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# A palynological investigation of seventeen till samples from Wales

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# A palynological investigation of seventeen till samples from Wales

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palynomorphs, Lower Palaeozoic, Carboniferous, Mesozoic, Palaeogene, Quaternary, glacial sediments, provenance, biostratigraphy, Wales.

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# Foreword

This report comprises a palynological study of 17 samples of glacial tills from Wales. Dr M. H. Stephenson helped with the identification of the Carboniferous spores.

# Contents



# Summary

The majority of the samples produced abundant palynomorph associations, ranging in age from Lower Palaeozoic to Quaternary. The majority of the material identified is Carboniferous, Jurassic and Quaternary; lower proportions of Lower Palaeozoic, Permian-Triassic, Cretaceous, and Eocene material was observed. Samples 2 and 6 are entirely comprised of Quaternary miospores. The nature and proportions of the Lower Palaeozoic to Quaternary components reflect the provenance of the ice sheets that deposited these tills. The majority of the Carboniferous to Quaternary component was apparently derived from the Irish Sea Basin. The Carboniferous input is from North Wales and Anglesey and the unequivocal Cretaceous elements are interpreted as being from Northern Ireland. The local solid geology of this part of Wales is Lower Palaeozoic, and the acritarchs in samples 14 and 16 are believed to be locally-derived, or from further north in Wales. Sample 1 is Irish Sea Till and this produced

Carboniferous, Jurassic, ?Lower Cretaceous, Palaeocene and Quaternary reworking. Sample 2, Welsh Till, yielded only Quaternary miospores. Sample 6 produced a similar association and is therefore interpreted as being from the same unit as sample 2. Samples 3 and 4 are from Welsh Till and yielded Carboniferous, Jurassic and Quaternary miospores. Samples 7 to 9 were attributed to the Irish Sea Till and produced abundant Carboniferous, Jurassic, ?Lower Cretaceous, Palaeogene and Quaternary reworking. Samples 10 to 17 are also believed to be from the Irish Sea Till because they yielded similar associations.

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# 1 Introduction

Seventeen samples of glacial tills from Wales were studied for their palynomorph content. This study aimed to determine the provenance of the till samples via allochthonous palynomorphs. This work has been undertaken in order to contribute to the geological mapping of this region and to help better understand the glacial history.

# 2 Sample Details

The seventeen samples studied are listed below. The columns are the (informal) sample number, the BGS micropalaeontological registration number (prefixed MPA), the locality, the grid reference details supplied, the lithology and, where supplied, details of which ice sheet is thought to have deposited the till respectively.

| | | | | | |
|---|---|---|---|---|---|
| 1 | MPA 53018 | Penavern-uchat | 278 396 | dark brown clay-rich till with clasts | Irish ice |
| 2 | MPA 53019 | Rhydygate | SN23/SW/SW | dark grey/green clay-rich till | Welsh Ice |
| 3 | MPA 53020 | Bwlch-gwyn (ditch) | 4030 2820 | massive grey, clay-rich till | Welsh Ice |
| 4 | MPA 53021 | Bwlch-gwyn | 4050 2832 | massive grey, clay-rich till | Welsh Ice |
| 5 | MPA 53022 | Triolbrith | SN 3980 3525 | mid-brown, clast clay-rich deposit | ?head |
| 6 | MPA 53023 | Nanty Grooes | SN23/SW/SW | mid-brown, clay-rich deposit | ?head |
| 7 | MPA 53154 | | SN 27625 47371 | clay; black shale clasts | Irish Sea Till |
| 8 | MPA 53155 | Fronlas Hirwain | SN 26976 47485 | brown clay; ORS clasts | ?Irish Sea Till |
| 9 | MPA 53156 | | SN 33 370 305 | clay matrix; ‘Welsh’ clasts | ?Irish Sea Till |
| 10 | MPA 53300 | Cei Bach | SN 4065 5983 | dark grey, massive, stone-free clay | |
| 11 | MPA 53301 | Cei Bach | SN 4065 5983 | mid grey diamicton; no erratics | |
| 12 | MPA 53302 | Cei Bach | SN 4118 5978 | dark brown, clast-rich diamicton | |
| 13 | MPA 53303 | Cei Bach | SN 4118 5978 | mid grey, clast-poor diamicton | |
| 14 | MPA 53332 | Tresaith | 227990 251420 | dark grey, clay-rich till with small dark erratics | |
| 15 | MPA 53333 | Llanpumsiant | 21H780 228800 | mid grey, clay-rich till with erratics | |
| 16 | MPA 53334 | Aberporth | 225910 251430 | mid grey, clay-rich till with erratics | |
| 17 | MPA 53335 | near Pontersais | 243650 228020 | light grey, clay-rich till with small erratics | |

# 3 Palynology

In this section, the palynofloras are described in five sections. Full listings of palynomorphs, including semiquantitative data, are held on the respective BGS micropalaeontology/palynology data sheets, which have been archived. Table 1 summarises the sample details and gives the numbers of palynomorphs per slide. Tables 2 and 3 illustrate the numbers and percentages of the several age-based palynomorph groups.

The material was all prepared using the sodium hexametaphosphate method of Riding and Kyffin-Hughes (2004).

Drs S. G. Molyneux and M. H. Stephenson helped with the identification of the Lower Palaeozoic and Carboniferous palynomorphs respectively.

## 3.1 SAMPLE 1 (MPA 53018)

Sample 1 produced an extremely rich and well-preserved organic residue and palynoflora (Tables 1, 2). Wood and plant fragments are common, however a highly diverse palynoflora overwhelmingly dominates the residue. This palynoflora is dominated by Quaternary pollen grains, with lesser proportions of Carboniferous and Jurassic miospores. Relatively lower proportions of Jurassic microplankton, possible Cretaceous spores, Palaeogene dinoflagellate cysts, Quaternary dinoflagellate cyst and non age-diagnostic palynomorphs were recorded (Tables 2, 3).

The Carboniferous input of 17.0% of the palynoflora is dominated by *Densosporites* spp. and *Lycospora pusilla*, and this is indicative of significant input from probable Namurian/Westphalian strata. Representatives of *Densosporites* are most common. Other taxa of this age recognised include *Cristatisporites* spp., *Endosporites zonalis*, *Knoxisporites* sp., ?*Radiizonates* sp., *Reticulatisporites polygonalis, Savitrisporites nux, Triquitrites marginatus,* and *Verrucosisporites morulatus*. *Endosporites zonalis* is characteristic of the Westphalian; the majority of the other taxa are consistent with this assessment. However, *Triquitrites marginatus* is characteristic of the Viséan, therefore the Carboniferous input may have been derived from several stratigraphical intervals. These Carboniferous spores were probably derived from the North Wales coast, and onshore and offshore Anglesey (Wilkinson and Halliwell, 1979; Hunt, 1984).

Spores and pollen of Jurassic aspect also proved common, representing 12.2% of the palynoflora. Taxa identified comprise *Callialasporites* spp., *Cerebropollenites macroverrucosus, Chasmatosporites* spp., *Classopollis classoides, Classopollis meyeriana, Dictyophyllidites* spp. and *Perinopollenites elatoides*. The long-ranging genus *Classopollis* is the most prominent element. The occurrence of *Callialasporites* spp. means that a significant part of this input is of Mid-Late Jurassic age. The range base of this genus is at the Early-Mid Jurassic transition (Riding et al., 1991).

The Jurassic microplankton include the dinoflagellate cysts *Adnatosphaeridium caulleryi, Nannoceratopsis deflandrei* subsp. *deflandrei, Nannoceratopsis deflandrei* subsp. *senex, Korystocysta gochtii* and *Pareodinia* spp. *Nannoceratopsis deflandrei* subsp. *deflandrei* and *Nannoceratopsis deflandrei* subsp. *senex* are indicative of input from the Toarcian (Early Jurassic), probably the early Toarcian (Riding et al., 1999). The association of *Adnatosphaeridium caulleryi, Korystocysta gochtii* and *Pareodinia* spp. is most indicative of the Mid Jurassic. The genus *Korystocysta* is most characteristic of the Callovian Stage.

The Jurassic palynomorphs are considered to have been derived from Irish Sea ice that came from the Cardigan Bay area (Garrard, 1977; Wilkinson and Halliwell, 1979; Hunt, 1984).

Low proportions (0.3%) of the spore genus *Cicatricosisporites* were observed. This genus is most characteristic of the Early Cretaceous, but is not confined to this interval. Hence it is considered that this is not *prima facie* evidence of input from Lower Cretaceous strata. These grains may be from Northern Ireland (Hunt, 1984).

Dinoflagellate cysts of Palaeogene age were also encountered in low numbers (0.3%). These include *Achilleodinium biformoides, Cordosphaeridium gracile, Deflandrea oebisfeldensis, Glaphyrocysta ordinata* and *Homotryblium tenuispinosum*. This association is indicative of input from the Ypresian Stage of the Eocene (Powell 1992; Stover et al., 1996). The source of this Palaeogene input is interpreted as being the Cardigan Bay area (Garrard, 1977; Wilkinson and Halliwell, 1979; Hunt, 1984).

Both terrestrially-derived and marine Quaternary palynomorphs are present (Table 3). Pollen and spores include *Alnus, Carya, Dryopteris, Erica, Picea, Pinus, Polypodium vulgare, Stereisporites* and *Tilia*. This flora includes pteridophytes, shrubs and trees; herb pollen is rare. Pine pollen (*Pinus*) is the most prevalent form. Assuming that the flora is a coherent one, i.e. not mixed, it is consistent with an upland environment, probably a wooded moorland/heath setting.

The Quaternary dinoflagellate cysts include *Achomosphaera andalousiensis, Bitectatodinium tepikiense, Operculodinium* spp. and *Spiniferites* spp. The Quaternary palynomorphs are thought to have been derived from Irish Sea ice that came from the Cardigan Bay area (Garrard, 1977; Wilkinson and Halliwell, 1979; Hunt, 1984).

There are certain forms that are stratigraphically long ranging, hence cannot be included in the age-related groupings. These include *Cyathidites* spp., pre-Quaternary bisaccate pollen, and *Micrhystridium* spp. They comprise 9.8% of the association (Table 3).

In conclusion, the reworked palynoflora from sample 1 indicates unequivocal input from the Carboniferous, Jurassic, Eocene and Quaternary. The input from the Eocene is at an extremely low level. No indications of the Lower Palaeozoic, Permian/Triassic, Late Cretaceous or Neogene were observed. The sample is described as being from an Irish Sea Till. Therefore the Jurassic to Quaternary palynomorphs are interpreted as being derived from the bed of the Irish Sea. The Carboniferous material is sourced from North Wales and Anglesey.

## 3.2 SAMPLES 2 AND 6 (MPA 53019 AND MPA 53023 RESPECTIVELY)

Samples 2 and 6 are treated together because of their close similarity. Both samples produced kerogen assemblages dominated by plant tissues; leaf cuticle is especially prominent, especially in sample 2. Wood fragments are subordinate to lighter plant tissues and palynomorphs are common. No pre-Quaternary palynomorphs are present; the assemblages are entirely made up of Quaternary pollen and spores. Taxa recognised include *Alnus, Aster,* Caryophyllaceae pollen, Compositae pollen, *Corylus, Dryopteris, Pinus, Polypodium vulgare, Scabiosa, Sphagnum, Stereisporites* and undifferentiated fern spores. This flora is similar in taxonomic makeup to that in sample 1 and includes herbs, pteridophytes, shrubs and trees. However, unlike in sample 1 which is dominated by *Pinus*, by far the most prevalent elements are the pteridophytic spores *Dryopteris*, *Polypodium vulgare* and *Stereisporites*. Assuming that the associations are not mixed, this flora indicates a damp, lowland setting. The shrub/herb pollen (e.g. Compositae, *Erica* and *Scabiosa*) is entirely consistent with this interpretation and the relatively rare tree pollen are assumed to derive from nearby woodland.

In summary, the palynofloras from samples 2 and 6 are entirely devoid of pre-Quaternary forms. No indications of the Lower Palaeozoic to Quaternary interval were observed. The samples yield abundant Quaternary pollen and spores that point to deposition in a low, wet environment such as a swamp. Sample 2 is described as being from a Welsh Till. Sample 6 was described as possible head. The virtually identical palynofloras indicates that both samples are from Welsh Till. It seems likely that the Quaternary palynomorphs were derived locally, rather than being far-travelled, due to the complete absence of pre-Quaternary forms. The absence of marine palynomorphs means that the source of this material may be from lake beds.

## 3.3 SAMPLES 3 TO 5 (MPA 53020 TO MPA 53022)

Samples 3 to 5 are described together due to their similarity. Wood and plant tissue are both prominent in all three samples. Sample 3 is by far the most palynologically productive; by contrast, samples 4 and 5 are relatively sparse (Table 1). Wood and plant tissue are both prominent in all the samples. Palynomorphs are common in sample 3, but relatively sparse in samples 4 and 5. All samples are rich in Quaternary pollen and spores and also have subordinate levels of Carboniferous miospores, Jurassic miospores and long-ranging palynomorph taxa (Tables 2, 3).

Significant Carboniferous input was observed in all the samples (Table 2). In sample 3, this represents 27.9% of the palynoflora and is dominated by *Densosporites* spp. and *Lycospora pusilla*. *Densosporites* spp. are most common. Other taxa recorded comprise rare *Raistrickia* sp.

This is indicative of input from Namurian/Westphalian strata from outcrops along the North Wales coast, and onshore and offshore Anglesey (Wilkinson and Halliwell, 1979; Hunt, 1984).

Jurassic miospores were also present. These are relatively rare in samples 3 and 5, but significant in sample 4, where they represent 17.0% of the palynoflora. The taxa comprise *Callialasporites turbatus*, *Chasmatosporites* spp., and *Classopollis classoides*. *Classopollis classoides* is most common. The occurrence of *Callialasporites turbatus* indicates that at least part of this input is of Mid-Late Jurassic age (Riding et al., 1991). These Jurassic miospores were derived from the Cardigan Bay area (Garrard, 1977; Wilkinson and Halliwell, 1979; Hunt, 1984).

The Quaternary palynomorphs include *Alnus, Aster,* Caryophyllaceae pollen, *Corylus, Dryopteris, Erica, Picea, Pinus, Polypodium vulgare, Silene, Stereisporites, Tilia,* and undifferentiated fern spores. These floras are similar in taxonomic spectra to those in samples 1 and 2 and include herbs, pteridophytes, shrubs and trees. *Pinus* and pteridophyte spores, most prominently *Dryopteris,* are prominent. If the associations are not mixed, this flora indicates a damp, lowland setting relatively close to Pine woodland. The Quaternary palynomorphs are thought to have been derived from Irish Sea ice from Cardigan Bay (Garrard, 1977; Wilkinson and Halliwell, 1979; Hunt, 1984).

Long-ranging forms are also present and in sample 3, these comprise 11.0% of the association (Table 3).

Sample 5 is a mid-brown, clast-rich deposit. The matrix was prepared using sodium hexametaphosphate. The majority of the palynomorphs were encountered in the matrix. The dark, fine-grained clasts did not break down in sodium hexametaphosphate. These were then prepared separately using the traditional acid digestion technique. The clasts yielded an extremely sparse palynoflora. The assemblage comprised four Quaternary pollen grains and a single specimen of *Classopollis classoides.* These clasts are clearly not of Quaternary age and all the palynomorph specimens may have been derived from material adherent to these clasts.

In conclusion, the allochthonous palynofloras from samples 3 to 5 indicates input from the Carboniferous, Jurassic and Quaternary. No indications of the Lower Palaeozoic, Permian/Triassic, Late Cretaceous or Palaeogene/Neogene were observed. Samples 3 and 4 are described as being from a Welsh Till; sample 5 is from a possible head deposit. The similarities of the palynofloras indicates that all three samples are from Welsh Till. The Carboniferous, Jurassic and Quaternary palynomorphs may be derived from the bed of the Irish Sea, alternatively, the Quaternary palynomorphs may have been locally-derived.

### 3.4 SAMPLES 7 TO 10 (MPA 53154 TO MPA 53156 AND MPA 53300)

Four samples, numbers 7 to 10, are described together due to their overall similarity (Tables 1-3). They are distinguished from samples 11 to 17 by the absence of Permian-Triassic miospores (see section 3.5, below). Wood and plant tissue are prominent in all the samples. Samples 7, 8 and 10 yielded abundant, well-preserved and extremely diverse palynofloras. However, sample 9 proved markedly less productive (Table 1). Sample 9 produced abundant fungal material, hence may have undergone weathering and thus partial loss of the organic fraction. All samples are extremely rich in Quaternary pollen and spores. These are the dominant element except for sample 9, where Carboniferous spores are more abundant (Tables 2, 3). The samples also yielded Carboniferous miospores, Jurassic miospores and microplankton, possible Cretaceous spores, rare Cretaceous dinoflagellate cysts, Palaeogene miospores and dinoflagellate cysts, Quaternary dinoflagellate cyst and non-age diagnostic palynomorphs (Tables 2, 3).

The Carboniferous input of between 7.8% (sample 7) to 51.3% (sample 9) is dominated by *Cingulizonates* spp., *Densosporites* spp. and *Lycospora pusilla*. Representatives of *Densosporites* are consistently the most common. This is indicative of major input from the

Namurian/Westphalian. Other taxa recognised include *Calamospora* spp., ?*Cristatisporites* sp., *Convolutispora* sp., *Endosporites globiformis*, ?*Knoxisporites* sp., *Punctatisporites* sp., *Raistrickia fulva,* ?*Raistrickia nigra, Reticulatisporites polygonalis, Reticulatisporites* spp., *Rugospora* sp., ?*Savitrisporites* spp., ?*Thymospora* sp., *Tripartites vetustus*, *Triquitrites* sp., *Verrucosisporites morulatus* and ?*Verrucosisporites* spp. *Endosporites globiformis* is characteristic of the Westphalian; the majority of the other taxa are consistent with this assessment. *Raistrickia fulva* is present in sample 9 and is a marker for the Late Namurian to Mid Westphalian interval. ?*Savitrisporites* spp. is present in sample 10 and is characteristic of the Namurian. Furthermore, *Tripartites vetustus* is characteristic of the Viséan-Namurian transition, therefore the Carboniferous input may have been derived from several stratigraphical intervals. This is likely to be derived from outcrops along the North Wales coast, and onshore and offshore Anglesey (Wilkinson and Halliwell, 1979; Hunt, 1984).

Spores and pollen characteristic of the Jurassic were also relatively prominent, representing between 8.6% (sample 10) and 14.3% (sample 7) of the palynoflora. Taxa identified comprise *Callialasporites* spp., *Cerebropollenites macroverrucosus, Chasmatosporites* spp., *Classopollis classoides, Classopollis meyeriana, Coronatispora valdensis, Dictyophyllidites* spp., *Ischysporites variegatus, Perinopollenites elatoides,* and *Todisporites major*. Species of *Callialasporites* and *Classopollis* are the most common. The presence of *Callialasporites* spp. indicates that much of this input is of Mid-Late Jurassic age; the range base of this genus is at the Lower-Middle Jurassic boundary.

Jurassic microplankton were encountered in all the four samples except sample 9 and include the dinoflagellate cysts ?*Atopodinium haromense,* ?*Cribroperidinium globatum, Gonyaulacysta centriconnata*, *Meiourogonyaulax* sp., *Nannoceratopsis deflandrei* subsp*. deflandrei*, *Pareodinia ceratophora*, *Pareodinia* spp., ?*Rhynchodiniopsis cladophora,* and *Tubotuberella dangeardii*. Additionally, the prasinophytes *Cymatiosphaera* spp., *Halosphaeropsis liassica* and *Tasmanites newtoni* were observed in samples 8 and 10. Many of these taxa have stratigraphical implications. Sample 7 only yielded *Pareodinia* spp., which are relatively long-ranging, however this genus is most characteristic of the Mid-Late Jurassic. Sample 8 produced the prasinophytes *Cymatiosphaera* spp. and *Tasmanites newtoni*. These forms are most common in the Toarcian Stage, especially the anoxic facies of the early Toarcian (Bucefalo Palliani et al., 2002). However, no characteristic early Toarcian dinoflagellate cysts were observed in this sample. Dinoflagellate cysts in sample 8 were ?*Atopodinium haromense*, *Gonyaulacysta centriconnata,* ?*Rhynchodiniopsis cladophora*, and *Tubotuberella dangeardii*. *Gonyaulacysta centriconnata* is confined to the late Callovian-early Oxfordian interval (Riding, 1983), and indicates input from strata equivalent to the Stewartby and Peterborough members of the Oxford Clay Formation of onshore England. ?*Rhynchodiniopsis cladophora* and *Tubotuberella dangeardii* are both entirely consistent with the late Callovian-early Oxfordian. ?*Atopodinium haromense* may be indicative of input from the Oxfordian/Kimmeridgian. *Pareodinia ceratophora* is relatively long-ranging within the Mid-Late Jurassic interval. *Halosphaeropsis liassica* and *Nannoceratopsis deflandrei* subsp*. deflandrei* were observed from sample 10. These taxa are indicative of input from the early Toarcian. Other dinoflagellate cysts from this sample are ?*Cribroperidinium globatum* and *Meiourogonyaulax* sp. These possibly indicate input from the Kimmeridgian and Middle Jurassic respectively.

These Jurassic palynomorphs were derived from Irish Sea from the Cardigan Bay area (Garrard, 1977; Wilkinson and Halliwell, 1979; Hunt, 1984).

Low numbers of *Cicatricosisporites* spp. were observed in samples 7, 8 and 10 (Table 2). These forms are especially characteristic of the Lower Cretaceous, but the genus is not confined to this substage. Therefore this is not unequivocal evidence of Lower Cretaceous input. It is possible that these palynomorphs may be from the Northern Ireland area (Hunt, 1984).

Sample 10 yielded a single sample of *Odontochitina operculata*. This is a characteristically Cretaceous dinoflagellate cyst that ranges from the early Barremian to the early Maastrichtian

(Costa and Davey, 1992). This occurrence points to definite, yet minor, Cretaceous input. This specimen is most likely to be from Northern Ireland (Mitchell, 2004). There are no known outcrops of the Cretaceous in Cardigan Bay (Garrard, 1977; Wilkinson and Halliwell, 1979). The ice sheet probably traversed Northern Ireland, the Lleyn Peninsula and Cardigan Bay on its route to southwest Wales (Hunt, 1984). This is consistent with clast analysis (Garrard, 1977).

A solitary specimen of the pollen grain *Spinizonocolpites echinatus* was encountered in sample 7. This distinctive form is characteristic of the Eocene. All four samples yielded low proportions of Palaeogene dinoflagellate cysts (Table 3). These include ?*Achilleodinium biformoides, Areoligera senonensis, Cordosphaeridium gracile, Diphyes ficusoides, Dracodinium solidum, Glaphyrocysta* spp., *Hystrichokolpoma salacium, Hystrichosphaeridium tubiferum, Spiniferites cornutus, Spiniferites* spp., and *Wetzeliella* spp. This association is indicative of input from the Ypresian and Lutetian stages of the Eocene (Powell 1992; Stover et al., 1996). Sample 7 produced the markers *Diphyes ficusoides, Hystrichosphaeridium tubiferum,* and *Wetzeliella* spp. The range top of *Hystrichosphaeridium tubiferum* is within the Ypresian and *Diphyes ficusoides* is confined to the Lutetian (Powell, 1992). Hence the Eocene input at this horizon may be mixed. The Palaeogene input to sample 8 is assessed as being of Ypresian age due to the occurrence of *Dracodinium solidum* and *Wetzeliella* spp. (Powell, 1992). No key Palaeogene markers are present in sample 9. The Palaeogene component of sample 10 is of undifferentiated Eocene age due to the occurrences of *Hystrichokolpoma salacium* and *Wetzeliella* spp. The source of these Palaeogene grains is the Cardigan Bay area (Garrard, 1977; Wilkinson and Halliwell, 1979; Hunt, 1984).

The Quaternary miospores include *Alnus, Aster, Carya, Corylus, Dryopteris,* Gramineae pollen, *Picea, Pinus, Polypodium vulgare, Scabriosa, Sphagnum,* and *Tilia.* These floras are similar in taxonomic spectra to those in the other samples in this study and include herbs, pteridophytes and trees. *Pinus* and pteridophyte spores, most prominently *Dryopteris,* are prominent. *Pinus* is the most common in samples 7, 8 and 10. *Dryopteris* is the most common miospore in sample 9. If these associations are not mixed, these associations indicate a damp, lowland setting close to Pine-dominated woodland. Quaternary dinoflagellate cysts observed include *Achomosphaera andalousiensis, Bitectatodinium tepikiense, Operculodinium* spp. and *Spiniferites* spp. The Quaternary palynomorphs are interpreted as having been derived from Irish Sea ice from Cardigan Bay (Garrard, 1977; Wilkinson and Halliwell, 1979; Hunt, 1984).

There are certain forms that are long ranging and cannot be included in the age-related groupings. These include *Cyathidites* spp., pre-Quaternary bisaccate pollen, and *Micrhystridium* spp. (Table 3).

The reworked palynofloras from samples 7 to 10 indicates input from the Carboniferous, Jurassic, Cretaceous, Eocene and Quaternary. The input from the Cretaceous and Eocene is low in abundance. No unequivocal indications of the Lower Palaeozoic, Permian/Triassic or Neogene were observed. The samples are largely described as being from an Irish Sea Till. Therefore the Carboniferous to Quaternary palynomorphs are interpreted as being derived from the bed of the Irish Sea.

### 3.5 SAMPLES 11 TO 17 (MPA 53301 TO MPA 53303 AND MPA 53332 TO MPA 53335)

Seven samples, numbers 11 to 17, are described here due to their similarity (Tables 1-3). They are distinguished from samples 7 to 10 by the presence of rare Permian-Triassic miospores. Wood and plant tissue are prominent in all seven samples. All the samples yielded relatively abundant, well-preserved and diverse palynofloras (Tables 1-3). All samples are dominated by Quaternary pollen and spores, especially samples 15 and 17, which yielded 91.7 % and 95.9% respectively (Table 3). The samples also yielded rare Lower Palaeozoic acritarchs, Carboniferous miospores, rare Permo-Triassic miospores, Jurassic miospores and microplankton, possible Cretaceous spores, rare Cretaceous dinoflagellate cysts, Palaeogene dinoflagellate cysts, Quaternary dinoflagellate cyst and non-age diagnostic palynomorphs (Tables 2, 3).

Samples 14 and 16 produced low numbers of Lower Palaeozoic acritarchs (Table 2). Sample 14 produced single specimens of *Diexallophasis* sp., *Stellechinatum helosum* and *Veryhachium trispinosum*. *Diexallophasis* sp. is indicative of the Silurian, *Stellechinatum helosum* is characteristic of the Mid-Late Ordovician and the specimen of *Veryhachium trispinosum* is of Ordovician aspect. Hence it appears that the Lower Palaeozoic input was sourced from at least two stratigraphical intervals. Sample 16 produced a single grain of *Multiplicisphaeridium* sp., which is of Silurian aspect. The Silurian forms are likely to have been derived locally from Llandovery age strata. By contrast, the Ordovician forms are most likely to be from areas to the north such as the Harlech Dome or the Lleyn Peninsula (Hunt, 1984).

The Carboniferous input of between 3.1% (sample 15) to 19.4% (sample 16) is largely *Cingulizonates* spp., *Densosporites* spp. and *Lycospora pusilla*. Other taxa include *Calamospora* cf. *microrugosa*, *Calamospora* spp., *Cirratriradites rarus*, ?*Colatisporites* sp., *Convolutispora* spp., *Knoxisporites* spp., *Punctatisporites* sp., *Radiizonates aligerens/difformis*, *Reticulatisporites* sp., ?*Rotaspora* sp., *Rugospora minuta*, ?*Savitrisporites nux*, ?*Secarisporites* sp., ?*Spelaeotriletes* sp., *Stenozonotriletes* sp., *Triquitrites* sp. and *Verrucosisporites* spp. This flora is largely indicative of significant input from the Namurian/Westphalian. Representatives of *Densosporites* are normally the most common. The large spore *Endosporites globiformis* is present in sample 16; this taxon is confined to the Westphalian (Clayton and Butterworth, 1984; Owens et al., 1978; Owens, 1996). The occurrence of *Radiizonates aligerens/difformis* in sample 12 and ?*Savitrisporites nux* in sample 14 is also reminiscent of the Westphalian. However, ?*Colatisporites* sp. (sample 11), *Knoxisporites* spp. (samples 13, 14 and 16), *Rugospora minuta* (sample 16) and *Stenozonotriletes* sp. (sample 16) are characteristic of the Lower Carboniferous. The Carboniferous input is likely to be from outcrops along the North Wales coast, and from onshore and offshore Anglesey (Wilkinson and Halliwell, 1979; Hunt, 1984).

Samples 11, 12, 14, 15 and 16 yielded extremely low numbers of Permian-Triassic miospores. The material in sample 11, were not identified to species level. Samples 12 and 14 produced single specimens of the pollen grain *Rhaetipollis germanicus*; this form is confined to the Rhaetian Stage according to Morbey and Dunay (1978). The distinctive spore *Ricciisporites tuberculatus* is present rarely in sample 15. This species is confined to the Triassic-Jurassic transition (Rhaetian-Hettangian), but is most characteristic of the Rhaetian (Morbey, 1978; Morbey and Dunay, 1978). The spore *Kraeuselisporites reissingeri* was recovered in low proportions from sample 16. This taxon ranges from the Late Triassic (Rhaetian) to the Early Jurassic (early Sinemurian) (Morbey, 1978; Morbey and Dunay, 1978). Indeterminate pollen grains of probable Permian-Triassic age were also observed in samples 14 and 16. It seems that the identifiable Permian-Triassic forms are indicative of input from the Rhaetian Stage. Other forms that could also be from this Stage include *Classopollis meyariana*. These Permian-Triassic miospores are interpreted as being derived from Irish Sea ice that came from the Cardigan Bay area (Garrard, 1977; Wilkinson and Halliwell, 1979; Hunt, 1984).

Spores and pollen of Jurassic aspect were also relatively prominent in samples 11 to 14 and 16, representing between 9.2% (samples 12 and 13) and 26.8% (sample 16) of the palynoflora (Table 2). Sample 15 proved sparse of these forms and sample 17 was entirely devoid of them. Taxa identified comprise *Callialasporites* spp., *Cerebropollenites macroverrucosus, Chasmatosporites* spp., *Cibotiumspora juriensis, Classopollis classoides, Classopollis meyeriana, Coronatispora valdensis, Dictyophyllidites* spp., *Ischysporites variegatus,* and *Perinopollenites elatoides*. *Callialasporites* spp. and *Classopollis* spp. are normally the most common. The presence of *Callialasporites* spp. indicates that much of this input is Mid-Late Jurassic because the range base of this genus lies at the Lower-Middle Jurassic boundary.

Jurassic microplankton were encountered in low proportions from samples 11 to 13 (Table 2). These floras include the dinoflagellate cysts *Cribroperidinium globatum*, ?*Ctenidodinium* sp., ?*Endoscrinium galeritum*, *Gonyaulacysta jurassica* subsp. *adecta*, *Nannoceratopsis deflandrei* subsp. *senex*, *Pareodinia* sp., *Rhynchodiniopsis cladophora*, *Systematophora areolata*, *Systematophora*? *daveyi*. Furthermore, the prasinophyte *Halosphaeropsis liassica* was observed in samples 12 and 13. Several of these taxa have stratigraphical significance. Samples 11 and 12 yielded *Nannoceratopsis deflandrei* subsp. *senex;* this together with the presence of *Halosphaeropsis liassica* is indicative of input from the early Toarcian (Bucefalo Palliani et al., 2002). Hence coeval strata to the Lower Toarcian Whitby Mudstone Formation have been eroded. *Cribroperidinium globatum* and *Systematophora*? *daveyi* are also present in sample 11; these taxa are indicative of input from the Kimmeridge Clay Formation (Kimmeridgian) (Riding and Thomas, 1988). The occurrence of *Gonyaulacysta jurassica* subsp. *adecta* in sample 12 is indicative of the incorporation of Callovian-mid Oxfordian strata (Riding and Thomas, 1992). The presence of *Pareodinia* spp. and *Rhynchodiniopsis cladophora* is consistent with this scenario. *Cribroperidinium globatum* is also present in sample 12 and indicates input from the Kimmeridgian. Sample 13 yielded ?*Endoscrinium galeritum*, *Cribroperidinium globatum* and *Systematophora areolata.* Again, these forms are suggestive of the incorporation of Kimmeridge Clay Formation.

The Jurassic forms are believed to have been derived from Irish Sea ice that came from the Cardigan Bay area (Garrard, 1977; Wilkinson and Halliwell, 1979; Hunt, 1984).

Low proportions of *Cicatricosisporites* spp. were observed in samples 11 to 13 and 16, 8 (Table 2). These forms are characteristic of the Lower Cretaceous, but the genus is not confined to this subsystem. Therefore this is not definite evidence of incorporation of Lower Cretaceous strata. *Cicatricosisporites* spp. appears to co-occur with Jurassic and Palaeogene microplankton (Tables 2, 3). This suggests derivation fro Cardigan Bay.

Sample 12 yielded a single specimen of the typically Upper Cretaceous dinoflagellate cyst genus *Isabelidinium*. Furthermore, a single grain of *Palaeoperidinium* sp. was recorded from sample 14. These occurrences indicate low levels of probable Late Cretaceous input. These forms were most likely to be derived from Northern Ireland (Mitchell, 2004). There are no definite Cretaceous outcrops in Cardigan Bay (Garrard, 1977; Wilkinson and Halliwell, 1979). The ice is thought to have moved across Northern Ireland, the Lleyn Peninsula and Cardigan Bay (Hunt, 1984) and this is consistent with clast analysis (Garrard, 1977).

Samples 11 to 13 and 16 yielded low to moderate proportions of Palaeogene dinoflagellate cysts (Table 3). These comprise *Apectodinium quinquelatum*, chorate cysts – undifferentiated, *Cordosphaeridium gracile*, *Glaphyrocysta ordinata*, *Hystrichokolpoma salacium*, *Hystrichosphaeridium tubiferum*, and *Wetzeliella* spp. This association is indicative of input from the Ypresian (Eocene) (Eaton, 1976; Powell 1992; Stover et al., 1996). *Cordosphaeridium gracile* was present throughout. The Eocene marker *Hystrichokolpoma salacium* was recorded in sample 11. Sample 12 produced the most diverse association including the markers *Apectodinium quinquelatum*, *Glaphyrocysta ordinata*, *Hystrichosphaeridium tubiferum*, and *Wetzeliella* spp. The range tops of *Apectodinium quinquelatum* and *Hystrichosphaeridium tubiferum* are within the Ypresian (Powell, 1992). This means that strata equivalent to the London Clay Formation was incorporated into these samples. The most likely source of the Palaeogene input is the Cardigan Bay area (Garrard, 1977; Wilkinson and Halliwell, 1979; Hunt, 1984).

Quaternary miospores recorded include Alnus, Armeria maritima, Aster, Carya, Caryophyllaceae pollen, Compositae pollen, Corylus, Dryopteris, Erica, Gramineae pollen, Lycopodium, Picea, Pinus, Polypodium vulgare, Scabriosa, Sphagnum, Stereisporites, and Tilia. These floras are similar in content and relative proportions to those in the other samples in this work and include herbs, pteridophytes and trees. Pinus and pteridophyte spores, most prominently Dryopteris and Polypodium vulgare, are the most abundant elements. Pinus is the most common in samples 11 to 14 and 16. Dryopteris and Polypodium vulgare are the most common miospores in samples 15 and 17. These associations indicate pine-dominated woodland and damp, lowland settings respectively. Quaternary dinoflagellate cysts observed include Achomosphaera andalousiensis, Operculodinium centrocarpum, Operculodinium spp. and Spiniferites spp. in samples 11 and 12. The Quaternary palynomorphs were derived from Irish Sea ice that came from the Cardigan Bay area (Garrard, 1977; Wilkinson and Halliwell, 1979; Hunt, 1984).

There are some forms that are long ranging and cannot be included in the age-related groupings including include *Cyathidites* spp., pre-Quaternary bisaccate pollen, and *Micrhystridium* spp. (Table 3).

The reworked palynofloras from samples 11 to 17 indicates input from the Lower Palaeozoic, Carboniferous, Permian-Triassic (largely Rhaetian), Jurassic, Cretaceous, Eocene and Quaternary. The input from the Lower Palaeozoic, Permian-Triassic, Cretaceous and Eocene is relatively rare. No evidence of input from the Devonian or the Neogene was observed. The Lower Palaeozoic acritarchs may have been derived locally. However, the Carboniferous to Quaternary palynomorphs are interpreted as having probably being derived from the bed of the Irish Sea.

# 4 Synthesis/Conclusions

All the samples studied except numbers 4 and 5 produced abundant, diverse and well-preserved palynomorphs, ranging in age from Lower Palaeozoic to Quaternary. Numbers 2 and 6 entirely comprised Quaternary miospores, however the remainder produced a variety of allochthonous material of Lower Palaeozoic, Carboniferous, Permian-Triassic, Jurassic, Cretaceous, Eocene and Quaternary age. Stratigraphically long-ranging forms were observed throughout, except in samples 2 and 6. The proportions of Lower Palaeozoic, Permian-Triassic, Cretaceous, and Eocene material are relatively low. The majority of the material identified is Carboniferous, Jurassic and Quaternary. This is a similar situation to the glacial sediments in Norfolk (Lee et al., 2002; Riding et al., 2003). British Carboniferous and Jurassic strata are typically rich in palynomorphs and some Carboniferous spores are relatively robust and therefore easy to rework (Wilson, 1961).

It is considered that the nature and proportions of the Lower Palaeozoic to Quaternary components reflect the provenance of the ice sheets that deposited these tills. As the glaciers migrated they picked up sediments, which were deposited as tills. The samples were described in section 3 in five subsections based on their content, reflecting differences in the nature of the associations.

In summary, sample 1 proved the most abundant, it is characterised by high levels of Jurassic, Carboniferous and Quaternary content, with low levels of possible Early Cretaceous spores and Eocene dinoflagellate cysts. Samples 2 and 6 are entirely comprised of Quaternary miospores. The samples 3, 4 and 5 are variably productive and contain only Jurassic, Carboniferous and Quaternary miospores. The samples 7 to 10 yielded relatively abundant Carboniferous, Jurassic and Quaternary palynomorphs, together with rarer representatives of Cretaceous and Eocene taxa. Sample 11 to 17 are similar to numbers 7 to 10, however the former samples contain rare representatives from the Lower Palaeozoic and Permian-Triassic.

In terms of the stratigraphical ranges of the material observed, certain key observations were made. Rare Lower Palaeozoic acritarchs were recovered from samples 14 and 16. The taxa recognised are confined to the Ordovician and Silurian, hence the Lower Palaeozoic input appears to have been sourced from at least two intervals. The majority of the Carboniferous input appears to have been derived from the Namurian/Westphalian interval. Some Westphalian markers were recognised, hence significant input from the Coal Measures is envisaged. Samples

11 to 16 produced extremely low numbers of Permian-Triassic miospores; the identifiable forms are indicative of input from the Rhaetian Stage. The Jurassic miospores are relatively long-ranging within the Mid-Late Jurassic. However, Jurassic dinoflagellate cysts indicate the incorporation of material of definite early Toarcian, late Callovian-early Oxfordian and Kimmeridgian age. This is positive evidence of at least three sources of Jurassic material in these samples. Samples 1 and 7 to 16 included extremely low numbers of the spore genus *Cicatricosisporites*. The genus is characteristic of the Early Cretaceous, but the genus is not confined to this interval. Hence there is no unequivocal evidence for the incorporation of Lower Cretaceous strata. *Cicatricosisporites* spp. appears to co-occur with Jurassic and Palaeogene microplankton. Samples 10, 12 and 14 yielded single specimens of Cretaceous dinoflagellate cysts. The samples 1, 7 to 13 and16 produced relatively low numbers of Eocene dinoflagellate cysts. This input appears largely to be of Ypresian age. Rich and diverse Quaternary miospores were recorded throughou and include pollen/spores from herbs, pteridophytes and trees. Pine (*Pinus*) pollen and pteridophyte spores, most prominently *Dryopteris* and *Polypodium vulgare*, are the most abundant elements. The samples are largely rich in either *Pinus* or pteridophyte spores. These associations indicate pine-dominated woodland and damp, lowland settings respectively. Quaternary dinoflagellate cysts were observed rarely in samples 7, 8 and 10-12.

It is considered that the majority of the Carboniferous to Quaternary component of these samples was derived from the Irish Sea Basin and is representative of the sedimentary geology of this region. The Carboniferous component is from North Wales and Anglesey and the unequivocal Cretaceous component is from Northern Ireland. The local solid geology of this part of south-west Wales is Lower Palaeozoic, and the acritarchs in samples 14 and 16 are believed to have been derived locally or from further north in Wales. Sample 1 was described as Irish Sea Till and this produced Carboniferous, Jurassic, ?Lower Cretaceous, Palaeocene and Quaternary reworking. Sample 2, described as Welsh Till, only yielded Quaternary miospores. Sample 6 (?head) produced a similar association and this sample and sample 2 are interpreted as being from the same unit on this basis. However samples 3 and 4 were described as Welsh Till, but they yielded Carboniferous, Jurassic and Quaternary miospores. Samples 7 to 9 were attributed to the Irish Sea Till and produced abundant Carboniferous, Jurassic, ?Lower Cretaceous, Palaeogene and Quaternary palynomorphs. Samples 10 to 17 are also believed to be from the Irish Sea Till because they yielded similar associations.

# 5 Comparison with published work

A brief account of the palynology of the blue-grey Devensian till of Irish Sea origin from the foreshore at Aberaeron (SN 464 634), 1 km northeast of the mouth of the Afon Aeron, was given by Hunt (1984). This is in the vicinity of the localities samples in this study.

Hunt (1984) reported palynomorphs of Ordovician, Silurian, Carboniferous, Permo-Triassic, Jurassic, Cretaceous, Palaeogene/Neogene and Quaternary age. These are clearly similar to those recorded in this study. Hunt (1984) concluded that the Silurian (Llandovery) taxa are likely to have been locally-derived and that the other forms were transported by Irish Sea ice from Cardigan Bay, North Wales and Northern Ireland.

# 6 Summary

The majority of the samples produced abundant palynomorph associations, ranging in age from Lower Palaeozoic to Quaternary. The majority of the material identified is Carboniferous, Jurassic and Quaternary; lower proportions of Lower Palaeozoic, Permian-Triassic, Cretaceous, and Eocene material was observed. Samples 2 and 6 are entirely comprised of Quaternary miospores. The nature and proportions of the Lower Palaeozoic to Quaternary components reflect the provenance of the ice sheets that deposited these tills. The majority of the Carboniferous to Quaternary component was apparently derived from the Irish Sea Basin. The Carboniferous input is from North Wales and Anglesey and the unequivocal Cretaceous elements are interpreted as being from Northern Ireland. The local solid geology of this part of Wales is Lower Palaeozoic, and the acritarchs in samples 14 and 16 are believed to be locally-derived, or from further north in Wales. Sample 1 is Irish Sea Till and this produced Carboniferous, Jurassic, ?Lower Cretaceous, Palaeocene and Quaternary reworking. Sample 2, Welsh Till, yielded only Quaternary miospores. Sample 6 produced a similar association and is therefore interpreted as being from the same unit as sample 2. Samples 3 and 4 are from Welsh Till and yielded Carboniferous, Jurassic and Quaternary miospores. Samples 7 to 9 were attributed to the Irish Sea Till and produced abundant Carboniferous, Jurassic, ?Lower Cretaceous, Palaeogene and Quaternary reworking. Samples 10 to 17 are also believed to be from the Irish Sea Till because they yielded similar associations.

# 7 References

BUCEFALO PALLIANI, R., MATTIOLI, E. and RIDING, J. B. 2002. The response of marine phytoplankton and sedimentary organic matter to the early Toarcian (Lower Jurassic) oceanic anoxic event in northern England. *Marine Micropaleontology*, **46**, 223-245.

CLAYTON, G. and BUTTERWORTH, M. A. 1984. Carboniferous range charts. *In: Pollen and spore biostratigraphy of the Phanerozoic in north-west Europe*. Proceedings volume of a British Micropalaeontological Society Palynology Group meting held at the University of Cambridge, 17th-19th December 1984, pp. 2-10.

COSTA, L. I., and DAVEY, R. J. 1992. Dinoflagellate cysts of the Cretaceous System. *In*: Powell, A. J. (ed.). *A stratigraphic index of dinoflagellate cysts*. Chapman and Hall, London, 99-153.

EATON, G. L. 1976. Dinoflagellate cysts from the Bracklesham Beds (Eocene) of the Isle of Wight, southern England. Bulletin of the British Museum (Natural History), 26(6), 225-332.

GARRARD, R. A. 1977. The sediments of the South Irish Sea and Nymphe Bank area of the Sea. *In* : Kidson, C. and Tooley. M. J. (eds.). *Quaternary history of the Irish Sea*. Wiley and Sons, Chichester, 69-92.

HUNT, C. O. 1984. Erratic palynomorphs from some British tills. *Journal of Micropalaeontology*, **3(1),** 71-74.

LEE, J. R., ROSE, J., RIDING, J. B., MOORLOCK, B. S. P. and HAMBLIN, R. J. O. 2002. Testing the case for a Middle Pleistocene Scandinavian glaciation in Eastern England: evidence for a Scottish ice source for tills within the Corton Formation of East Anglia, UK. *Boreas*, **31**, 345-355.

MITCHELL, W. I. (ed.). 2004. *The Geology of Northern Ireland: Our natural foundation*. Geological Survey of Northern Ireland, Belfast.

MORBEY, S. J. 1978. Late Triassic and Early Jurassic subsurface palynostratigraphy in northwestern Europe. *Palinologia* número extraordinario, **1,** 355-365.

MORBEY, S. J. and DUNAY, R. E. 1978. Early Jurassic to Late Triassic dinoflagellate cysts and miospores. *In:* THUSU B., (ed.). *Distribution of biostratigraphically diagnostic dinoflagellate cysts and miospores from the northwest European continental shelf and adjacent areas.* Continental Shelf Institute Publication, **100,** 47-59.

OWENS, B. 1996. Chapter 18D. Upper Carboniferous spores and pollen. *In:* Jansonius, J. and McGregor, D. C. (eds.). *Palynology: principles and applications.* American Association of Stratigraphic Palynologists Foundation, Dallas, **2,** 597-606.

OWENS, B., LOBOZIAK, S., and TETERIUK, V. K. 1978. Palynological subdivision of the Dinantian to Westphalian deposits of northwest Europe and the Donetz Basin of the U.S.S.R. *Palynology*, **2**, 69-91.

POWELL, A. J. 1992. Dinoflagellate cysts of the Tertiary System. *In*: Powell, A. J. (ed.). *A stratigraphic index of dinoflagellate cysts*. Chapman and Hall, London, 155-251.

RIDING, J. B. 1983. *Gonyaulacysta centriconnata* sp. nov., a dinoflagellate cyst from the late Callovian and early Oxfordian of eastern England. *Palynology*, **7,** 197-204.

RIDING, J. B., FEDOROVA, V. A. and ILYINA, V. I. 1999. Jurassic and lowermost Cretaceous dinoflagellate cyst biostratigraphy of the Russian Platform and northern Siberia, Russia. *American Association of Stratigraphic Palynologists Contributions Series*, No. **36**, 179 p.

RIDING, J. B. and KYFFIN-HUGHES, J. E. 2004. A review of the laboratory preparation of palynomorphs with a description of an effective non-acid technique. *Revista Brasileira de Paleontologia*, No. **7(1)**, 13-44.

RIDING, J. B., ROSE, J. and BOOTH, S. J. 2003. Allochthonous and indigenous palynomorphs from the Devensian of the Warham Borehole, Stiffkey, north Norfolk, England; evidence for sediment provenance. *Proceedings of the Yorkshire Geological Society*, **54**, 223-235.

RIDING, J. B. and THOMAS, J. E. 1988. Dinoflagellate cyst stratigraphy of the Kimmeridge Clay (Upper Jurassic) from the Dorset coast, southern England. *Palynology*, **12,** 65-88.

RIDING, J. B. and THOMAS, J. E. 1992. Dinoflagellate cysts of the Jurassic System. *In:* Powell, A. J. (ed.). *A stratigraphic index of dinoflagellate cysts.* British Micropalaeontological Society Publications Series. Chapman and Hall, London, 7-97.

RIDING, J. B., WALTON, W. and SHAW, D. 1991. Toarcian to Bathonian (Jurassic) palynology of the Inner Hebrides, northwest Scotland. *Palynology*, **15,** 115-179.

STOVER, L. E., BRINKHUIS, H., DAMASSA, S. P., de VERTEUIL, L., HELBY, R. J., MONTEIL, E., PARTRIDGE, A. D., POWELL, A. J., RIDING, J. B., SMELROR, M. and WILLIAMS, G. L. 1996. Chapter 19. Mesozoic-Tertiary dinoflagellates, acritarchs and prasinophytes. *In:* Jansonius, J. and McGregor, D. C. (eds.). *Palynology: principles and applications.* American Association of Stratigraphic Palynologists Foundation, Dallas, **2,** 641-750.

WILKINSON, I. P. and HALLIWELL, G. P. (compilers) 1979. Offshore micropalaeontological biostratigraphy of southern and western Britain. *Institute of Geological Sciences Report*, No. **79/9**, 65 p.

WILSON, L. R. 1961. Palynological fossil response to low-grade metamorphism in the Arkoma basin. *Tulsa Geological Society Digest*, **29**, 131-140.

| Sample no. | Reg. No. (MPA) | Unit | Lithology | Grains/slide |
|---|---|---|---|---|
| 1 | 53018 | Irish Sea Till | brown, clay-rich till, w. clasts | 3049 |
| 2 | 53019 | Welsh Till | grey/green clay-rich till | 1043 |
| 3 | 53020 | Welsh Till | massive grey, clay-rich till | 319 |
| 4 | 53021 | Welsh Till | massive grey, clay-rich till | 59 |
| 5 | 53022 | ?head | mid brown, clast-rich deposit | 42 |
| 6 | 53023 | ?head | mid brown, clay-rich deposit | 1953 |

| | | | | |
|---|---|---|---|---|
| 7 | 53154 | Irish Sea Till | clay matrix, with black shale clasts | 1734 |
| 8 | 53155 | ?Irish Sea Till | brown clay matrix, with ORS clasts | 1236 |
| 9 | 53156 | ?Irish Sea Till | brown clay matrix, with 'Welsh' clasts | 725 |
| 10 | 53300 | ? | dark grey, massive, stone-free clay | 1073 |
| 11 | 53301 | ? | mid-grey diamicton, no erratics | 865 |
| 12 | 53302 | ? | dark brown, clast-rich diamicton | 1324 |
| 13 | 53303 | ? | mid-grey, clast-poor diamicton | 1059 |
| 14 | 53332 | ? | dark grey, clay-rich till, with clasts | 876 |
| 15 | 53333 | ? | grey, clay-rich till, with clasts | 519 |
| 16 | 53334 | ? | grey, clay-rich till, with clasts | 515 |
| 17 | 53335 | ? | grey, clay-rich till, w. small clasts | 487 |

Table 1. Details of sample numbers, lithological units, lithologies and the overall numbers of palynomorphs per microscope slide in the 17 samples in this study.

| Sample no. | L. Pal. acs. | Carb. spores | P/T miospores | Jur. miospores | Jur. microplankton | ?L. Cret. spores |
|---|---|---|---|---|---|---|
| 1 | … | 517 (17.0%) | … | 371 (12.2%) | 20 (0.6%) | 10 (0.3%) |
| 2 | … | … | … | … | … | … |
| 3 | … | 89 (27.9%) | … | 15 (4.7%) | … | … |
| 4 | … | 11 (18.6%) | … | 10 (17.0%) | … | … |
| 5 | … | 3 (7.1%) | … | 1 (2.4%) | … | … |
| 6 | … | … | … | … | … | … |
| 7 | … | 135 (7.8%) | … | 249 (14.3%) | 2 (0.1%) | 17 (1.0%) |
| 8 | … | 189 (15.3%) | … | 138 (11.2%) | 9 (0.7%) | 14 (1.1%) |
| 9 | … | 372 (51.3%) | … | 63 (8.7%) | … | … |
| 10 | … | 113 (10.5%) | … | 92 (8.6%) | 10 (0.9%) | 8 (0.8%) |
| 11 | … | 99 (11.5%) | 1 (0.1%) | 166 (19.2%) | 6 (0.7%) | 11 (1.3%) |
| 12 | … | 84 (6.4%) | 1 (0.1%) | 122 (9.2%) | 19 (1.4%) | 19 (1.4%) |
| 13 | … | 89 (8.4%) | … | 97 (9.2%) | 17 (1.6%) | 16 (1.5%) |
| 14 | 4 (0.5%) | 130 (14.8%) | 2 (0.2%) | 107 (12.2%) | … | … |
| 15 | … | 16 (3.1%) | 1 (0.2%) | 2 (0.4%) | … | … |
| 16 | 1 (0.2%) | 100 (19.4%) | 3 (0.6%) | 138 (26.8%) | … | 2 (0.4%) |
| 17 | … | 19 (3.9%) | … | … | … | … |

Table 2. The numbers and percentages of palynomorphs (in parentheses) respectively of Lower Palaeozoic acritarchs, Carboniferous spores, Permian-Triassic miospores, Jurassic miospores and microplankton and possible Lower Cretaceous spores in the 17 samples in this study. Three dots (...) indicates that the respective palynomorph group is not represented.

| Sample no. | Cret. dino. cysts | P.gene miospores | P.gene dino. cysts | Quat. miospores | Quat. dino. cysts | Non age-diagnostics |
|---|---|---|---|---|---|---|
| 1 | … | … | 10 (0.3%) | 1754 (57.5%) | 69 (2.3%) | 298 (9.8%) |
| 2 | … | … | … | 1043 (100%) | … | … |
| 3 | … | … | … | 180 (56.4%) | … | 35 (11.0) |
| 4 | … | … | … | 36 (61.0%) | … | 2 (3.4%) |
| 5 | … | … | … | 36 (85.7%) | … | 2 (4.8%) |

| | | | | | | |
|---|---|---|---|---|---|---|
| 6 | … | … | … | 1953 (100%) | … | … |
| 7 | … | 1 (0.1%) | 22 (1.3%) | 729 (42.0%) | 42 (2.4%) | 537 (31.0%) |
| 8 | … | … | 9 (0.8%) | 673 (54.5%) | 6 (0.5%) | 198 (16.0%) |
| 9 | … | … | 1 (0.1%) | 240 (33.1%) | … | 49 (6.8%) |
| 10 | 1 (0.1%) | … | 39 (3.6%) | 628 (58.5%) | 6 (0.6%) | 176 (16.4%) |
| 11 | … | … | 44 (5.1%) | 354 (40.9%) | 8 (0.9%) | 176 (20.3%) |
| 12 | 1 (0.1%) | … | 40 (3.0%) | 735 (55.5%) | 22 (1.7%) | 281 (21.2%) |
| 13 | … | … | 25 (2.4%) | 481 (45.4%) | … | 334 (31.5%) |
| 14 | 1 (0.1%) | … | … | 413 (47.2%) | … | 219 (25.0%) |
| 15 | … | … | … | 476 (91.7%) | … | 24 (4.6%) |
| 16 | … | … | 4 (0.8%) | 176 (34.2%) | … | 91 (17.6%) |
| 17 | … | … | … | 467 (95.9%) | … | 1 (0.2%) |

Table 3. The numbers and percentages of palynomorphs (in parentheses) respectively of Cretaceous dinoflagellate cysts, Palaeogene miospores, Palaeogene dinoflagellate cysts, Quaternary miospores, Quaternary dinoflagellate cysts and non age-diagnostic palynomorphs in the 17 samples in this study. Three dots (...) indicates that the respective palynomorph group is not represented.