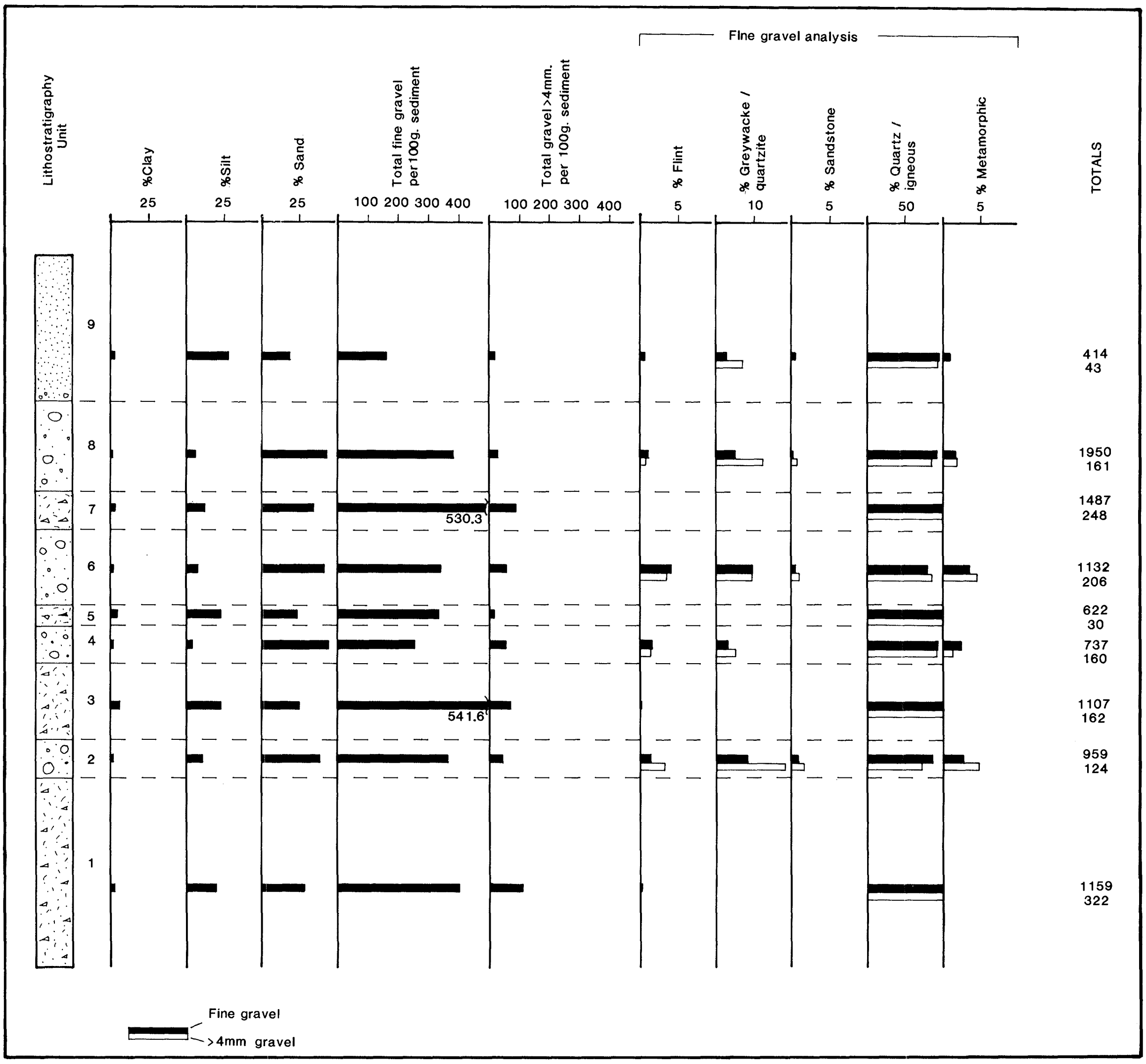

Figure 32. Battery: grainsize and clast lithological data in stratigraphic context.

coarser mean grain size and in being slightly better sorted. It also contains substantially more sand and less silt than the other breccia units.

The sandy gravels contrast with the breccia units in being very much better sorted, containing 87–91 % sand, 8–12 % silt and 1–2 % clay, and they are very similar granulometrically. These units stand apart from the breccia units most clearly in containing a rich and diverse erratic assemblage that is strikingly similar to that obtained from the stratotype of the Scilly Till (figures 25 and 32). The analysis of unit 6 also revealed a striated greywacke, and a clast of Miocene glauconitic micrite identical with that from the Scilly Till. In contrast, of 4375 granules counted from the breccia units, only three were non-granitic in origin, two from unit 3 and one from unit 1. The breccia units can also be differentiated from the gravels in having a higher clast concentration of between 333 and 542 granules per 100 g dry sediment compared with a range of 252 and 352 in the gravels.

The breccia units are interpreted as solifluction deposits comprising material largely derived from the breakdown of the local granite, whereas the gravels are interpreted as fluvial, probably glaciofluvial, outwash material. The erratic assemblage and stratigraphic position of the gravels suggest that they were deposited during the same glacial event responsible for the Scilly Till. The occasional erratic found within the breccia units is suggestive of the ingestion of the underlying outwash material into the solifluction flows. The single erratic granule found in unit 1 is difficult to explain, in that no gravel units have been identified below it; perhaps a small, as yet unidentified, outwash gravel channel exists within unit 1, or perhaps a small channel has been completely eroded out by the solifluction flow of unit 1.

Unit 9 is moderately well sorted with a dominant mode in the coarse silt fraction, contains 57 % silt, 37 % sand and 6 % clay, and is characterized by an erratic fine gravel and pebble assemblage consistent with the underlying outwash material; these data confirm its affinities with the Hell Bay Gravel.

The overall impression of the sequence is of solifluction occurring penecontemporaneously with pulses of fluvial outwash. The outwash palaeocurrent is estimated to have been in an easterly direction on the basis of the bed geometry, with solifluction occurring normal to this from the south and north. Breccia bed 7, however, represents a solifluction lobe moving downslope parallel with the dominant outwash direction; it is significant that this is the breccia unit with high sand content, for this sand must have been ingested from the underlying gravel during longitudinal movement down-channel. Those lobes crossing the channels transversely had less opportunity for the ingestion of the underlying material. At the base of the sequence, solifluction was clearly the dominant process, but gradually the solifluction lobes were overwhelmed by outwash activity. The sequence was then covered in a sandloess blanket that was then mixed with the underlying outwash material and itself soliflucted.

The gravel units represent the composite stratotype of the Tregarthen Gravel, and the breccia units are correlated with the Bread and Cheese Breccia as they contain erratic material.

5. STRATIGRAPHIC AND PALAEOENVIRONMENTAL SYNTHESIS

(*a*) *Interpretation of evidence*

The raised beach sediments of the Watermill Sands and Gravel in the southern Scillies are overlain by the Porthloo Breccia, a unit of variable soliflucted material derived entirely from the weathering of the granite bedrock. The organic sequences at Carn Morval, Watermill Cove, Porth Askin, Porth Seal and Bread and Cheese Cove occur within this unit, usually towards its base. These organic sequences are all interpreted as the infillings of small lakes or ponds associated with active solifluction. The radiocarbon determinations from these organic sequences are critical, as the organic sediments pre-date the units associated with the glacial event (figure 3), the Scilly Till, Tregarthen Gravel, Hell Bay Gravel and Old Man Sandloess. The determinations accepted as reliable for each respective site, in combination, therefore provide a maximum age for the glacial event. The reliable determinations suggest deposition of the organic material between $34\,500^{+885}_{-800}$ (Q-2410) and $21\,500^{+890}_{-800}$ (Q-2358) years BP. The assemblages from these organic sites are all similar in recording open grassland vegetation (see §6) and represent the earliest vegetational record for the Scillies.

In the southern Scillies, the Porthloo Breccia is overlain by the Old Man Sandloess, a coarse aeolian silt with subdominant fine sand and minor amounts of clay, from which two TL dates, both of $18\,600^{+3700}_{-3700}$ (QTL-1d and 1f) years BP (Wintle 1981), and two optical dates, of $20\,000^{+7000}_{-7000}$ (738 al) and $26\,000^{+10\,000}_{-9000}$ (741 al) years BP (Smith *et al.* 1990), have previously been published. This unit occurs in a variety of facies related to different modes of reworking.

In the northern Scillies, the Porthloo Breccia is overlain by three units, the Scilly Till, Tregarthen Gravel and Hell Bay Gravel, which are all related to a single glacial event. The Scilly Till, a massive, poorly sorted, clay-rich pale brown diamicton containing abundant striated and faceted erratics, occurs at Bread and Cheese Cove, and Pernagie and White Island Bars. The precise depositional origin of this material is uncertain, although the available evidence suggests that it may be, at least partly, a lodgement till; it is nevertheless interpreted as an *in situ* till unit unaffected by post-depositional downslope movement. At Bread and Cheese Cove, the Scilly Till occurs in association with a matrix-supported sandy gravel, the Tregarthen Gravel, which has an erratic assemblage consistent with the underlying Till. This material, which is interpreted as glaciofluvial outwash gravel, also occurs at the Battery section.

Aeolian loessic processes, in association with the glacial advance, resulted in the deposition of the Old Man Sandloess in the southern Scillies. The relative coarseness of this material is a function of proximity to its glacially derived source material. The mineralogy of the Scilly Till is sufficiently similar to the Old Man Sandloess to suggest a genetic link between the two units: 'both contain the same suite of non-weatherable minerals in approximately similar proportions; the small differences in some of these minerals... can probably be explained by the lateral variation in composition often seen in glacial deposits' (Catt 1986, p. 135).

Overlying the Scilly Till and Tregarthen Gravel in the northern Scillies is the Hell Bay Gravel, an extremely widespread matrix-supported gravel containing a similar assemblage of striated and faceted erratics as the underlying Till, but alongside a considerable proportion of locally derived granitic material. The matrix of the Hell Bay Gravel is identical with facies D of the Old Man Sandloess (figure 5). This material represents an initial phase of solifluction post-dating the glacial event in which Scilly Till, Tregarthen Gravel and Old Man Sandloess were mixed and transported downslope. In situations where these sediments were stripped from the land surface, weathered granite once again became the dominant raw material for solifluction, this subsequent phase being represented by the Bread and Cheese Breccia. In the southern Scillies, this post-glacial phase of solifluction is represented by the soliflucted facies D of the Old Man Sandloess (figure 6) and the upper Porthloo Breccia. The facies model for the Old Man Sandloess (figure 6) reflects in microcosm the tripartite sequence of solifluction–sandloess–solifluction represented in the southern Scillies, with *in situ* facies A between facies C and D, which represents fluvial or colluvial reworking of the sandloess.

(*b*) *Age of identified units*

Taken together, the ^{14}C determinations, TL and optical dates constrain the age of most of the identified units. The Watermill Sands and Gravel cannot have been deposited after $34\,500^{+885}_{-800}$ years BP (Q-2410), because this is the oldest reliable determination from the overlying Porthloo Breccia. It occurs at approximately the same elevation as interglacial raised beaches on the shores of the southern Irish Sea Basin, which now appear to be of composite age (Davies & Keen 1985; Bowen *et al.* 1985). Assuming the Watermill Sands and Gravel to be an interglacial beach, it cannot be younger than the Ipswichian, which implies a considerable hiatus between it and the overlying Porthloo Breccia. If it is older than the Ipswichian then the length of the hiatus is even greater.

The lower Porthloo Breccia was deposited between $34\,500^{+885}_{-800}$ (Q-2410) and $21\,500^{+890}_{-800}$ (Q-2358) years BP. As the dated organic sequences always occur at, or very near, the base of the Porthloo Breccia, this suggests that most of this soliflual material was probably deposited towards the more recent end of this range. The base of the late Devensian Substage therefore falls within the Porthloo Breccia. This is the first direct dating of 'head' or solifluction sediments from southwest England.

The Scilly Till and Tregarthen Gravel cannot have been deposited before $21\,500^{+890}_{-800}$ (Q-2358) years BP. The TL dates of $18\,600^{+3700}_{-3700}$ (QTL-1d and 1f) from the Old Man Sandloess suggest that the Hell Bay Gravel must be of similar age as the two units are directly correlated, and the two optical dates of $20\,000^{+7000}_{-7000}$ (738 al) and $26\,000^{+10\,000}_{-9000}$ (741 al) are consistent with this interpretation. As the Hell Bay Gravel overlies and contains material derived from the Scilly Till and Tregarthen Gravel, the latter two units cannot be younger than $18\,600^{+3700}_{-3700}$ years BP. These dates therefore constrain the deposition of the Scilly Till and Tregarthen Gravel to the interval between $21\,500^{+890}_{-800}$ and $18\,600^{+3700}_{-3700}$. Although these two dates overlap because the error bars are wide, the direct association between the Old Man Sandloess and the glacial event suggests that the younger TL dates represent the most accurate estimation of the age of the glaciation.

The Bread and Cheese Breccia and the upper Porthloo Breccia cannot have been deposited prior to $18\,600^{+3700}_{-3700}$ years BP because they overlie the Old Man Sandloess and the Hell Bay Gravel with which they are correlated.

This evidence suggests that ice advanced at least as far as the northern Isles of Scilly during the Dimlington Stadial (Rose 1985) of the late Devensian Substage around $18\,600^{+3700}_{-3700}$ (QTL-1d and 1f) years BP (Wintle 1981). This was probably not the first glacial event to have influenced the islands, because erratics are widespread in some exposures of the Watermill Sands and Gravel, but this earlier event is quite distinct from the late Devensian advance.

(*c*) *Distribution of identified units*

The Watermill Sands and Gravel is distributed fairly widely throughout the islands, but the exposures are thickest and most widespread in the southwest islands, notably on St Agnes and Annet, and become thinner and less widespread northwards. This distribution can be explained in one of three ways: (i) erosion and removal of the unit on the northern islands; (ii) exposure to southwesterly gales; and (iii) removal of the overlying Porthloo Breccia in the southwest.

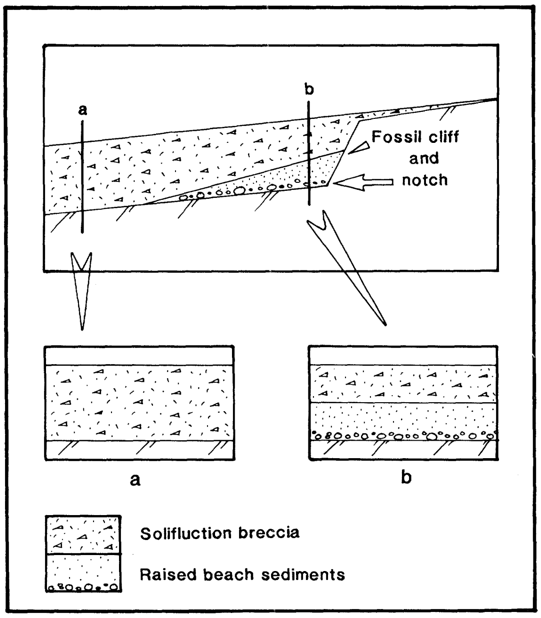

Figure 33. Diagram illustrating different stratigraphic relations between solifluction and raised beach sediments in relation to the degree of post-depositional erosion.

After the deposition of the raised beaches, soliflucted material in the form of the Porthloo Breccia spread out over the beach material, in some cases completely enveloping it. The extent of coastal erosion since will therefore have produced a variety of stratigraphical relationships (figure 33). Enhanced exposure to coastal erosion associated with prevailing southwesterly gales on the southwestern islands may have resulted in more raised beaches being exposed in section, as in figure 33*b*. This implies that the raised beaches are present, but not exposed, in the north.

Alternatively, the raised beach material may have been removed in the north by solifluction or glacial ice. Although the Scilly Till is only present in the north, glacial ice cannot have been responsible for removing the beaches, because at the few sites where it can be seen in section the Till directly overlies the Porthloo Breccia, and not the Watermill Sands and Gravel or bedrock. However, intense solifluction certainly appears to be an effective agent in the reworking of beach material (cf. Porth Seal), so this may partly explain the lack of raised beaches in the north.

The Scilly Till is limited to four exposures on the northern side of St Martin's (figure 1). These exposures can be taken as the 'minimum' limit of glacial ice in the northern Scillies. The Hell Bay Gravel, however, is much more extensive (figure 1). It is exposed in almost every section of Pleistocene material north of a line drawn across Bryher, Tresco, Northwethel, Tean and St Martin's. As it contains soliflucted till and outwash gravel, this limit can be regarded as a 'composite' feature representing either the former maximum extent of ice or the zone of proximal outwash. Dr J. R. Hawkes (personal communication, 1983) has found an erratic block of olivine basalt, of estimated mass 10 tonnes†, on Great Crebawethan (Western Rocks; figure 1). This can only have been emplaced by glacial action, and constitutes the basis for the extension of the glacial limit to the Western Rocks. The distribution of the Scilly Till, Tregarthen Gravel, Hell Bay Gravel, their fine gravel and pebble content, and the likely provenance of their contained erratics (Appendix 2) are all consistent with ice movement from the northeast of the Scillies.

The Old Man Sandloess is very widespread throughout the southern Scillies, and must formerly have been

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† 1 tonne = 10^3 kg.

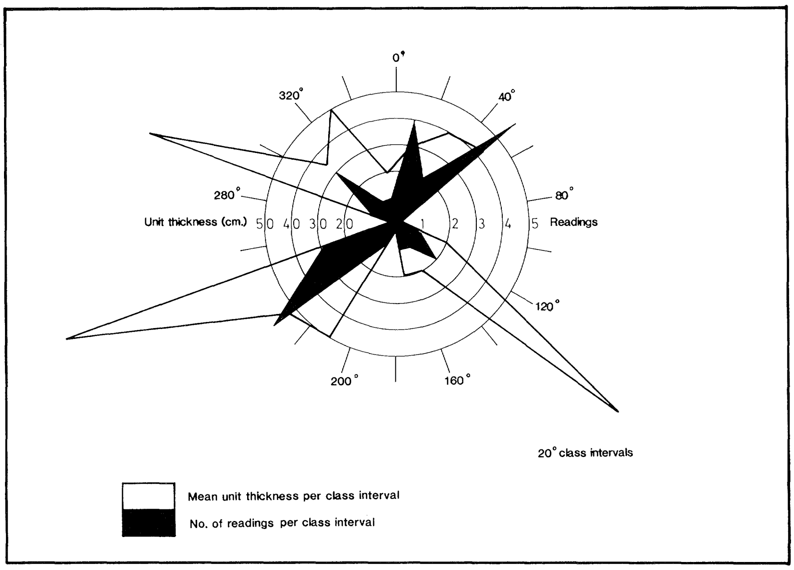

Figure 34. Old Man Sandloess occurrence and thickness in relation to aspect.

widespread in the northern Scillies before its incorporation into the Hell Bay Gravel. A rose diagram (figure 34)of the thickness of this unit against aspect has been constructed from 32 exposures on St Mary's and St Agnes. This diagram has been plotted both on the number of readings per 20° class interval, and on the mean thickness of the unit within the 20° classes. This shows that exposures facing the northeast or southwest most commonly contain sandloess, and the sandloess exposures facing the southwest are thicker than those facing the northeast, although the thickness data is much less significant than the aspect data. These data suggest prevailing wind palaeocurrents from the northeast.

(*d*) *Distribution of geomorphological features*

Scourse (1987) has defined four tor forms from the Scillies, and there appears to be a good correlation between highly smoothed, eroded tors and the southern limit of the Hell Bay Gravel, suggesting that the glacial advance, although unable to penetrate far into the Scilly massif, was nevertheless capable of eroding the solid granite. Tor forms in the southern Scillies are, in contrast, 'mammilated' or 'castellated'.

A number of large marine bars occur within the limit of the Hell Bay Gravel, and two of these, Pernagie Bar and White Island Bar (figure 1), are underlain by Scilly Till. Although most of the boulders comprising these bars are granite, many are erratics, dominantly flint and red sand- and siltstones. Whereas contemporary marine processes clearly control their detailed morphology at the present day, the internal structure of the bars and their distribution in relation to the sedimentary units defined above suggests a possible morainic origin.

(*e*) *Garrison Boulder Bed Member*

The raised beach cobbles constituting the Garrison Boulder Bed must be attributed to an early high stand of sea level before the deposition of the Watermill Sands and Gravels, but the precise age of this event is unknown.

(*f*) *Pollen records*

The pollen records for all the sites in this study contain very similar assemblages, with a range of non-obligate aquatic herb taxa, which would be consistent with open temperate grassland, particularly if disturbance has taken place. This conflicts with the radiocarbon evidence, which suggests that the organic sequences were deposited between about $34\,500^{+885}_{-800}$ (Q2410) and $21\,500^{+890}_{-800}$ (Q-2358) years BP. The assemblages contain taxa that have not been recorded from modern Arctic or tundra environments, including *Plantago coronopus*, *Spergula* type and *Herniaria* type, and yet lack many of the taxa characteristic of such environments, notably *Oxyria* type, Ericaceae, *Lycopodium* and *Betula* (Lichti–Federovich & Ritchie 1968; Elliot–Fisk *et al.* 1982; Heusser 1983; Peterson 1983). Nevertheless, the pollen assemblages are broadly similar to other full-glacial spectra of this age from elsewhere in N.W. Europe (cf. West 1977; Bell *et al.* 1972; Morgan 1973).

Dry land herb taxa, which are significant in a number of the sites, include *Solidago* type, Rubiaceae and *Artemisia*. In the absence of associated macrofossil determinations it is not possible to be more precise about the likely species contributing to these rather large pollen taxa. The significance of cf. *Scutellaria* at Carn Morval deserves further comment. Hultén (1950) plots the modern distributions in N.W. Europe for three species, *S. galericulata*, *S. minor*, and *S. hastifolia*. Of these, only *S. galericulata* is found north of the Arctic Circle today. Its ecological preference for damp sites is supported by the inferred conditions at Carn Morval.

The obligate aquatic taxon cf. *Sagittaria* includes *S. sagittifolia* and *S. natans*, and both of these species are equally likely candidates for the source of the pollen at Watermill Cove. Certain identification was precluded by poor preservation. Macrofossils of both species have now been recorded from cold-stage floras in Britain, the fruits of *S. sagittifolia* from the Beestonian, the late Wolstonian at Ilford (West *et al.* 1964) and the Middle Devensian at Earith (Bell 1969), and achenes of *S. natans* from late Devensian deposits at Abingdon (Aalto *et al.* 1984). These fossil occurrences conflict somewhat with the modern distribution of these species. Hultén (1950) places *S. sagittifolia* in his category of West European–South Siberian plants, but in Scandinavia it barely reaches Norway; there are occasional records for this species from within the Arctic Circle 'though in most northern sites it is represented by sterile submerged phenotypes (Godwin 1975, p. 355). The distribution in N.W. Europe of *S. natans* is very similar to *S. sagittifolia* (Hultén 1950). Brown (1977) records *Sagittaria* pollen on Bodmin Moor just before 12635 years BP and, based on the modern distribution of the two species, regards this as an indicator of climatic amelioration just before the Allerød. The occurrence of this temperate thermophilous taxon in these full glacial spectra reinforces the element of thermophilous indicators in these records. This may well be a function of the proximity of the Scillies to the moderating climatic influence of the Atlantic even at a time of lowered sea level.

6. DISCUSSION

The evidence and interpretations presented here to support a late Devensian glaciation of the Scillies clearly conflict in a number of important respects with Mitchell & Orme's (1967) scheme of events. The major differences are: (i) recognition of only one raised beach unit stratified with other sediments; (ii) recognition of widespread loessic sediment in the Scillies, and an appreciation of the genetic relation between this sediment and the Scilly Till; (iii) revised sedimentological interpretations; (iv) dating of these units based on radiometric methods rather than on the inferred ages of raised beach units; and (v) detailed palynological analyses of critical organic sequences as an aid to palaeoenvironmental reconstructions and local inter-site correlations.

The revised interpretation presented here must be seen as a working hypothesis. The evidence on which it is based is clearly equivocal in a number of important respects. However, this evidence is impossible to reconcile with a Wolstonian age for the glaciation of the Scillies. The fundamental points in the argument are: (i) the reliability of the TL dates and ^{14}C determinations; (ii) the demonstration that the Scilly Till is *in situ*, and not slumped or soliflucted; and (iii) the validity of the lithostratigraphic correlations between sites and islands.

The reliability of the TL dates has been accepted by Wintle (1981), and the individual ^{14}C determinations have been discussed in the context of the specific site problems above. However, with the exception of the clearly aberrant Bread and Cheese Cove determinations, they do form a fairly consistent group given the problems of analysing material of this general age. Both the sediments and the pollen spectra from the organic sequences are clearly cold-stage, and probably periglacial in their affinities; they are not interglacial or post-glacial. If, however, the organic sequences were deposited during a cold-stage before the Devensian, such as the Wolstonian, and then contaminated with modern carbon, a wider spread of dates would have resulted. If the organic sediments were deposited earlier in the Devensian than the determinations suggest, i.e. during the early Devensian or early Middle Devensian, then a Devensian age for the glaciation can still be sustained.

The available evidence suggests that the Scilly Till is indeed *in situ*; this evidence includes the lithological character of the material, which is quite distinct from juxtaposed soliflual sediments, its occurrence in situations such as Pernagie and White Island Bars, which are not coastal sections and which possess no slope, and the fabric data. This point is less critical than it seems, however, for, even without the existence of the Scilly Till, the consistency of the stratigraphic relation between the Porthloo Breccia and the Hell Bay Gravel at over 50 sites in the northern Scillies suggests primary glacigenic deposition and subsequent solifluction or slumping within one cold-stage post-dating organic sedimentation. This is a conclusion consistent with the Devensian model.

A false argument concerning the stratigraphy of reworked till has bedevilled thinking concerning the chronology of Pleistocene events in the southern Irish Sea Basin. This is exemplified by Bowen (1984, p. 2) concerning the stratigraphy in South Wales: 'superposition of diamicton (recycled glacial beds) as part of as laterally continuous formation of head, on top of raised (*Patella*) beach showed that in most of south Gower the last local glaciation occurred before (*sic*) the raised beach event'. This statement implies that all reworked material was originally emplaced before the unit over which it lies. The Hell Bay Gravel effectively represents reworked Scilly Till, and at many sites in the northern Scillies it directly overlies the solid granite, but there is no question that the Scilly Till was emplaced before the granite. There is no reason why sedimentation of the Scilly Till should not have occurred post-dating the deposition of the Porthloo Breccia, and then have been recycled as the Hell Bay Gravel within a single cold phase.

The lithostratigraphic correlations indicated on figure 3 are open to question. There is only one organic deposit that directly underlies the Scilly Till, at Bread and Cheese Cove. It is acknowledged that this is also the most unsatisfactory of the organic sites in that it has yielded clearly aberrant ^{14}C determinations. An argument could therefore be made that the Porthloo Breccia in the northern Scillies correlates with the upper Porthloo Breccia in the southern Scillies, thereby overturning the stratigraphic relationship between the radiometric dates and the Scilly Till. This scenario would, however, raise a number of new problems. It would imply an extremely complex depositional history with, for instance, two periods of sandloess deposition instead of one. It would also imply very steep depositional gradients over very short distances, but, most importantly, it conflicts with the mineralogical association established between the Scilly Till and Old Man Sandloess (Catt 1986).

The hypothesis of a Devensian glaciation of the Scillies is not new, John (1971) and Synge (1977, 1985) both having raised the possibility, but onshore on the Scillies, and in West Cornwall there is no direct evidence for high relative sea levels in the southern Irish Sea Basin during the glaciation as Synge (1985) suggested.

The occurrence of late Devensian glacial deposits on the northern Isles of Scilly clearly has a number of important implications for the regional Pleistocene stratigraphy and ice limits of southern Britain. The Pleistocene stratigraphy of the southern Irish Sea Basin has traditionally been based on the relation of raised beaches to overlying head and glacial deposits. Implicit in the work of Mitchell (1960, 1972), Mitchell & Orme (1967), Stephens (1966, 1971) and Synge (1971) is the assumption that the 'main raised beach' of the region, exemplified by the beach exposures at Courtmacsherry in southern Ireland, on the Gower coast of South Wales, around Barnstaple Bay in North Devon, and on the Scillies, could be dated as Hoxnian. The basis for this correlation was not evidence from the beach itself, but the interpretation of the age of the deposits overlying the beach. Wherever glacial deposits have been found overlying the beach they have been interpreted as Wolstonian if they lie outside the accepted limit of the Devensian glaciation. In this way the 'main raised beach' (Chad Girt) on Scilly was interpreted by Mitchell & Orme (1967) as Hoxnian, and the overlying glacial sediments as Wolstonian. A major problem in this scheme of events was the lack of Ipswichian sediments (Kidson 1977).

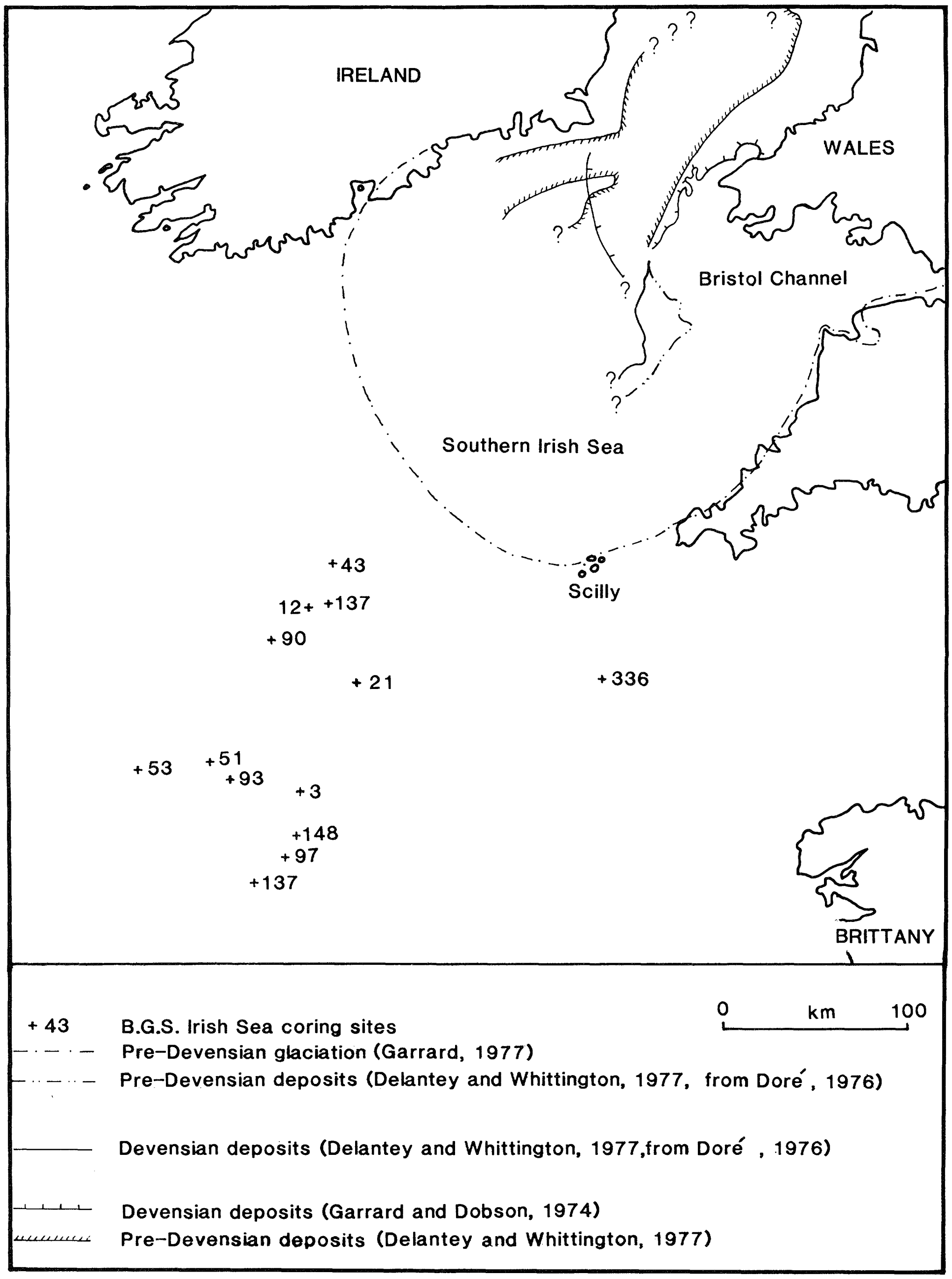

Figure 35. Glacial limits in the southern Irish Sea as defined from offshore evidence. The BGS coring sites represent vibrocores recovering glacial or glaciomarine sediment of probable late Devensian age.

As a result of this procedure, the 'main raised beach' emerged as a stratigraphical marker of some importance (Bowen 1981). A number of other workers (Bowen 1971, 1973; Kidson 1971; Kidson & Wood 1974) resolved the difficulty of the lack of Ipswichian sites by regarding the 'main raised beach' as Ipswichian and not Hoxnian in age. Here the main problem was the interpretation of the overlying glacial deposits. Bowen (1969, 1973) reinterpreted the Scilly stratigraphy in the light of this problem, suggesting that the glacial deposits were originally emplaced during the Wolstonian, but then reworked by solifluction during the Devensian. Once again, the glacial material had to be primarily Wolstonian, because the sites lay outside the accepted limit of the Devensian glaciation.

In both of these schemes, the limit of the Devensian glaciation has had a crucial role, and in both schemes the rigid definition of glacial limits has carried with it the danger of a circularity of argument as a product of negative evidence. This can be summarized as follows: the limit of a certain till body is interpreted as last glaciation in age, so that any tills occurring further to the south cannot be of the same age because the accepted limit lies further to the north. This circular argument has arisen because there has hitherto been a lack of biostratigraphical and radiometric data from which to argue, thus forcing the correlation of lithostratigraphic units over large areas. The interpretation presented here breaks this circular argument by being based on a wide body of positive evidence from a small area which is totally independent of the raised beach stratigraphy. To regard raised beaches as critical stratigraphical markers in the erection of a Pleistocene stratigraphy, as Warren (1985) has recommended, is bound to lead to homotaxial errors. This is reinforced by recent aminostratigraphic data from these raised beaches (Andrews *et al.* 1979; Davies 1983; Davies & Keen 1985; Bowen *et al.* 1985), which suggests that raised beaches occurring at roughly the same elevation around the southern Irish Sea and English Channel fall into a number of well-defined groups which are representative of different ages.

The evidence from the Scillies is clearly incompatible with the orthodox Wolstonian limit on the northern shores of southwest England (cf. Catt 1981; Lowe & Walker 1984) and forces a re-examination of the evidence from the other sites at Trebetherick in North Cornwall (Arkell 1943; Mitchell & Orme 1967) and Fremington in North Devon (Stephens 1966). New evidence from Trebetherick and related sites in the Camel Estuary suggests that the Trebetherick Boulder Gravel is not of glacigenic origin but represents a river-ice deposit of probable late Devensian age from within the catchment of the Camel (J. D. Scourse, unpublished results), and a recent re-examination of the Fremington Till has cast some doubt over its assumed glacigenic origin (D. Croot, personal communication). There are, therefore, serious doubts concerning the age and the glacigenic status of all these critical deposits, suggesting that the continued acceptance of a Wolstonian ice limit in this region can no longer be sustained.

The key to the understanding of the dynamics of the glacier that deposited the Scilly Till lies offshore in the Celtic Sea. Pantin & Evans (1984) identified two main Quaternary formations in the central and southwestern Celtic Sea, the late Pliocene–early Pleistocene upper Little Sole Formation and the late Devensian–early Flandrian Melville Formation. The Melville Formation consists mainly of tidal deposits, but at a number of sites it also contains glacigenic sediment. This material suggests the existence of a glacier lobe on the continental shelf with a glaciomarine terminus at the shelf break; it is similar lithologically and mineralogically to the Scilly Till, and is probably its offshore equivalent (Scourse *et al.* 1990). These glaciomarine sediments occur between 300 km and 500 km to the southwest of the previously suggested limits of Devensian material in the St. George's Channel area (figure 35). The glaciological implications of this major ice lobe at the terminus of the Irish Sea ice stream during the Dimlington Stadial are considered in Scourse *et al.* (1990).

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APPENDIX 1. LITHOSTRATIGRAPHIC DEFINITIONS

(*a*) *Watermill Sands and Gravel Member*

Formation: Watermill
Type-site: Watermill Cove, St Mary's; SV925123–924123 (figure 1)
Base of stratotype from base of open section: −0.5 m
Stratotype base altitude: 4.25 m O.D.
Stratotype thickness: up to 1 m
Sediment characteristics: rounded clast-supported granite cobbles and boulders overlain by bed of structureless medium sand
Granulometry: sand very well sorted with leptokurtic distribution
Variation at other sites: altitudinal range 4.25–7.27 m O.D. Some exposures contain wide range of erratic clasts. Upper contact with Porthloo Breccia frequently entrained downslope
Depositional environment: beach

(*b*) *Porthloo Breccia member*

Formation: Watermill
Type-site: Porthloo, St Mary's; SV908115 (figure 1)
Base of stratotype from base of open section: 0.5 m
Stratotype base altitude: 5.0 m O.D.
Stratotype thickness: up to 5 m
Sediment characteristics: a wide size range of angular granite clasts, up to boulder grade, set in a matrix of granules, sand and silt. Some localized lobate structures and stratification
Granulometry: extremely poorly sorted and coarse skewed
Fabric: downslope orientation, predominant dip into flow direction
Heavy mineralogy: restricted assemblage flooded by tourmaline with subdominant biotite, zircon, andalusite, garnet, epidote and traces of staurolite, chlorite, brown hornblende and augite (J. Catt personal communication, 1985)
Light mineralogy: assemblage dominated by quartz, feldspar and muscovite with traces of flint and glauconite (J. Catt, personal communication, 1985)
Variation at other sites: contains interbedded lacustrine organic deposits and localized lenses of aeolian loessic material
Depositional environment: solifluction (periglacial)

(*c*) *Scilly Till member*

Formation: Bread and Cheese
Type-site: Bread and Cheese Cove, St Martin's; SV940158 (figure 1)
Base of stratotype from base of open section: 0–3 m
Stratotype base altitude: under 3.0 m O.D.
Stratotype thickness: 2 m
Sediment characteristics: well-consolidated pale brown to brown diamicton; distinctive pebble lithological assemblage (1–3 % flint, 11–29 % greywackes and quartzites, 1–6 % sandstones, 2–6 % metamorphics, 60–81 % locally derived granitic material in granule fraction; 4–12 % flint, 16–47 % greywackes and quartzites, 0–15 % sandstones, 0–6 % metamorphics, 42–77 % locally derived granitic material in pebble fraction); 58–135 granules per 100 g dry sediment, 8–18 pebbles greater than 4 mm per 100 g dry sediment. Clasts matrix supported in admixed clay, silt and sand. Very poorly stratified with occasional sand partings up to 2 mm thick
Granulometry: very poorly sorted and highly coarse skewed
Fabric: of variable strength, but strong preferred orientations aligned N.W.–S.E. dipping towards S.E.
Heavy mineralogy: distinctive assemblage rich in epidote, zircon, chlorite, tourmaline, green hornblende, tremolite and actinolite, and yellow rutile with subdominant zoisite, biotite, brown hornblende, garnet, anastase and sphene with occasional traces of augite, brown rutile, brookite, brown spinel, apatite, olivine, staurolite and kyanite (Catt 1986)
Light mineralogy: dominated by quartz, feldspar and muscovite, with subdominant glauconite and flint with an occasional trace of calcite (Catt 1986)
Variation at other sites: not recorded higher than 7 m O.D. Little facies variation. Upper contact with Porthloo Breccia entrained downslope. Sometimes characterized by basal lag gravel dominated by granite boulders
Depositional environment: glacigenic; possibly lodgement till

(*d*) *Tregarthen Gravel member*

Formation: Bread and Cheese
Type-site: Battery, Tresco; SV887166 (figure 1)
Base of stratotype from base of open section: 2.5 m
Stratotype base altitude: 8.0 m O.D.
Stratotype thickness: 4.0 m (comprising four beds in complex)
Sediment characteristics: sandy gravel; clast-supported lag at base passing upwards into medium to fine sand matrix-supported gravel. Distinctive pebble lithological assemblage (1–5 % flint, 3–25 % greywackes and quartzites, 0–0.5 % sandstones, 1–6 % metamorphics, 63–92 % locally derived granitic material in granule fraction; 0.5–6 % flint, 5–19 % greywackes and quartzites, 0–3 % sandstones, 1–5 % metamorphics, 67–92 % locally derived granitic material in pebble fraction); 170–380 granules per 100 g dry sediment, 10–60 pebbles greater than 4 mm per 100 g dry sediment
Granulometry: well sorted, coarse skewed
Depositional environment: glaciofluvial, proximal outwash gravel

(*e*) *Old Man Sandloess member*

Formation: Bread and Cheese
Type-site: Old Man, Gugh, St Agnes; SV893085 (figure 1)
Base of stratotype from base of open section: 1.5 m
Stratotype base altitude: 6.5 m O.D.
Stratotype thickness: 1.0 m
Sediment characteristics: sandy silt. Facies D contains matrix-supported granite clasts and granules, facies C contains quartz granules (see §2*b* above)
Granulometry: variable; some facies well sorted with peaked distributions, others more poorly sorted
Fabric: facies C and D downslope
Heavy mineralogy: distinctive assemblage rich in epidote, zircon, chlorite, green hornblende, garnet and yellow rutile with subdominant zoisite, tourmaline, biotite, brown hornblende, tremolite and actinolite, brown rutile and anastase with traces of augite, brookite, monazite, staurolite and kyanite (Catt 1986)
Light mineralogy: assemblage dominated by quartz and feldspar with subdominant muscovite, glauconite and flint (Catt 1986)
Variation at other sites: considerable facies variation (see §2*b* above)
Depositional environment: primarily aeolian under periglacial conditions

(*f*) *Hell Bay Gravel Member*

Formation: Bread and Cheese
Type-site: Great Bottom, Bryher; SV877160 (figure 1)
Base of stratotype from base of open section: 1.5 m
Stratotype base altitude: 5 m O.D.
Stratotype thickness: 1.8 m
Sediment characteristics: pebbles matrix-supported in well sorted sandy silt derived from the Old Man Sandloess Member. Distinctive pebble lithological assemblage (0.5–8 % flint, 2–22 % greywackes and quartzites, 0–1 % sandstones, 1–8 % metamorphics, 67–96 % locally derived granitic material in granule fraction; 0–11 % flint, 7–51 % greywackes and quartzites, 0–3 % sandstones, 0–16 % metamorphics, 37–92 % locally derived granitic material in pebble fraction); 78–242 granules per 100 g dry sediment, 15–45 pebbles greater than 4 mm per 100 g dry sediment. Some slump and flow structures, with clasts characteristically concentrated towards base of unit

Granulometry: moderately well sorted with peaked distribution

Fabric: prominent downslope preferred orientation, with predominant dips into the flow direction

Heavy mineralogy: distinctive assemblage rich in zircon, tourmaline, staurolite, garnet, epidote, brown hornblende, augite and apatite with subdominant yellow rutile, andalusite, kyanite, zoisite and clinozoisite, tremolite and actinolite and traces of anastase, hypersthene, biotite and chlorite (J. Catt, personal communication, 1985)

Light mineralogy: dominated by quartz and feldspar with subdominant flint muscovite and glauconite (J. Catt, personal communication, 1985)

Variation at other sites: altitudinal range 5.0–25.0 m O.D. Little facies variation

Depositional environment: solifluction and mudflow under periglacial conditions with Old Man Sandloess, Scilly Till and Tregarthen Gravel representing source materials

(*g*) *Bread end Cheese Breccia Member*

Formation: Bread and Cheese

Type-site: Bread and Cheese Cove, St Martin's; SV940158 (figure 1)

Base of stratotype from base of open section: 2.0 m

Stratotype base altitude: 7.8 m O.D.

Stratotype thickness: 3 m

Sediment characteristics: large angular clasts of granite from pebble to boulder grade, with occasional erratic clasts, matrix-supported in poorly sorted granules, sand and silt. Some lobate structures and basal conduct either erosional or deformational

Granulometry: very poorly sorted and coarse skewed

Fabric: downslope orientation, predominant dip into flow direction

Heavy mineralogy: distinctive assemblage flooded with tourmaline, with dominant andalusite, garnet, epidote, brown hornblende and augite with subdominant zircon, staurolite, biotite, chlorite, tremolite and actinolite and apatite with traces of yellow rutile, sillimanite, kyanite, zoisite and clinozoisite and hypersthene (J. Catt, personal communication, 1985)

Light mineralogy: assemblage dominated by quartz and feldspar with subdominant flint and muscovite and a trace of glauconite (J. Catt, personal communication, 1985)

Variation at other sites: considerable facies variation, discussed in detail in Scourse (1987)

Depositional environment: solifluction under periglacial conditions with weathered granite, Scilly Till, Tregarthen Gravel and Hell Bay Gravel representing source materials

(*h*) *Garrison Boulder Bed member*

Formation: Garrison

Type-site: The Garrison, St Mary's; SV901107 (figure 1)

Base of stratotype from base of open section: 0 m

Stratotype base altitude: 23 m O.D.

Stratotype thickness: up to 1 m

Sediment characteristics: large clast-supported rounded granite boulders with interstitial sand

Variation at other sites: not recorded elsewhere; altitudinal variation at type-site 23–25 m O.D.

Depositional environment: beach

APPENDIX 2. IDENTIFICATIONS OF ERRATICS FROM THE HELL BAY GRAVEL

Identifications by J. R. Hawkes, Petrology Unit, British Geological Survey, Keyworth, Nottingham NG12 5GG (present address: 19 Jenner Drive, West End, Woking, Surrey).

Numbers refer to specimens held at the School of Ocean Sciences, University College of North Wales.

Hand specimens:

1. fine sandstone (Palaeozoic greywacke)
2. silicified shale (?Lower Palaeozoic)
3. fine dark red brown sandstone (?Devonian cf. Devon, Pembroke, Ireland)
4. iron-stained fine sandstone (?Lower Palaeozoic–?Carboniferous)
5. acid igneous rock
6. fine granitic rock, probably local material
7. grey medium-grained sandstone (?Lower Palaeozoic greywacke)
8. chert (?Cretaceous)
9. weathered grey sandstone (?Lower Palaeozoic greywacke)
10. weathered fine sandstone (?Lower Palaeozoic greywacke)
11. conglomerate fragment (?Lower Palaeozoic–?Carboniferous)
12. weathered acid igneous rock (?elvan or Lower Palaeozoic)
13. weathered sandstone (?Lower Palaeozoic greywacke–?Carboniferous)
14. flint (?Cretaceous)
15. purplish fine sandstone (?Devonian cf. Devon, Pembroke, Ireland)
16. weathered greenish-grey sandstone (?Lower Palaeozoic–?Carboniferous)
17. weathered fine granite, probably local material
18. quartzitic sandstone (?Lower Palaeozoic)
19. sandstone (?Lower Palaeozoic)
20. quartz laminated argillaceous rock (?Devonian)
21. fine sandstone (?Lower Palaeozoic–?Carboniferous)
22. sandstone (?Lower Palaeozoic)
23. fine greenish sandstone (?Carboniferous)
24. greywacke sandstone (?Palaeozoic)
25. quartz-variety chert
26. grey sandstone (Lower Palaeozoic greywacke, ?Carboniferous)
27. fine iron-impregnated siltstone (?Lower Palaeozoic)
28. grey sandstone (?Lower Palaeozoic–?Carboniferous greywacke)
29. purplish-reddish sandstone (?Devonian cf. Devon, Pembroke, Ireland)
30. purplish sandstone (?Devonian)
31. grey sandstone (Lower Palaeozoic greywacke, ?Carboniferous)
32. quartz-porphyry (local elvan, Permian)
33. chert (?Lower Palaeozoic)
34. fine sandstone (?Lower Palaeozoic)
35. red silty sandstone (Devonian cf. Devon, Pembroke, Ireland)
36. indurated siltstone (?Lower Palaeozoic–?Carboniferous)
37. weathered fine sandstone (?Lower Palaeozoic greywacke–?Carboniferous)
38. sandstone (?Lower Palaeozoic)
39. fine sandstone (?Lower Palaeozoic–?Carboniferous)
40. ferruginized silty argillaceous rock (?Lower Palaeozoic–?Carboniferous)
41. weathered sandstone (?Lower Palaeozoic–?Carboniferous)
42. fine red-brown sandstone (?Devonian cf. Devon, Pembroke, Ireland)

43. fine dark grey sandstone (?Palaeozoic greywacke)
44. fine pink sandstone (?Devonian cf. Devon, Pembroke, Ireland)
45. fine grey sandstone (?Lower Palaeozoic–?Carboniferous greywacke)
46. fine dolerite (?Lower Palaeozoic)
47. dark grey fine sandstone (?Lower Palaeozoic–?Carboniferous)
48. siltstone (?Lower Palaeozoic)
49. flint (Cretaceous)
50. sandstone (?Lower Palaeozoic greywacke)
51. weathered sandstone (?Lower Palaeozoic)
52. grey sandstone (?Lower Palaeozoic greywacke–?Carboniferous)
53. fine grey sandstone (?Lower Palaeozoic)
54. grey phyllitic rock (?Devonian shale)
55. chert (?Lower Carboniferous)
56. weathered sandstone (Lower Palaeozoic–?Carboniferous)

Thin section identifications:

1–3. sandstones

4. medium-grained greywacke, consisting chiefly of quartz grains with some fragments of feldspar, acid igneous rock and fine silty sandstone materials, set in a matrix of clay constituents

5. greywacke type, coarse grained with little clay matrix; contains large quartz grains, potassium and sodium feldspar, quartzite, acid and trachytic igneous rock and ?cherty rock

6. medium-grained protoquartzite consisting of quartz and some feldspar and altered igneous rock fragments in a spare clay matrix

APPENDIX 3. POLLEN PREPARATION AND IDENTIFICATION METHODS

Pollen samples were prepared by using the standard treatment with hydrochloric acid, hydrofluoric acid and acetolysis mixture (Faegri & Iversen 1975). In addition, some samples were treated with sodium pyrophosphate as outlined by Bates *et al.* (1978) for the preparation of clay-rich samples. Sieve washings from the samples were scanned and recorded. The pollen residues were mounted in silicone oil. The addition of known quantities of *Lycopodium* spores by tablet (Benninghoff 1962; Matthews 1969; Bonny 1972) to volumetric subsamples of the sediment enabled the calculation of pollen concentrations. The prepared slides were traversed at regular intervals across the coverslip to avoid the problem of differential pollen distribution as a function of size (Brookes & Thomas 1967). Routine counting was done at a magnification of ×400 using a Leitz S. M. microscope with ×10 periplan oculars and a ×40 apochromatic objective. For critical identifications, a ×95 apochromatic oil-immersion objective was used, with anisole as the immersion fluid.

The pollen and spores were identified to the narrowest limits within the constraints of the British flora using the reference collection of the Subdepartment of Quaternary Research in Cambridge. Plant names follow Clapham *et al.* (1962), and the pollen and spore types follow the schemes of Faegri & Iverson (1975) and Birks (1973); the conventions used to indicate the certainty of identification follow Birks (1973). Indeterminable grains were scored as one of five classes: broken, crumpled, corroded, degraded or concealed (Cushing 1967).

APPENDIX 4. POLLEN CONTAMINATION BY *ANDRENA* SP.

It was noted during sampling at Carn Morval that the organic sediments had been bored by solitary bees of the genus *Andrena*. As this was clearly an important potential source of pollen contamination, the face of the section was removed by up to 0.75 m before sampling. However, when counting commenced it quickly became apparent that some levels were contaminated. An objective method was therefore required to differentiate the modern bee-introduced pollen from the fossil pollen. The following factors are indicators of bee contamination: (i) the presence of bee tunnels at a particular level before cleaning; (ii) anomalous pollen assemblages, the vertical homogeneity broken by sudden influxes of new taxa; (iii) very high pollen concentrations compared with stratigraphically juxtaposed levels; and (iv) the presence of large numbers of pollen clumps.

If contamination was suspected on the basis of these criteria, the taxa under consideration were critically examined in the light of two additional factors: (i) insect (entomophilous), rather than wind (anemophilous), pollination; and (ii) state of preservation.

If a suspected taxon was from an entomophilous plant, and was in an excellent state of preservation, combined with one or more of the initial four criteria, it was regarded as a contaminant. The only major separation problem occurred when a single taxon was, in terms of preservation, clearly comprised of both fossil and bee contaminant pollen; this applied particularly to the Compositae. In such cases, the preservation was used to assign the grain to the fossil or contaminant groups. The pollen diagrams (figure 10 and 11) are uncorrected and include both fossil and contaminant pollen. Corrected diagrams with the contaminant pollen removed from the pollen sum are presented in Scourse (1985).

The most important bee contaminant taxa were *Rubus fruticosus* and Compositae Liguliflorae. At 115 cm, *R. fruticosus* reaches a concentration of 348000 grains cm^{-3} and Compositae Liguliflorae 146000 grains cm^{-3}. Level 85 cm is also badly contaminated. Only levels 0 to 25 cm, 60 cm, 75 cm, 95 cm, 100 cm and 130 cm were uncontaminated, although the remaining levels were only slightly affected.

Apart from *R. fruticosus* and Compositae Liguliflorae, taxa thought to have been introduced by bees include *Angelica* type, *Bidens* type, Caryophyllaceae, Chenopodiaceae, Ranunculaceae, Liliaceae, *Cirsium–Carduus*, *Allium* type, *Empetrum*, *Armeria–Limonium*, Rosaceae, Leguminosae, *Ononis* type, *Silene maritima* type, *Herniaria* and Umbelliferae. Entomophilous plants contributing to these taxa grow locally at the present day.

Bottema (1975) has reported contamination by bees of soil pollen profiles in the Mediterranean. He attributed abnormally high (90%) Compositae values to burrowing digger bees; analysis of nests and bees themselves yielded 85% Compositae pollen, whereas modern surface samples in the same area only contained 20% Compositae pollen. However, Faegri (1961, p. 66) reported very low Compositae pollen in his analysis of a bumble bee nest, which included the bees themselves, their pollen load, faeces and cocoons: 'the almost complete absence of pollen of composites is noteworthy'. Faegri did discover high frequencies, up to 4.9%, of anemophilous pollen adhering to the bees, and reports the distinctive 'flower constancy' of the bees favouring certain species through the phenological season.

The apparent conflict in the amount of Compositae pollen being harvested may be explained by the differences between the bee species being studied. In this study, and that of Bottema (1975), solitary digger bees are the cause of contamination, whereas Faegri (1961) was dealing with social bees, principally *Bombus lucorum* and *B. muscorum*. Alternatively, the differences may be seasonal and related to flower constancy. The high frequencies of anemophilous pollen reported by Faegri suggest that anemophilous taxa should not be rejected as possible contaminants in a bee-disturbed profile. This is almost certainly not a species-related phenomenon, as the anemophilous pollen was probably picked up during flight or nectar collecting, functions common to both solitary and social bees. Faegri's flower constancy conclusions suggest that although certain taxa are likely to dominate any bee-harvested spectrum, the preferred taxa change through the phenological season. This suggests that a contaminated profile would be expected to show considerable variation in the contaminant taxa and their frequency between levels.

Such variations can be seen in the Carn Morval diagrams. At 110 cm, for instance, the contaminants include *R. fruticosus*, Compositae Liguliflorae, *Angelica* type, Caryophyllaceae undiff., *Empetrum*, Chenopodiaceae and Liliaceae undiff., whereas at the juxtaposed level 115 cm, *Allium* type, *Cirsium–Carduus*, *Armeria–Limonium* and *Lonicera* type are recorded in the absence of Caryophyllaceae undiff., *Empetrum*, Chenopodiaceae and Liliaceae undiff., although *R. fruticosus*, Compositae Liguliflorae and *Angelica* type still predominate.

APPENDIX 5. POLLEN ANALYSIS OF UNIT 1 AT PORTH ASKIN, ST AGNES

Pinus	2.1%	broken	0.3%
Picea	0.06%	crumpled	26.9%
Hippophaë rhamnoides	0.2%	degraded	16.6%
Gramineae	69.9%	concealed	2.0%
Cyperaceae	7.1%		
Calluna vulgaris	0.4%		
Artemisia	0.06%		
Achillea type	0.7%		
Solidago type	2.7%		
Compositae Liguliflorae	0.3%		
Helianthemum	0.06%		
Plantago undiff.	1.0%		
Rubus fruticosus	14.5%		
Rosaceae undiff.	0.4%		
Rubiaceae	0.4%		
Sphagnum	0.1%		
Filicales	0.1%		

Total non-obligate aquatic pollen and spores (ΣP) = 1599.

$\Sigma P + \Sigma I + \Sigma Aq = 3001$.
$\% I = 46.7\%$.

APPENDIX 6. POLLEN ANALYSES OF UNIT 4 AT PORTH SEAL, ST MARTIN'S

Sample A (lower):

Pinus	2.8%	broken	10.8%
Alnus	0.3%	crumpled	30.1%
Corylus	0.3%	degraded	12.2%
Gramineae	75.1%	concealed	0.5%
Cyperaceae	1.4%		
cf. *Empetrum*	5.2%		
Solidago type	1.4%		
Achillea type	0.3%		
Compositae Liguliflorae	0.8%		
Plantago maritima	0.6%		
Plantago undiff.	1.7%		
Ranunculus repens type	6.4%		
Rubiaceae	3.0%		
Potamogeton	1.0%		
Sparganium type	1.1%		
Typha latifolia	0.1%		

Total non-obligate aquatic pollen and spores (ΣP) = 362.
$(\Sigma P + \Sigma I + \Sigma Aq) = 818$.

$\% I = 45.7\%$.

Sample B (upper):

Pinus	0.3%	broken	0.2%
Corylus	0.3%	crumpled	33.2%
Gramineae	78.7%	degraded	13.6%
Cyperaceae	1.3%	concealed	0.5%
Solidago type	9.3%	corroded	0.3%
Achillea type	0.3%		
Cruciferae	0.6%		
Plantago major–P. media type	0.6%		
Rubiaceae	6.0%		
Apium–Berula type	0.3%		
Sparganium	2.0%		

Total non-obligate aquatic pollen and spores (ΣP) = 300.
$(\Sigma P + \Sigma I + \Sigma Aq) = 603$.

$\% I = 50.2\%$.

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