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A palynological investigation of the Oxford Clay Formation and the Quaternary succession of Northamptonshire (Sheets 171 and 186)

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A palynological investigation of the Oxford Clay Formation and the Quaternary succession of Northamptonshire (Sheets 171 and 186)

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Foreword

This report comprises a palynological study of fifteen samples from the Oxford Clay Formation and the Quaternary deposits of Northamptonshire (Sheets 171 and 186).

Contents

Summary

The samples examined in this study are from an area of Northamptonshire where the youngest unit of the solid geology is the Peterborough Member (Oxford Clay Formation). This, and the overlying Quaternary sediments, were studied. The Quaternary succession comprises till overlain by chalky till. In the Biggin Grange 1 Borehole, possible glaciofluvial sands and clays are intercalated between the till and chalky till.

The *in situ* Peterborough Member samples from the Biggin Grange 1 Borehole are probably referable to the Jason Zone. All the samples of the Quaternary units have similar palynomorph signatures. These are characterised by low proportions of Carboniferous and early Toarcian palynomorphs and extremely high levels of Callovian (Oxford Clay Formation) palynomorphs. However, the till in the Biggin Grange 1 borehole lacks early Toarcian palynomorphs. Of the allochthonous Oxford Clay Formation palynomorphs, the majority are interpreted as having been derived from the Peterborough Member. The chalky till samples are, surprisingly, entirely devoid of Late Cretaceous palynomorphs. However, the sands/clays and chalky till of the Biggin

Grange 1 borehole and the till of the Woodford borehole contain late Callovian dinoflagellate cysts, that indicate input from the Stewartby Member.

The dominance of the Peterborough Member (Oxford Clay Formation) indicates that the majority of the material in the Quaternary units was derived locally. However, the early Toarcian material is more far-travelled. The closest *in situ* early Toarcian strata in this area is to the north-west in the Welland valley. It is also possible that this material was sourced from further north, possibly from the Cleveland Basin. Early Toarcian palynomorphs are well known from the tills of East Anglia. It is possible that the tenacious lithologies which characterise strata of this age are especially conducive to the preservation of their palynofloras during glacial reworking processes. The Carboniferous spores may have been sourced from *in situ* outcrops or from allochthonous Carboniferous spores that have been reworked into the Oxford Clay Formation. If the Carboniferous material, which is most likely to be all Westphalian, was sourced directly, the closest outcrops are the West Midlands coalfield, again to the north-west. However, it is also possible that they were sourced from coalfields further north. In conclusion, the non-local Carboniferous and early Toarcian palynomorphs are consistent with ice movement from the north-west.

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1 Introduction

Fifteen samples from the Oxford Clay Formation and the Quaternary succession from three boreholes drilled on 1:50,000 geological sheets 171 and 186 were studied for their palynomorph content. This study aimed to determine the age and palaeoecology of the units studied. In particular the lithostratigraphy (to member level) of the Oxford Clay Formation and provenance of the Quaternary units sampled is of interest. The biostratigraphical resolution of Callovian-Oxfordian (Jurassic) dinoflagellate cysts is normally sufficient to enable the differentiation of the three members of the Oxford Clay Formation. This work has been undertaken in order to help the geological mapping of this region.

2 Sample Details

The fifteen samples studied are listed in the three tables below. The columns are, respectively, the (informal) sample number, the BGS micropalaeontological registration number (prefixed MPA), the collectors number (prefixed AMB), the depth below ground level in metres and the lithostratigraphical unit.

2.1 BIGGIN GRANGE NUMBER 1 BOREHOLE, NORTHAMPTONSHIRE (TL 02093 89089)

1	MPA 51841	AMB 715	3.35	chalky till
2	MPA 51842	AMB 716	6.0	?glaciofluvial interbedded sand and clay
3	MPA 51843	AMB 717	6.12	?glaciofluvial interbedded sand and clay
4	MPA 51844	AMB 718	6.35	?glaciofluvial interbedded sand and clay
5	MPA 51845	AMB 719	6.46	?glaciofluvial interbedded sand and clay
6	MPA 51846	AMB 720	6.65	?glaciofluvial interbedded sand and clay
7	MPA 51847	AMB 721	7.15	till
8	MPA 51848	AMB 722	8.08	till
9	MPA 51849	AMB 723	8.17	Oxford Clay Formation
10	MPA 51850	AMB 724	9.1	Oxford Clay Formation

2.2 BIGGIN GRANGE NUMBER 2 BOREHOLE, NORTHAMPTONSHIRE (TL 02091 89090)

11	MPA 51851	AMB 725	6.76	?glaciofluvial interbedded sand and clay
12	MPA 51852	AMB 726	7.05	?glaciofluvial interbedded sand and clay

2.3 WOODFORD NUMBER 1 BOREHOLE, NORTHAMPTONSHIRE (SP 94530 76327)

13	MPA 51853	AMB 727	2.52	chalky till
14	MPA 51854	AMB 728	3.65	till

15 MPA 51855 AMB 729 4.13 till

3 Palynology

In this section, the palynofloras are described in three main sections, referring to the three boreholes. Full listings of palynomorphs, including semiquantitative data, are held on the respective BGS micropalaeontology/palynology data sheets, which have been archived.

3.1 BIGGIN GRANGE NUMBER 1 BOREHOLE (TL 02093 89089)

The palynofloras are described in four sections that refer to each of the units sampled.

3.1.1 Samples 10 and 9 (AMB 724 and AMB 723) – Oxford Clay Formation

Samples 10 and 9 produced abundant and well-preserved organic residues and palynofloras. Wood fragments, other plant tissues and amorphous organic material are all common. The palynoflora is dominated by the Mesozoic pollen grain *Classopollis classiodes*, with smaller proportions of Jurassic miospores and dinoflagellate cysts. The pollen flora includes bisaccate pollen grains, *Callialasporites* spp., *Cerebropollenites macroverrucosus, Cycadopites* spp., *Perinopollenites elatiodes* and *Vitreisporites pallidus*. The pteridophyte spores are less diverse and include *Coronatispora valdensis, Cyathidites* spp. and *Dictyophyllidites* sp. A single specimen of a reworked Carboniferous spore, *Densosporites* sp., was observed in sample 9. Miscellaneous microplankton are also present, e.g. acritarchs and foraminiferal test linings.

Dinoflagellate cysts observed include *Chytroeisphaeridia hyalina, Fromea tornatilis, Gonyaulacysta jurassica* subsp. *adecta, Nannoceratopsis pellucida, Paragonyaulacysta* sp., *Pareodinia* spp., *Sirmiodinium grossii, Stephanelytron redcliffense* and *Tubotuberella dangeardii.* This association is characteristic of the mid Callovian. Key markers are *Chytroeisphaeridia hyalina* and *Stephanelytron redcliffense* in sample 10; the overlapping ranges of these two species is indicative of the Jason and Coronatum zones. It is most likely that sample 10 is referable to the Jason Zone as *Chytroeisphaeridia hyalina* typically became extinct in this zone (Raynaud, 1978). The inception of *Stephanelytron redcliffense* is also in the Jason Zone (Riley and Fenton, 1982). The remainder of the dinoflagellate cyst floras are entirely consistent with a mid Callovian age. This means that these samples are referable to the Peterborough Member of the Oxford Clay Formation.

3.1.2 Samples 8 and 7 (AMB 722 and AMB 721) – till

Samples 8 and 7 yielded abundant, well-preserved organic residues and palynofloras. Amorphous organic material is abundant and wood fragments and other plant tissues are both common. The palynofloras are similar to those of the underlying samples 10 and 9 and are dominated by the Mesozoic pollen grain *Classopollis classiodes*, with smaller proportions of other Jurassic miospores and dinoflagellate cysts. The pollen flora also comprises bisaccate pollen grains, *Callialasporites* spp., *Cerebropollenites macroverrucosus* and *Perinopollenites elatiodes*. The pteridophyte spores are less diverse and are dominated by *Cyathidites* spp. A single specimen of the reworked Carboniferous spore, *Densosporites* sp., was observed in sample 7. Miscellaneous microplankton are also present in low numbers.

Dinoflagellate cysts observed include *Fromea tornatilis, Gonyaulacysta jurassica* subsp. *adecta, Kalyptea stegasta, Korystocysta gochtii, Mendicodinium groenlandicum, Nannoceratopsis pellucida, Pareodinia ceratophora*, *Rhynchodiniopsis cladophora, Rigaudella aemula* and *Tubotuberella dangeardii.* This association is characteristic of the early-mid Callovian. Late Callovian associations are much more diverse and *Kalyptea stegasta* is characteristic of the mid

Callovian. The remainder of the palynofloras are consistent with a mid Callovian age. This means that these samples are referable to the Peterborough Member of the Oxford Clay Formation. This age determination is unsurprising, as the Peterborough Member underlies this till (see above). The organic material in this till may be entirely locally-derived.

3.1.3 Samples 6 to 2 (AMB 720 to AMB 716) – possible glaciofluvial interbedded sands and clays

These five samples produced similar organic residues and palynofloras and clearly reflect a single genetic unit. The abundant palynomorphs and phytoclasts are well-preserved. Amorphous organic material, wood fragments and other plant tissues are common, but the residue is dominated by palynomorphs. Gymnospermous pollen such as bisaccate pollen and *Classopollis classoides* is most abundant. Pteridophytic spores include *Contignisporites* spp., *Coronatispora valdensis, Cyathidites* spp. *Ischysporites variegatus* and *Retitriletes austroclavatidites*. Dinoflagellate cysts and other microplankton are also present. The overwhelming majority of the palynomorphs observed are Jurassic in age.

Three ages of palynomorphs were recognised. Rare Carboniferous spores were present in samples 6, 5 and 2. These are largely *Densosporites* spp. and may represent Carboniferous reworking into Jurassic strata rather than being derived glaciogenically, directly from Carboniferous rocks. Two distinct ages of Jurassic palynomorphs were recognised. The oldest Jurassic elements are low proportions of typically early Toarcian palynomorphs and the youngest, and most abundant, are Callovian.

The occurrence of the dinoflagellate cysts *Mancodinium semitabulatum, Nannoceratopsis deflandrei* subsp. *senex*, the prasinophyte *Halosphaeropsis liassica* and the sporomorphs *Chasmatosporites* spp. and *Kekryphalospora distincta* are indicative of the early Toarcian interval. Palynomorphs of this age have also been observed in the tills of East Anglia and may be derived locally from the East Midland Shelf or perhaps from the Cleveland Basin.

The most abundant palynomorphs were derived locally from the Oxford Clay Formation. The dinoflagellate cysts observed include *Chytroeisphaeridia chytroeides, Chytroeisphaeridia hyalina, Ctenidodinium continuum, Ctenidodinium ornatum, Ctenidodinium* spp., *Endoscrinium galeritum, Fromea tornatilis, Gonyaulacysta jurassica* subsp. *adecta, Korystocysta gochtii, Meiourogonyaulax caytonensis, Mendicodinium groenlandicum, Nannoceratopsis pellucida, Pareodinia ceratophora*, *Rhynchodiniopsis cladophora, Scriniodinium crystallinum, Sirmiodinium orbis, Surculosphaeridium vestitum, Tubotuberella apatela, Tubotuberella dangeardii, Wanaea acollaris* and *Wanaea* cf. *thysanota.* These forms indicate mixed assemblages of the members of the Oxford Clay Formation. However, no indications of the Oxfordian were observed, so the Weymouth Member is unlikely to be represented. Furthermore, species such as *Ctenidodinum continuum* are present which has its range top at the Callovian-Oxfordian boundary. *Chytroeisphaeridia hyalina* is present in sample 5. This species is an index for the early-mid Callovian and hence the Peterborough Member. Key markers for the late Callovian are present in sample 3, thus indicating input of the Stewartby Member. These include *Scriniodinium crystallinum* and *Wanaea* cf. *thysanota*. A summary of the samples is presented below.

SAMPLE NO.	AGE	MEMBER(S)
Sample 6	early-mid Callovian	Peterborough Member
Sample 5	early-mid Callovian	Peterborough Member
Sample 4	early-mid Callovian	Peterborough Member
Sample 3	early-mid-late Callovian	Peterborough and Stewartby members
Sample 2	early-mid Callovian	Peterborough Member

These age/lithostratigraphical determinations are unsurprising because the Peterborough Member is the youngest unit in the solid geology of this area (see above).

Sample 4 also yielded small numbers of Quaternary pollen grains, e.g. Compositae (*Taraxacum* - dandelion) and *Pinus*. These occurrences indicate the presence of pine trees and dandelion. Pine pollen may be far-travelled, but the dandelion pollen is probably local. The occurrence of dandelion pollen is consistent with a climatic amelioration (i.e an interglacial or interstadial); these herbs would not grow in full glacial conditions.

3.1.4 Sample 1 (AMB 715) – chalky till

Sample 1 yielded an abundant organic residue and palynoflora. The phytoclasts are dominated by dark, woody fragments. The palynoflora is dominated by Jurassic miospores, particularly the pollen grain *Classopollis classiodes*, with smaller proportions of Jurassic dinoflagellate cysts and Carboniferous spores. Surprisingly, no evidence of the Chalk Group via the occurrence of Late Cretaceous dinoflagellate cysts was observed.

Carboniferous spores are rare and comprise *Densosporites* spp., *Endosporites globiformis* and *Lycospora pusilla*. Assuming that these spores were derived glacigenically, they indicate that the ice traversed Westphalian strata because *Endosporites globiformis* is a marker for the Westphalian. Carboniferous spores are known to be reworked into Jurassic strata. However the significant numbers of these Carboniferous spores in this sample supports them being directly incorporated into the till rather than being supplied via Jurassic strata.

The Jurassic input can be subdivided into material from the Toarcian and Callovian. The presence of *Chasmatosporites* spp., *Halosphaeropsis liassica, Mancodinium semitabulatum, Nannoceratopsis deflandrei* subsp. *senex* and *Nannoceratopsis gracilis* indicates that material of early Toarcian age was incorporated into the till. This assemblage is characteristic of this interval and similar allochthonous early Toarcian associations have been observed in many tills of East Anglia. The most likely source is the early Toarcian part of the Whitby Mudstone Formation either from the Cleveland Basin, the East Midlands Shelf or from the immediate vicinity.

The majority of the palynomorphs are indicative of the Callovian Stage, i.e. are locally derived from the Oxford Clay Formation. The miospores comprise both gymnosperm pollen and pteridophytic spores. The pollen includes bisaccate pollen, *Callialasporites* spp., *Chasmatosporites* spp., *Classopollis classoides, Cerebropollenites macroverrucosus, Perinopollenites elatiodes* and *Vitreisporites pallidus*. The pteridophyte spores are less common and include *Coronatispora valdensis* and *Cyathidites* spp.

The dinoflagellate cysts are relatively diverse and include *Batiacasphaera* spp., *Ctenidodinium* spp., *Endoscrinium galeritum, Fromea tornatilis, Gonyaulacysta jurassica* subsp. *adecta,* ?*Kalyptea stegasta, Meiourogonyaulax caytonensis, Pareodinia ceratophora, Rigaudella aemula, Scriniodinium crystallinum, Stephanelytron scarburghense, Wanaea acollaris* and *Wanaea thysanota*. There are minor levels of various marine microplankton that include *Micrhystridium* spp. and *Tasmanites*. The dinoflagellate cysts are indicative of a mid-late Callovian age. Taxa such as *Endoscrinium galeritum, Rigaudella aemula, Scriniodinium crystallinum, Stephanelytron scarburghense* and *Wanaea thysanota* typically have range bases close to the mid-late Callovian transition. No evidence of the Oxfordian was observed. *Fromea tornatilis, Gonyaulacysta jurassica* subsp. *adecta,* ?*Kalyptea stegasta, Meiourogonyaulax caytonensis, Pareodinia ceratophora* and *Wanaea acollaris* are typical of the entire Callovian. Because of the occurrence of the late Callovian markers, it is concluded that the Stewartby Member was incorporated into this till. It is probable that some Peterborough Member material is also present because of the presence of certain early-mid Callovian indices, such as ?*Kalyptea stegasta* and *Meiourogonyaulax caytonensis.*

3.1.5 Differences between the till and the chalky till

Despite several similarities, there are significant differences between the till and the chalky till at this locality. The till samples are dominated by amorphous organic material, lack Toarcian palynomorphs and the Oxford Clay Formation component is characteristic of the Peterborough Member. By contrast, the overlying chalky till lacks amorphous organic material and is dominated by wood. The chalky till also yields early Toarcian forms and the Oxford Clay Formation input includes material from the Stewartby Member.

3.2 BIGGIN GRANGE NUMBER 2 BOREHOLE (TL 02091 89090) (SAMPLES 12 AND 11)

The palynofloras from these two samples (AMB 726 and AMB 725 respectively), taken from interbedded possible glaciofluvial sands and clays are described in this section. Well-preserved palynomorphs dominate the residues, with lesser proportions of wood and other plant tissues. Amorphogen is rare. Two questionable specimens of the Carboniferous spore genus *Densosporites* were observed in sample 12. This may indicate minor Carboniferous input or these may be allochthonous grains reworked into Jurassic rocks. Jurassic palynomorphs dominate the associations. The miospores and miscellaneous microplankton are similar to those from the Biggin Grange 1 Borehole (see above). Minor levels of early Toarcian input were observed. This is due to the presence of *Chasmatosporites* spp., *Halosphaeropsis liassica, Kekryphalospora distincta* and *Nannoceratopsis deflandrei* subsp. *senex.* The remainder of the Jurassic palynofloras are Callovian. This means that these assemblages are virtually identical to the interbedded ?glaciofluvial sands and clays of the Biggin Grange 1 borehole (see above). The Callovian dinoflagellate cysts include *Fromea tornatilis, Gonyaulacysta jurassica* subsp. *adecta, Kalyptea* sp.*,* ?*Korystocysta gochtii, Mendicodinium groenlandicum, Nannoceratopsis pellucida* and *Pareodinia ceratophora.* This association does not include any of the many late Callovian markers and hence is indicative of the early-mid Callovian. This means that the abundant Callovian input is from the Peterborough Member of the Oxford Clay Formation.

3.3 WOODFORD BOREHOLE (SP 94530 76327) (SAMPLES 13 TO 15)

The palynofloras are described in two sections that refer to each of the units sampled.

3.3.1 Samples 15 and 14 (AMB 729 and AMB 728) – till

These samples produced abundant organic residues that are dominated by the Mesozoic pollen grain *Classopollis classoides* and wood. Amorphous organic material is common in sample 14.

The majority of palynomorphs are of Jurassic age, however small numbers of Carboniferous spores are also present. These include *Cristatisporites* sp., *Densosporites* spp. and *Lycospora pusilla.* These forms could have been sourced directly or via reworking into Jurassic strata.

As in the overlying chalky till (see below), low proportions of early Toarcian palynomorphs were observed in both samples. These include *Chasmatosporites* spp., *Nannoceratopsis deflandrei* subsp. *senex, Nannoceratopsis gracilis* and *Nannoceratopsis* sp. indicates that material from the early Toarcian part of the Whitby Mudstone Formation was incorporated into this till unit. The likely source of this is the Cleveland Basin, further north in the East Midlands Shelf or locally, to the north-west.

The majority of the palynomorphs in this till are indicative of the Callovian Stage, and hence were sourced locally from the Oxford Clay Formation. Miospores were dominated by gymnospermous pollen and have similar species spectra to the other samples in this study. The dinoflagellate cysts include *Ambonosphaera? staffinensis, Batiacasphaera* spp., *Compositosphaeridium polonicum, Endoscrinium galeritum, Gonyaulacysta jurassica* subsp. *adecta, Korystocysta* sp.*, Meiourogonyaulax* sp.*, Mendicodinium groenlandicum,*

Nannoceratopsis pellucida, Pareodinia ceratophora, Pareodinia halosa, Rhynchodiniopsis cladophora, Rigaudella aemula, Scriniodinium crystallinum, ?*Scriniodinium inritibile, Systematophora* spp.*, Tubotuberella dangeardii, Wanaea acollaris* and *Wanaea* sp. The occurrence here of late Callovian markers such as *Scriniodinium crystallinum* indicates input from the Stewartby Member. No unequivocal Oxfordian markers were observed, so the presence of Weymouth Member material is not confirmed. It is possible that some Peterborough Member material was incorporated. Common amorphous organic material is present in sample 14; this palynofacies is typical of the Peterborough Member. However no mid Callovian markers were encountered in either sample.

3.3.2 Sample 13 (AMB 727) – chalky till

Sample 13 yielded an organic association similar to the chalky till from the Biggin Grange 1 borehole (see above) and a direct correlation is indicated. The sample produced an abundant residue and palynoflora, dominated by wood and the pollen grain *Classopollis classiodes*. Bisaccate pollen is also common and smaller proportions of Jurassic dinoflagellate cysts and Carboniferous spores are present. No evidence of the Chalk Group was observed.

The Carboniferous spores *Densosporites* spp., *Lycospora pusilla* and *Radiizonates* sp. were observed, and are interpreted as being derived glaciogenically. Low proportions of early Toarcian palynomorphs are present. These include *Chasmatosporites* spp., *Halosphaeropsis liassica, Nannoceratopsis deflandrei* subsp*. senex* and ?*Nannoceratopsis gracilis* indicates that early Toarcian material has been incorporated into this till. This assemblage is from the early Toarcian part of the Whitby Mudstone Formation and is similar to allochthonous early Toarcian palynofloras from other English tills. The most likely provenance is the either from the Cleveland Basin, the northern East Midlands Shelf or the immediate vicinity, i.e. to the north-west.

The majority of the palynomorphs are indicative of the Callovian Stage, i.e. were derived locally from the Oxford Clay Formation. The miospores comprise both gymnosperm pollen and pteridophytic spores. These include bisaccate pollen, *Callialasporites* spp., *Classopollis classoides, Coronatispora valdensis* and *Cyathidites* spp. The dinoflagellate cysts are of low diversity and include *Batiacasphaera* spp., *Chytroeisphaeridia hyalina, Fromea tornatilis, Nannoceratopsis pellucida* and *Tubotuberella dangeardii.* These dinoflagellate cysts are indicative of a early-mid Callovian age due to the absence of late Callovian markers. Thus it is postulated that the Oxford Clay Formation input was from the Peterborough Member.

3.3.3 Differences between the till and the chalky till

There are some differences between the till and the chalky till. Till sample 14 is rich in amorphous organic material, which is not prominent in the chalky till. Both tills yield early Toarcian palynomorphs. The Oxford Clay Formation content of the till appears to be largely from the Stewartby Member. In the chalky till, no late Callovian markers were recorded and the occurrence of forms such as *Chytroeisphaeridia hyalina* indicates that the Peterborough Member forms the bulk of the Oxford Clay Formation component. The configuration of the Oxford Clay Formation units in these till units in the Woodford and the Biggin Grange 1 boreholes is therefore not consistent. The single distinguishing feature is that the till is consistently rich in amorphous organic material, which is typical of the Peterborough Member of the Oxford Clay Formation.

The chalky till at both these localities is dominated by wood and has similar relative proportions of palynomorphs. However the Jurassic dinoflagellate cyst associations from the Biggin Grange 1 Borehole include some late Callovian markers which were not observed in the Woodford Borehole.

4 Summary of Results

The table below concisely summarises the results of this study. OCF = Oxford Clay Formation.

Biggin Grange 1 borehole:

1 **chalky till** Low Carboniferous and early Toarcian input; dominated by material from the Stewartby and Peterborough members (OCF).

2 **?glaciofluvial sands/clays** Low Carboniferous and early Toarcian input; dominated by material from the Peterborough Member (OCF). Sample 3 has evidence of input from the Stewartby Member (OCF). Rare Quaternary pollen.

3 **till** Extremely low Carboniferous input; dominated by material from the Peterborough Member (OCF).

4 **Oxford Clay Formation** Dinoflagellate cyst markers indicate a mid Callovian age, probably the Jason Zone. This indicates that the samples are from the Peterborough Member.

Biggin Grange 2 Borehole:

1 **?glaciofluvial sands/clays** Extremely low Carboniferous input and some early Toarcian palynomorphs; dominated by material from the Peterborough Member (OCF).

Woodford Borehole:

1 **chalky till** Low Carboniferous and early Toarcian input; dominated by material from the Peterborough Member (OCF).

2 **till** Low Carboniferous and early Toarcian input; dominated by material from the Peterborough and Stewartby members (OCF).

5 Summary/Conclusions

The samples examined in this study are from an area of Northamptonshire where the youngest unit of the solid geology is the Peterborough Member (Oxford Clay Formation). This, and the overlying Quaternary sediments, were studied. The Quaternary succession comprises till overlain by chalky till. In the Biggin Grange 1 Borehole, possible glaciofluvial sands and clays are intercalated between the till and chalky till.

The *in situ* Peterborough Member samples from the Biggin Grange 1 Borehole are probably referable to the Jason Zone. All the samples of the Quaternary units have similar palynomorph signatures. These are characterised by low proportions of Carboniferous and early Toarcian palynomorphs and extremely high levels of Callovian (Oxford Clay Formation) palynomorphs. However, the till in the Biggin Grange 1 borehole lacks early Toarcian palynomorphs. Of the allochthonous Oxford Clay Formation palynomorphs, the majority are interpreted as having been derived from the Peterborough Member. The chalky till samples are, surprisingly, entirely devoid of Late Cretaceous palynomorphs. However, the sands/clays and chalky till of the Biggin Grange 1 borehole and the till of the Woodford borehole contain late Callovian dinoflagellate cysts, that indicate input from the Stewartby Member.

The dominance of the Peterborough Member (Oxford Clay Formation) indicates that the majority of the material in the Quaternary units was derived locally. However, the early Toarcian material is more far-travelled. The closest *in situ* early Toarcian strata in this area is to the north-west in the Welland valley. It is also possible that this material was sourced from further north, possibly from the Cleveland Basin. Early Toarcian palynomorphs are well known from the tills of East Anglia. It is possible that the tenacious lithologies which characterise strata of this age are especially conducive to the preservation of their palynofloras during glacial reworking processes. The Carboniferous spores may have been sourced from *in situ* outcrops or from allochthonous Carboniferous spores that have been reworked into the Oxford Clay Formation. If the Carboniferous material, which is most likely to be all Westphalian, was sourced directly, the closest outcrops are the West Midlands coalfield, again to the north-west. However, it is also possible that they were sourced from coalfields further north. In conclusion, the non-local Carboniferous and early Toarcian palynomorphs are consistent with ice movement from the north-west.

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