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A palynological investigation of diamictons from the Britons Lane Borehole, north Norfolk

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A palynological investigation of diamictons from the Britons Lane Borehole, north Norfolk

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Foreword

This report describes the palynology of ten samples of diamictons from the Britons Lane Borehole, north Norfolk between 32.00 m and 2.70 m.

Contents

Summary

The ten samples studied produced extremely abundant palynofloras of high diversity with a wide overall stratigraphical range. Typically the assemblages contain Carboniferous (mainly Westphalian spores), Permo-Triassic, Jurassic (largely miospores), Cretaceous (chiefly Chalk Group dinoflagellate cysts), Palaeogene (Eocene), Quaternary and non-age diagnostic taxa. The most persistent and common forms are Carboniferous, Jurassic and Late Cretaceous. Many grains are not age diagnostic forms. These associations are generally typical of the Tills of North Norfolk and area significant contribution to the database. Certain familiar patterns were

observed, for example while a wide range of Carboniferous ages were observed, spores of Westphalian age tend to dominate. The Carboniferous input is most likely to have been derived from the Northumberland-Durham area of north-east England and/or southern Scotland. Permo-Triassic input was extremely rare and probably reflects the organic-lean nature of much of this succession in the UK. The provenance of this is likely to be the Yorkshire Basin or the East Midlands Shelf. The consistently abundant associations of Jurassic miospores indicate significant input of Early and Mid-Late Jurassic strata; the Yorkshire Basin and/or the East Midlands Shelf are the most likely sources of these forms. When Jurassic marine microplankton are present, early Toarcian and Kimmeridgian dinoflagellate cysts tend to dominate. This is probably related to the mechanically tenacious and organic-rich, nature of lithological units of these ages. These units are relatively resistant to weathering as compared to other, softer units. This means that the eroded fragments of early Toarcian mudstones have the propensity to travel long distances while retaining their organic contents. Additionally, the Kimmeridge Clay Formation outcrops extensively in and around the Wash area (Cox and Gallois, 1981). Characteristically Early Cretaceous marker are either entirely absent or are present in low proportions. This is somewhat surprising as the Early Cretaceous succession of eastern England is known to be highly palyniferous. Late Cretaceous dinoflagellate cysts derived from the Chalk Group are present throughout in varying proportions. They occur in the normal grey/brown diamictons in relatively low numbers, however in the highly chalky diamictons they are unsurprisingly dominant. The Chalk Group dinoflagellate cyst floras are deemed to be of Campanian-Maastrichtian age based on the occurrences of key dinoflagellate cyst taxa. There appears to have been virtually no mixing of the Chalk Group input and indicates that the derivation is entirely from local sources of Upper Chalk. Other chalky diamictons from north Norfolk have yielded similar Campanian and Maastrichtian markers. Most of the Palaeogene dinoflagellate cysts tend to be of Eocene age, which is consistent with previous studies. The majority of the relatively sparse Quaternary spores, pollen and dinoflagellate cysts are not environmentally or biostratigraphically significant.

It is possible to subdivide this succession based on the palynofloras. The grey diamicton between 32.00 and 23.00 yields small proportions of Carboniferous spores and Chalk Group dinoflagellate cysts, moderate levels of Jurassic palynomorphs and consistently relatively high numbers of Quaternary spores/pollen. The light grey diamicton at 18.00 m is dominated by Quaternary spores and pollen; Carboniferous, Jurassic and Late Cretaceous species are rare. The highly chalky diamicton between 17.00-19.90 m and 22.95 and 21.50 m is overwhelmingly dominated by abundant, diverse and well preserved dinoflagellate cysts characteristic of the local Upper Chalk. Other elements are relatively sparse due to the diluting effect of the Chalk Group input. The grey/brown diamicton between 6.50 and 2.70 m is characterised by the highest proportions of Carboniferous spores and Jurassic palynomorphs in this succession. Late Cretaceous and Eocene dinoflagellate cysts and Quaternary palynomorphs are consistently relatively sparse.

1 Introduction

Ten samples of diamictons from the Britons Lane Borehole, Beeston Regis, near Sheringham, north Norfolk were studied for their palynomorph content. The Britons Lane Borehole was drilled at Britons Lane Quarry and cored grey, brown and highly chalky diamictons to 32.00 m. Analyses of these palynofloras helps determine the provenance of glaciogenic sediments and may help in the characterisation of specific units (e.g. Riding, 2001a,b,c,d; Lee *et al.*, 2002). Tables 1 and 2 give both numbers and percentages of specimens per microscope slide in age-related groupings.

2 Sample Details

The location of the Britons Lane Borehole is TG 168 415. The borehole was sited in a quarry near Beeston Regis, west of Sheringham, north Norfolk. The following table lists the (informal) sample number, the BGS registration number (prefixed MPA), the sample type, the depth in metres and the lithology respectively. All samples were prepared using sodium hexametaphosphate as a dissagregant; this is an alternative to the traditional mineral acid preparation technique.

Number	BGS Reg. No.	Sample Type	Depth (m)	Lithology
1	MPA 50991	Tube U1	2.70-3.15	light grey diamicton
2	MPA 50992	Tube U2	3.50-3.95	light brown diamicton
3	MPA 50993	SA2	6.50	light grey diamicton
4	MPA 50994	SA9/10	16.90-17.00	highly chalky diamicton
5	MPA 50995	SA11	18.00	light grey diamicton
6	MPA 50996	SA15	21.50	highly chalky diamicton
7	MPA 50997	Tube U7	22.50-22.95	highly chalky diamicton
8	MPA 50998	SA17	23.00	mid grey diamicton
9	MPA 50999	SA25	31.00	dark grey diamicton
10	MPA 51000	SA26	32.00	dark grey diamicton

3 Palynology

In this section, the palynofloras are described in four sections, based on lithological/depth divisions and the palynological content. Full listings of palynomorphs, including quantitative data, are held on the respective BGS micropalaeontology/palynology data sheets, which have been archived. The numbers and percentages of palynomorphs per microscope slide in age-related groupings are given in Tables 1 and 2.

3.1 SAMPLES 1-3 (GREY/BROWN DIAMICTON BETWEEN 6.50 AND 2.70 METRES)

Samples 1 to 3 are from a grey/brown diamicton and produced similar residues and palynofloras. They produced well preserved, abundant and diverse palynomorphs and other phytoclasts. Wood, other plant tissues and amorphous organic material proved common/abundant throughout. Amorphous organic material was especially abundant in sample 2. The samples produced between 1563 and 2014 specimens per microscope slide and the age diagnostic fraction comprises comprises derived Carboniferous, Permo-Triassic, Jurassic, Upper Cretaceous, Palaeogene and Quaternary elements (Tables 1 and 2).

Carboniferous spores are consistently present in significant proportions (11.9% to 20.1% of the palynoflora) (Table 1). They are dominated by *Densosporites* spp. Other forms recorded were *Cingulizonates* spp., *Lycospora pusilla, Punctatisporites sinuatus*, *Radiizonates* spp., *Reticulatisporites reticulatus*. *Simozonotriletes* sp. and *Tripartites trilinguis*. *Tripartites trilinguis* is characteristic of the Viséan-Namurian transition (Owens *et al*., 1977), hence strata of this age were incorporated to Sample 1. *Punctatisporites sinuatus* and *Radiizonates* spp. range throughout the Namurian and Westphalian (Clayton *et al*., 1977; Clayton and Butterworth, 1984). *Reticulatisporites reticulatus,* however, is typical of the Westphalian (Clayton and Butterworth, 1984). These spores indicate that a range of ages within the Carboniferous, signifying that several lithological units within this System were incorporated into this diamicton. This input probably was most likely to have been derived from the Northumberland-Durham area, north-east England and/or southern Scotland.

A single specimen of taeniate pollen was recorded from sample 1 (Table 1); this is indicative of minor input of Permo-Triassic strata to this unit. The provenance of this pollen grain is likely to be the Yorkshire Basin or the East Midlands Shelf.

The Jurassic palynomorph content of this diamicton is considerable and is dominated by miospores. These terrestrially-derived forms represent between 20.2% and 26.8% of the whole palynoflora (Table 1). The taxa include *Callialasporites dampieri, Callialasporites microvelatus, Callialasporites trilobatus, Cerebropollenites macroverrucosus, Chasmatosporites* spp*., Classopollis classoides, Classopollis meyeriana, Contignisporites* spp*., Coronatispora valdensis, Cyathidites* spp*., Ischyosporites variegatus, Leptolepidites* sp., *Perinopollenites elatoides, Retitriletes austroclavatidites, Todisporites major* and *Todisporites minor*. Of these forms, *Cerebropollenites macroverrucosus, Chasmatosporites* spp*., Classopollis classoides* and *Perinopollenites elatoides* are especially common. This association indicates significant input of Mid-Late Jurassic strata (Riding *et al*., 1991). The Yorkshire Basin is probably the major source of these Jurassic miospores, which are most likely to be from one or more of the non-marine formations within the Aalenian–Bathonian Ravenscar Group (Riding and Wright, 1989). However, it is also possible that they may have been derived from the Middle Jurassic succession of the East Midlands Shelf.

Jurassic marine microplankton were recorded from all three samples in varying proportions. Samples 1 and 3 yielded 4.4% and 2.0% respectively, however sample 2 produced 10.4% (Table 1). The Jurassic dinoflagellate cysts are indicative of the input from at least four separate intervals within this System. The overwhelming majority are characteristic of the Toarcian and the Kimmeridgian stages, however some Middle Jurassic markers have also being found.

Significant levels of Lower Jurassic marine microplankton were found throughout. Samples 1 and 2 produced small numbers of *Liasidium variabile*. The occurrences of this distinctive species are indicative of the incorporation of Upper Sinemurian sediments. These are either the Siliceous Shales (Redcar Mudstone Formation) of north-east England (Bucefalo Palliani and Riding, 2000) or the Brant Mudstone Formation of the East Midlands Shelf. This species is a reliable marker for the late Sinemurian interval of Europe, being by far the most common in the *Oxynoticeras oxynotum* standard (ammonite) Zone (Drugg, 1978; Wiess, 1986; Riding & Thomas 1992). This species was found in Late Devensian glaciolacustrine sediments from the Warham Borehole, Stiffkey (Riding *et al*., in press). All three samples contained evidence of some derivation from the Toarcian. Key species include *Halosphaeropsis liassica, Mancodinium semitabulatum, Nannoceratopsis deflandrei* subsp. *deflandrei* and *Nannoceratopsis deflandrei* subsp. *senex*. This association is indicative of the early Toarcian (Bucefalo Palliani and Riding, 2000; Riding *et al*., 1999) and the source of this material is likely to be the Lower Toarcian strata of the Yorkshire Basin or the East Midlands Shelf.

Sample 1 has yielded sparse dinoflagellate cysts of possible Mid Jurassic age. These are *Chytroeisphaeridia chytroeides* and *Gonyaulacysta jurassica* subsp. *adecta*. The former is relatively long ranging, but *Gonyaulacysta jurassica* subsp. *adecta* is prominent in the Callovian, having a total range of Callovian to mid Oxfordian (Riding and Thomas, 1992). Again, these are interpreted to have been derived from eastern England.

All three samples produced significant levels of characteristically Kimmeridgian dinoflagellate cysts. These comprise *Cribroperidinium globatum, Cribroperidinium longicorne, Cribroperidinium* spp., *Hystrichosphaerina orbifera, Perisseiasphaeridium pannosum, Scriniodinium inritibile, Systematophora penicillata* and *Systematophora* spp. This association is typical of the Kimmeridge Clay Formation. It is not possible to distinguish the Lower or

Upper Kimmeridgian based on this association. However the absence of typically early Kimmeridgian markers such as *Endoscrinium luridum*, *Gonyaulacysta jurassica* subsp. *jurassica* and *Scriniodinium crystallinum* mitigates against derivation from the Lower Kimmeridgian (Riding and Thomas, 1988). The occurrences of *Cribroperidinium longicorne* and *Perisseiasphaeridium pannosum,* by contrast, are characteristic of the lowermost Upper Kimmeridgian succession (*Pectinatites elegans* to *Pavlovia pallasioides* standard (ammonite) zones) (Riding and Thomas, 1988). The most likely provenance of the Kimmeridge Clay Formation is from eastern England. Possible regions would be the Yorkshire Basin, the northern part of the East Midlands Shelf or the Wash area. This unit outcrops extensively in and around the Wash (Cox and Gallois, 1981, fig. 11) and this is the most likely source region.

There is also evidence of minor reworking of the uppermost Jurassic. Small numbers of forms of *Cribroperidinium* which are typical of the Portlandian were recognised in samples 1 and 2. These include *Cribroperidinium gigas* and are interpreted as having being derived from Lincolnshire, to the north.

The occurrence of early Toarcian and Kimmeridgian palynomorphs is a recurring one in the Tills of north Norfolk and may be related to the relative resistance to weathering of lithologies of this age. Both the early Toarcian mudstones deposited during the widespread oceanic anoxic event and the Kimmeridge Clay Formation are rich in amorphous organic material and, as a consequence, are relatively resistant lithologies, being especially resistant to oxidation during weathering.

Input of material from the Late Cretaceous is evidenced by small proportions of dinoflagellate cysts of this age. The percentages of these varies from 1.2% to 4.4% (Table 2). The numbers are highest in sample 3, which has 83 specimens per microscope slide. The species present include *Areoligera senonensis, Hystrichokolpoma* sp., *Hystrichosphaeropsis quasicribrata*, small *Microdinium* spp. (and related partiform genera), *Odontochitina operculata, Oligosphaeridium complex*, *Spiniferites scabrosus*, *Spongodinium delitiense, Trithyrodinium* spp. and *Xenascus ceratioides*. Several of these forms have relatively long stratigraphical ranges. However, certain taxa are indicative of the Campanian-Maastrichtian interval. *Spongodinium delitiense* ranges through the Campanian and Maastrichtian into the early Danian and is most characteristic of the Campanian-Maastrichtian stage transition (Wilson, 1974; Foucher in Robaszynski, 1985; Powell, 1992; Slimani, 1994; Stover *et al*., 1996). *Hystrichosphaeropsis quasicribrata* is also characteristic of the Campanian and Maastrichtian (Wilson, 1974; Foucher, 1979; Herngreen *et al*., 1996; Schiøler *et al*., 1997). In Italy, this taxon is restricted to the mid-late Maastrichtian (Roncaglia and Corradini, 1997). Furthermore, the presence of small *Microdinium* spp. and related partiform genera is also characteristic of the Campanian-Maastrichtian (Slimani, 1994). In summary, this association is deemed to be of late Campanian to Maastrichtian age based on the occurrences of *Hystrichosphaeropsis quasicribrata,* small *Microdinium* spp and *Spongodinium delitiense*. This age assessment proves that the Chalk Group input to this interval is from the Upper Chalk and is locally derived, assuming that there was no mixing of the Chalk Group fraction.

Relatively small proportions of Palaeogene dinoflagellate cysts were recorded from all samples. The percentages of these varies from 0.5% to 1.4% (Table 2). The numbers are highest in sample 3, which has 27 specimens per microscope slide. Taxa recognised include *Areoligera* spp., *Cordosphaeridium gracile*, *Dracodinium varielongitudum*, *Glaphyrocysta ordinata*, *Glaphyrocysta* spp., *Heteraulacacysta*? *leptalea, Homotryblium* spp. and *Wetzeliella* spp. This association is indicative of an Early-Mid Eocene (Ypresian to Luteian) age due to the occurrence of *Dracodinium varielongitudum* (Powell, 1992). The other taxa are consistent with this age assessment. For example, the range base of *Heteraulacacysta*? *leptalea* is also in the Ypresian. These Palaeogene dinoflagellate cysts were probably derived from the North Sea.

All three samples were found to yield relatively small proportions of both terrestrially-derived and marine Quaternary palynomorphs (Table 2). These were derived from Quaternary strata to the north; the presence of dinoflagellate cysts suggests that the source area was the North Sea. Species diversity is low; the pollen and spores include *Alnus* and *Stereisporites*. The dinoflagellate cyst floras include *Habibacysta tectata, Operculodinium centrocarpum, Operculodinium* spp. and *Spiniferites* spp. These forms do not allow a definitive stratigraphical or palaeoclimatological breakdown to be made. However, *Habibacysta tectata* (sample 3) is confined to the Early Pleistocene according to Harland (1992).

3.2 SAMPLES 4, 6 AND 7 (HIGHLY CHALKY DIAMICTON AT 17.00-19.90 METRES AND BETWEEN 22.95 AND 21.50 METRES)

Samples 4, 6 and 7 are all from highly chalky diamictons. They produced extremely rich palynofloras which, unsurprisingly, are dominated by Late Cretaceous dinoflagellate cysts (Table 2). This clearly is a reflection of the obvious chalk-rich nature of this unit. Samples 4 and 7 were found to have 18813 and 21879 palynomorphs per microscope slide respectively. Sample 6 proved less productive with 3871 specimens per slide (Table 2). Relatively small proportions of dark woody fragments are also present and sample 6 yielded abundant plant tissues. Amorphous organic material is rare to absent. In addition to Chalk Group dinoflagellate cysts, Carboniferous, Jurassic, Lower Cretaceous, Palaeogene and Quaternary palynomorphs were recorded.

Relatively low proportions of Carboniferous spores are present in samples 6 and 7 only and represent 1.5% and 0.07% of the palynoflora respectively. *Densosporites* spp. and *Lycospora pusilla* are the only forms recorded (Table 1). Both are long ranging and thus the age of the Carboniferous input to this till is not resolvable to either series or stage level. These Carboniferous elements were derived from a northerly direction, most probably the Northumberland-Durham region and/or southern Scotland.

Jurassic palynomorphs in this highly chalky diamicton are relatively rare. Samples 4 and 7 produced only 0.1% and 0.06% respectively, however, sample 6 yielded a significantly larger proportion (4.8%) (Table 1). The most prevalent Jurassic components are miospores and include *Callialasporites dampieri, Callialasporites microvelatus, Callialasporites trilobatus, Callialasporites turbatus, Chasmatosporites* spp.*, Classopollis classoides, Cyathidites* spp.*, Ischyosporites variegates* and *Retitriletes austroclavatidites*. Of these forms, *Callialasporites* spp., *Chasmatosporites* spp.*, Classopollis classoides* and *Perinopollenites elatoides* are particularly prominent. This association indicates significant input of Early and Mid-Late Jurassic strata (Srivastava, 1987; Riding *et al*., 1991). The Yorkshire Basin and/or the East Midlands Shelf are the most likely sources of these Jurassic miospores (see section 3.1).

Jurassic dinoflagellate cysts are present in samples 4 and 6 only (Table 1). Small numbers of *Nannoceratopsis deflandrei* subsp. *senex* were recognised in sample 6. These are most likely to have been sourced from the Lower Toarcian strata of the Yorkshire Basin or the East Midlands Shelf (see section 3.1). Samples 4 and 6 also yielded significant proportions of Kimmeridgian dinoflagellate cysts. These comprise *Cribroperidinium globatum, Cribroperidinium longicorne,* ?*Glossodinium dimorphum, Gonyaulacysta jurassica* subsp. *jurassica*, *Leptodinium sp., Perisseiasphaeridium pannosum, Rhynchodiniopsis cladophora, Systematophora penicillata* and *Tubotuberella dangeardii.* Some of these, e.g. *Gonyaulacysta jurassica* subsp. *jurassica*, *Rhynchodiniopsis cladophora* and *Tubotuberella dangeardii* have pre-Kimmeridgian range bases. These species have range tops within the early Kimmeridgian, thus this association is interpreted to be characteristic of this interval (Riding and Thomas, 1988, figs 4, 6). This indicates that the source is mainly the Lower Kimmeridge Clay Formation. The provenance of this unit is from eastern England, probably the Wash area (section 3.1). This Jurassic marine input being mainly of Toarcian and Kimmeridgian age is typical of the Tills of north Norfolk (section 3.1).

Sample 6 yielded 3 specimens of the latest Jurassic-Early Cretaceous dinoflagellate *Gochteodinia villosa* (Table 2). This distinctive taxon ranges from the late Portlandian to the earliest Valanginian (Riding and Thomas, 1992; Costa and Davey, 1992). The presence of this species in isolation is enigmatic because Lower Cretaceous dinoflagellate cyst associations are typically extremely diverse. These forms are probably derived from the East Midlands Shelf area. They may be sourced from the Portlandian of Lincolnshire/Fenland or from the Speeton Clay Formation. The lack of other species suggests that the Portlandian (Sandringham Sands and equivalents) is a more likely source than the Speeton Clay Formation.

The three samples produced extremely abundant levels of Late Cretaceous dinoflagellate cysts. All the samples are dominated by these forms and this reflects the lithological nature of this unit. Counts of 18571, 1617, and 21741 were counted from samples 4, 6 and 7 respectively. These account for 98.7%, 44.1% and 99.30% of the palynofloras respectively (Table 2). It is not clear why sample 6 is relatively less productive. The species present include *Alisocysta circumtabulata, Alisocysta sp., Apteodinium deflandrei* (previously *Aldorfia deflandrei), Cannosphaeropsis utinensis, Chatangiella granulifera, Chatangiella victoriensis*, *Chatangiella* spp.*, Cladopyxidium paucireticulatum, Cometodinium* sp.*, Cribroperidinium "reticulatum"* of Wilson (1974), ?*Cribroperidinium wetzelii*, *Dinogymnium* sp., *Exochosphaeridium phragmites*, *Exochosphaeridium* spp., *Gillinia hymenophora, Hystrichosphaeridium salpingophorum, Hystrichosphaeridium tubiferum, Hystrichosphaeridium* spp., *Hystrichosphaeropsis quasicribrata* (= *Triblastula nuda*), *Isabelidinium belfastense, Isabelidinium cooksoniae,* small *Microdinium* spp. (and related partiform genera), *Neoeurysphaeridium glabrum, Neonorthidium perforatum (= Northidinium perforatum* of Wilson 1974), *Odontochitina operculata, Palaeoperidinium pyrophorum, Palaeotetradinium maastrichtiense, Pterodinium cingulatum,* the *Spiniferites scabrosus* group, *Spiniferites ramosus*, *Spiniferites* spp.*, Spongodinium delitiense*, *Wilsonisphaera petila* (= *Glaphyrosphaera glabra* of Wilson, 1974 and Schiøler and Wilson, 1993), *Xenascus ceratioides* and *Xenascus "wetzelii"* of Slimani (1996).

Many of these forms have restricted stratigraphical ranges and are indicative of derivation largely from late Campanian and Maastrichtian strata. *Xenascus "wetzelii"* of Slimani (1996) is a marker for the Campanian Stage (Slimani, 1996). *Wilsonisphaera petila* spans the Campanian and Maastrichtian stages according to Slimani (1994). However Wilson (1971; 1974) and Schiøler and Wilson (1993; 1994) reported that this species, as *Glaphyrosphaera glabra,* is restricted to the Maastrichtian. *Hystrichosphaeropsis quasicribrata* is also characteristic of the Campanian and Maastrichtian stages (Wilson, 1974; Foucher, 1979; Herngreen *et al*., 1996; Schiøler *et al*., 1997) and in Italy is confined to the mid-late Maastrichtian (Roncaglia and Corradini, 1997). The occurrence of *Cannosphaeropsis utinensis* and small *Microdinium* spp. is also indicative of the Campanian-Maastrichtian (Slimani, 1994; Stover *et al*., 1996). Several taxa are indicative of the Campanian-Maastrichtian stage transition, including *Cribroperidinium "reticulatum"* of Wilson (1974), *Gillinia hymenophora, Neoeurysphaeridium glabrum, Neonorthidium perforatum* and *Spongodinium delitiense* (Wilson, 1974; Foucher in Robaszynski, 1985; Herngreen *et al*., 1986; Slimani, 1994; Stover *et al*., 1996). The most stratigraphically restricted of these is *Neoeurysphaeridium glabrum,* which is confined to the *Belemnitella mucronata* and *Belemnella lanceolata* standard (belemnite) zones (Slimani, 1994). Certain forms which have range bases in the Maastrichtian stage are also present. These include *Alisocysta circumtabulata* (Wilson, 1974; Marheinecke, 1992). This species ranges into the Palaeocene (Powell, 1992; Stover *et al*., 1996). *Cladopyxidium paucireticulatum and Palaeotetradinium maastrichtiense* are confined to the Maastrichtian (Herngreen *et al*., 1986; Slimani, 1994). The range top of *Isabelidinium cooksoniae* lies in the late Maastrichtian according to Schiøler and Wilson (1993, fig. 2).

The Chalk Group dinoflagellate cyst flora is deemed to be of latest Campanian to early Maastrichtian age based on the occurrences of key taxa such as *Alisocysta circumtabulata, Cladopyxidium paucireticulatum, Isabelidinium cooksoniae, Neoeurysphaeridium glabrum, Palaeotetradinium maastrichtiense* and *Xenascus "wetzelii"* of Slimani (1996). This conclusion assumes that there was no mixing of the Chalk Group input into this interval and proves that the Chalk Group input to this sample is entirely from the Upper Chalk and is therefore locally derived. Other chalky diamictons from north Norfolk have yielded similar Campanian and Maastrichtian markers (Riding, 2002).

Extremely low numbers of Palaeogene dinoflagellate cysts were recovered from sample 6 (Table 2). These comprise two specimens of *Cordosphaeridium gracile* and a single specimen of *Dracodinium simile*. The range of *Dracodinium simile* is mid-late Ypresian (Early Eocene) (Powell, 1992). These minor levels of Early Eocene input are thought to be derived from the North Sea.

The samples produced small numbers of Quaternary palynomorphs; sample 4 did not yield any recognisable Quaternary species (Table 2). This is partly due to the overwhelming dominance of Late Cretaceous dinoflagellate cysts. Sample 6, however, produced 9.9% of Quaternary forms. The provenance of these is probably the North Sea area. Species diversity is fairly low. The pollen and spores include *Chenopodium*, Compositae, *Erica*, *Stereisporites* and *Tilia* and the dinoflagellate cysts comprise *Achomosphaera andalousiensis,* *Brigantedinium* spp., *Operculodinium* spp., *Selenopemphix quanta* and *Spiniferites* spp. These forms do not allow an unequivocal stratigraphical, palaeoecological or palaeoclimatological breakdown to be made. However *Selenopemphix quanta* (sample 6) is confined to the Mid Pleistocene to Holocene according to De Vernal *et al*. (1992).

3.3 SAMPLE 5 (LIGHT GREY DIAMICTON AT 18.00 METRES)

Sample 5 is from a light grey diamicton unit at 18.00 m. The sample produced an extremely abundant palynoflora and organic residue. Various plant tissues, wood fragments and palynomorphs are all abundant. This sample yielded between 3871 specimens per microscope slide (Table 1). Carboniferous, Jurassic, Upper Cretaceous and Quaternary palynomorphs were recognised.

Carboniferous spores represent 0.7% of the palynoflora. They are not diverse; the only forms present are the long ranging *Densosporites* spp. and *Lycospora pusilla* (Table 1). Therefore the precise age of the Carboniferous input at this horizon is not resolvable. The Carboniferous spores were derived from the north, probably the Northumberland-Durham area, north-east England and/or southern Scotland.

Jurassic palynomorphs are rare (1.0%) and entirely comprise a low diversity miospore flora (Table 1). *Classopollis classoides,* *Classopollis meyeriana,* *Cyathidites* spp*.,* and *Perinopollenites elatoides* were identified. This association indicates the probable minor input of Jurassic strata. These forms are common in the Jurassic, but are not confined to the System. The Yorkshire Basin and/or the East Midlands Shelf are the most likely sources of these miospores (see section 3.1).

Input from the Cretaceous comprises extremely small numbers of dinoflagellate cysts. The percentage of these is 0.5%, which equals 5 grains per microscope slide (Table 2). The taxa present are *Circulodinium distinctum*, an indeterminate peridiniacean form and *Hystrichosphaeridium* sp. These forms do not permit a detailed age determination to be made. However, their preservation and thermal maturity levels are similar to unequivocal Late Cretaceous dinoflagellate cysts from other units in this borehole. They are therefore interpreted as having being derived from the Chalk Group, probably locally.

No characteristically Palaeogene palynomorphs were observed in this sample.

This sample yielded relatively abundant Quaternary spores and pollen (27.9%). However, small proportions of dinoflagellate cysts of this age (1.4%) (Table 2). These are most likely to have been derived from the North Sea. The pollen and spores include *Alnus*, *Chenopodium*, Gramineae, *Stereisporites* and *Tilia* and the dinoflagellate cysts comprise *Achomosphaera* *andalousiensis, Habibacysta tectata, Spiniferites membranaceus* and *Spiniferites* spp. This low diversity flora does not allow a detailed stratigraphical/palaeoecological interpretation to be made. However, *Habibacysta tectata* is confined to the Early Pleistocene (Harland, 1992).

3.4 SAMPLES 8-10 (GREY DIAMICTON BETWEEN 32.00 AND 23.00 METRES)

Samples 8, 9 and 10 (32.00-23.00 m) are from a grey diamicton unit. They produced similar organic residues and palynological associations therefore are described together in a single subsection. All three yielded relatively abundant palynofloras and kerogen assemblages. Wood and other plant tissues proved abundant; amorphous organic material was rare to absent. Palynomorphs are extremely abundant and diverse, the samples produced between 2906 and 4686 specimens per microscope slide (Table 1). The age diagnostic fraction is dominated by derived forms of Carboniferous, Jurassic, Cretaceous, Palaeogene and Quaternary age (Tables 1 and 2).

Carboniferous spores are persistent, being present in relatively small proportions (2.0%-5.1% of the palynoflora). They are dominated by *Densosporites* spp. and *Lycospora pusilla* (Table 1). Other forms recorded were *Auroraspora* cf. *macra* (Sample 10), *Endosporites globiformis* (Sample 9), *Punctatisporites sinuatus*, (Sample 8), *Reticulatisporites* sp. (Sample 8) and *Tripartites trilinguis* (Sample 8). The single specimen of *Auroraspora* cf. *macra* in Sample 10 indicates probable input from the Late Devonian (Famennian) to Early Carboniferous (Tournasian-early Viséan) (Clayton *et al*., 1977; Clayton and Butterworth, 1984). *Endosporites globiformis* is indicative of the Westphalian (Clayton and Butterworth, 1984), thus strata of this age were incorporated into Sample 9. *Tripartites trilinguis* is characteristic of the Viséan-Namurian transition (Owens *et al*., 1977), hence rocks of this age inputted to Sample 8. *Punctatisporites sinuatus* ranges throughout the Namurian and early Westphalian (Clayton *et al*., 1977). These Carboniferous spores indicate a wide range of ages throughout the Carboniferous, indicating that several lithological units within this System were incorporated into this diamicton. This Carboniferous input probably was largely derived from the Northumberland-Durham area, north-east England and/or southern Scotland.

The Jurassic palynomorphs in this diamicton are dominated by spores and pollen. These represent between 3.4% and 13.6% of the entire flora (Table 1). Taxa represented include *Callialasporites dampieri, Callialasporites microvelatus, Callialasporites trilobatus, Callialasporites turbatus, Cerebropollenites macroverrucosus, Chasmatosporites* spp*., Cibotiumspora juriensis, Classopollis classoides, Coronatispora valdensis, Cyathidites* spp*., Ischyosporites variegatus, Perinopollenites elatoides* and *Retitriletes austroclavatidites*. Of these forms, *Classopollis classoides* and *Perinopollenites elatoides* are especially common. This miospore association indicates that the reworking is mostly no older than Mid Jurassic, largely due to the abundance and diversity of *Callialasporites* (Riding *et al*., 1991; Seidenkrantz *et al*., 1993, fig. 3). The Yorkshire Basin may be the source of these Jurassic miospores, which are most likely to be from one or more of the non-marine formations within the Aalenian–Bathonian Ravenscar Group in this depocentre (Riding and Wright, 1989). They may also be derived from the paralic units within the Aalenian to Bathonian succession of the East Midlands Shelf (Riding, 1987). Jurassic microplankton, by contrast, are relatively sparse, comprising between 0.1% and 1.7% of the assemblages (Table 1). Samples 10 and 9 yielded few of these forms. Single samples of *Cribroperidinium globatum* and *Gonyaulacysta jurassica* subsp. *adecta* were recognised in samples 9 and 10 respectively. These taxa indicate minor levels of input from, respectively, the Kimmeridgian and the Callovian-mid Oxfordian (Riding and Thomas, 1997). Sample 8 produced the most abundant and diverse association of Jurassic dinoflagellate cysts. Species recognised include *Cribroperidinium globatum*, ?*Endoscrinium galeritum, Glossodinium dimorphum, Pareodinia ceratophora, Pareodinia prolongata, Perisseiasphaeridium pannosum,* ?*Rhynchodiniopsis cladophora, Systematophora penicillata* and ?*Wanaea acollaris. Cribroperidinium globatum* is the most abundant form. This is a mixed flora; the association of

Cribroperidinium globatum, *Glossodinium dimorphum, Perisseiasphaeridium pannosum* and *Systematophora penicillata* is indicative of the Kimmeridgian (Riding and Thomas, 1988) and therefore indicates input from the Kimmeridge Clay Formation. This is probably from the East Midlands Shelf and/or the Wash area (Cox and Gallois, 1981, fig. 11). By contrast, *Pareodinia prolongata* and ?*Wanaea acollaris* are characteristic of the Mid Jurassic, especially the Callovian Stage (Riding and Thomas, 1992). These forms are, however, relatively rare, so the input of Callovian strata, probably from the East Midlands Shelf, was relatively low.

The only indication of derived material from the Lower Cretaceous is in sample 10 (Table 2). This sample yielded ten specimens of typically Early Cretaceous palynomorphs, making up 0.3% of the association. These comprise the characteristically Early Cretaceous spore *Cicatricosisporites* and the dinoflagellate cyst *Cribroperidinium*, including *Cribroperidinium edwardsii*. These taxa cannot precisely identify the age of this Lower Cretaceous input. All three samples, however, produced marine microplankton indicative of the Chalk Group. The levels of Late Cretaceous dinoflagellate cysts vary from 0.6% to 1.2% (Table 2). Taxa identified include *Callaiosphaeridium asymmetricum, Chatangiella* spp., *Cribroperidinium "reticulatum"* of Wilson (1974), *Cribroperidinium wetzelii, Exochosphaeridium phragmites, Hystrichosphaeridium salpingophorum, Hystrichosphaeropsis quasicribrata, Isabelidinium* spp*., Odontochitina operculata, Oligosphaeridium* spp*., Spiniferites scabrosus* and *Spongodinium delitiense*. Several of these forms are relatively long-ranging. The range top of *Callaiosphaeridium asymmetricum* is within the early Campanian (Haq *et al*., 1987; Costa and Davey, 1992). *Spongodinium delitiense* ranges from the Campanian to early Danian and is most characteristic of the Campanian-Maastrichtian stage transition (Wilson, 1974; Foucher in Robaszynski, 1985; Powell, 1992; Slimani, 1994; Stover *et al*., 1996). *Cribroperidinium "reticulatum"* of Wilson (1974) is also typical of Campanian-Maastrichtian boundary strata (Wilson, 1974). Similarly, *Cribroperidinium wetzelii* and *Hystrichosphaeropsis quasicribrata* are indicative of the Campanian and Maastrichtian (Wilson, 1974; Foucher, 1979; Herngreen *et al*., 1996; Roncaglia and Corradini, 1997; Schiøler *et al*., 1997). This Chalk Group dinoflagellate cyst association is interpreted as being of Campanian age based on the overlapping ranges of *Callaiosphaeridium asymmetricum, Cribroperidinium "reticulatum"* of Wilson (1974), *Cribroperidinium wetzelii, Hystrichosphaeropsis quasicribrata* and *Spongodinium delitiense.* This is assuming that there was no mixing of the Chalk Group input into his interval. It proves that the Chalk Group input to this unit is entirely from the Upper Chalk and was thus derived locally.

Palaeogene dinoflagellate cysts were recorded throughout in relatively small proportions. The percentages of these forms varies from 0.4% to 3.6% (Table 2). Numbers are highest in sample 9 (169 specimens per microscope slide). Taxa recognised include *Apectodinium augustum*, *Apectodinium* spp., *Areoligera* spp., *Charlesdowniea clathrata*, ?*Charlesdowniea reticulata*, *Cordosphaeridium gracile*, *Deflandrea* spp., *Dracodinium* sp., *Glaphyrocysta divaricata*, *Glaphyrocysta*? *vicina*, *Glaphyrocysta* spp., *Homotryblium abbreviatum*, *Homotryblium* spp., *Hystrichokolpoma torquatum*, *Muratodinium fimbriatum*, *Pentadinium laticinctum*, *Rhombodinium*? *glabrum*, *Spiniferella cornuta*, *Thalassiphora* sp., *Wetzeliella articulata* and *Wetzeliella* spp. The majority of this association are indicative of a Ypresian (Early Eocene) age (Powell, 1992). *Charlesdowniea reticulata, Glaphyrocysta*? *vicina, Homotryblium abbreviatum Pentadinium laticinctum, Wetzeliella articulata* all have range bases in the Ypresian (Powell, 1992, fig. 4.6). The range base of *Muratodinium fimbriatum* is also in the Ypresian and *Dracodinium* spp. are typical of this stage. It is possible that several levels in the Palaeogene have been incorporated into this diamicton; *Apectodinium augustum* is typical of the late Thanetian (Powell, 1992). These Palaeogene marine microplankton were most probably derived from the North Sea.

The three samples all yielded abundant Quaternary pollen and spores; the percentages vary between 19.2% and 24.2% (Table 2). Samples 9 and 10 both produced extremely low levels of Quaternary dinoflagellate cysts (Table 2). These forms were probably derived from the

Quaternary strata of the north; North Sea. The pollen and spores include *Chenopodium*, Compositae, *Erica*, *Stereisporites* and *Tilia* and the dinoflagellate cysts comprise *Brigantedinium* spp. and *Habibacysta* sp. These forms do not allow a definitive stratigraphical or palaeoclimatological breakdown to be made.

4 Conclusions/Summary

The ten samples studied produced extremely abundant palynofloras of high diversity with a wide overall stratigraphical range. Typically the assemblages contain Carboniferous (mainly Westphalian spores), Permo-Triassic, Jurassic (largely miospores), Cretaceous (chiefly Chalk Group dinoflagellate cysts), Palaeogene (Eocene), Quaternary and non-age diagnostic taxa. The most persistent and common forms are Carboniferous, Jurassic and Late Cretaceous. Many grains are not age diagnostic forms. These associations are generally typical of the Tills of North Norfolk and area significant contribution to the database. Certain familiar patterns were observed, for example while a wide range of Carboniferous ages were observed, spores of Westphalian age tend to dominate. The Carboniferous input is most likely to have been derived from the Northumberland-Durham area of north-east England and/or southern Scotland. Permo-Triassic input was extremely rare and probably reflects the organic-lean nature of much of this succession in the UK. The provenance of this is likely to be the Yorkshire Basin or the East Midlands Shelf. The consistently abundant associations of Jurassic miospores indicate significant input of Early and Mid-Late Jurassic strata; the Yorkshire Basin and/or the East Midlands Shelf are the most likely sources of these forms. When Jurassic marine microplankton are present, early Toarcian and Kimmeridgian dinoflagellate cysts tend to dominate. This is probably related to the mechanically tenacious and organic-rich, nature of lithological units of these ages. These units are relatively resistant to weathering as compared to other, softer units. This means that the eroded fragments of early Toarcian mudstones have the propensity to travel long distances while retaining their organic contents. Additionally, the Kimmeridge Clay Formation outcrops extensively in and around the Wash area (Cox and Gallois, 1981). Characteristically Early Cretaceous marker are either entirely absent or are present in low proportions. This is somewhat surprising as the Early Cretaceous succession of eastern England is known to be highly palyniferous. Late Cretaceous dinoflagellate cysts derived from the Chalk Group are present throughout in varying proportions. They occur in the normal grey/brown diamictons in relatively low numbers, however in the highly chalky diamictons they are unsurprisingly dominant. The Chalk Group dinoflagellate cyst floras are deemed to be of Campanian-Maastrichtian age based on the occurrences of key dinoflagellate cyst taxa. There appears to have been virtually no mixing of the Chalk Group input and indicates that the derivation is entirely from local sources of Upper Chalk. Other chalky diamictons from north Norfolk have yielded similar Campanian and Maastrichtian markers. Most of the Palaeogene dinoflagellate cysts tend to be of Eocene age, which is consistent with previous studies. The majority of the relatively sparse Quaternary spores, pollen and dinoflagellate cysts are not environmentally or biostratigraphically significant.

It is possible to subdivide this succession based on the palynofloras. The grey diamicton between 32.00 and 23.00 yields small proportions of Carboniferous spores and Chalk Group dinoflagellate cysts, moderate levels of Jurassic palynomorphs and consistently relatively high numbers of Quaternary spores/pollen. The light grey diamicton at 18.00 m is dominated by Quaternary spores and pollen; Carboniferous, Jurassic and Late Cretaceous species are rare. The highly chalky diamicton between 17.00-19.90 m and 22.95 and 21.50 m is overwhelmingly dominated by abundant, diverse and well preserved dinoflagellate cysts characteristic of the local Upper Chalk. Other elements are relatively sparse due to the diluting effect of the Chalk Group input. The grey/brown diamicton between 6.50 and 2.70 m is characterised by the highest proportions of Carboniferous spores and Jurassic palynomorphs in this succession. Late

Cretaceous and Eocene dinoflagellate cysts and Quaternary palynomorphs are consistently relatively sparse.

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Sample no.	Depth (m)	Grains/slide	Carb. spores	Permo-Triassic	Jur. miospores	Jur. microplankton
1	2.70-3.15	2014	404 (20.1%)	1 (0.1%)	541 (26.8%)	90 (4.4%)
2	3.50-3.95	1563	250 (16.0%)	…	414 (26.5%)	162 (10.4%)
3	6.5	1907	226 (11.9%)	…	386 (20.2%)	38 (2.0%)
4	16.9-17.0	18813	…	…	10 (0.06%)	6 (0.04%)
5	18	3871	28 (0.7%)	…	37 (1.0%)	…
6	21.5	3664	54 (1.5%)	…	161 (4.4%)	16 (0.4%)
7	22.50-22.95	21879	17 (0.07%)	…	14 (0.06%)	…
8	23	2906	147 (5.1%)	…	396 (13.6%)	49 (1.7%)
9	31	4686	93 (2.0%)	…	227 (4.8%)	24 (0.5%)
10	32	3205	104 (3.2%)	…	110 (3.4%)	4 (0.1%)

Table 1. Table illustrating the overall numbers of palynomorphs per microscope slide and the numbers and percentages of palynomorphs of Carboniferous to Jurassic age in the ten samples of this study. Three dots (...) indicates that the respective palynomorph group is not represented.

Sample no.	Depth (m)	L. Cret.		U. Cret.	Palaeogene	Quaternary		Non age-
		mios.	d. cysts	dino. cysts	dino. cysts	miospores	dino. cysts	diagnostics
1	2.70-3.15	…	…	30 (1.5%)	9 (0.5%)	42 (2.1%)	57 (2.8%)	842 (41.7%)
2	3.50-3.95	…	…	19 (1.2%)	10 (0.6%)	21 (1.3%)	9 (0.5%)	698 (44.7%)
3	6.5	…	…	83 (4.4%)	27 (1.4%)	64 (3.4%)	22 (1.1%)	1061 (55.6%)
4	16.9-17.0	…	…	18571 (98.7%)	…	…	…	226 (1.2%)
5	18	…	…	5 (0.1%)	…	1080 (27.9%)	54(1.4%)	2667 (68.9%)
6	21.5	…	3 (0.1%)	1617 (44.1%)	3 (0.1%)	312 (8.5%)	50 (1.4%)	1448 (39.5%)
7	22.50-22.95	…	…	21741 (99.30%)	…	37 (0.17%)	9 (0.04%)	79 (0.36%)
8	23	…	…	35 (1.2%)	13 (0.4%)	558 (19.2%)	…	1709 (58.8%)
9	31	…	…	28 (0.6%)	169 (3.6%)	1134 (24.2)	5 (0.1%)	3006 (64.2)%
10	32	6 (0.2%)	4 (0.1%)	21 (0.7%)	80 (2.5%)	656 (20.5%)	5 (0.2%)	2215 (69.1%)

Table 2. Table illustrating the percentages of palynomorphs of Cretaceous to Quaternary age and non age-diagnostic forms in the ten samples of this study. Three dots (...) indicates that the respective palynomorph group is not represented.