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The Pleistocene College Farm Silty Clay at Great Blakenham, Suffolk, England – additional information on the course of the early River Thames

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Abstract

The Pleistocene College Farm Silty Clay Member of the Creeting Formation at Great Blakenham, Suffolk, south-east England is shown to contain indigenous and recycled dinoflagellate cysts and other derived palynomorphs. The indigenous dinoflagellate cysts indicate a marine influence during deposition of the clay, whilst the other palynomorphs demonstrate derivation of sediment from a wide catchment of Carboniferous, Jurassic and Cretaceous bedrocks. It is argued, by comparison with palynological data from the Chillesford Clay Member of the Norwich Crag Formation some 25km to the east, that these sediments were eroded from western, south-central and south-eastern Britain, and transported by the early River Thames to its estuary, where they were redeposited at the western margin of the Crag Basin, during the Early Pleistocene Tiglian TC3 Substage. This interpretation refines earlier research which concluded the College Farm Silty Clay was deposited in a predominantly freshwater environment, such as a lagoon, without any direct access to the sea or major river.

Keywords: England, Suffolk, Pleistocene, Crag, Thames

Introduction

Sections in the large quarry complex at Great Blakenham [Ordnance Survey National Grid Reference TM 113 504] (Fig. 1), on the western side of the Gipping Valley in Suffolk, expose an important sequence of Early and Middle Pleistocene sediments totalling some 15m in thickness.

The site was mentioned by Markham (1972), Rose & Allen (1977) and Rose et al. (1976), but the first detailed account was provided by Allen (1983), who later proposed formal terms for the identifiable stratigraphical units (Allen 1984). Further work by Gibbard et al. (1996) revealed that the sediments contain both indigenous and derived palynomorphs, although the latter were not described.

Recent work by Riding et al. (1997, 2000) on the Pleistocene Chillesford Clay Member and other clays within the Norwich Crag Formation in East Anglia has demonstrated that derived palynomorphs can be useful tools for determining both palaeogeography and sediment provenance in the Early Pleistocene of southern Britain. It was thought, therefore, that a further study of the palynology of the College Farm Silty Clay, with particular emphasis on the derived palynomorphs, might reveal new information on its provenance. Samples for analysis were collected by the British Geological Survey (BGS) in June 1998.

The locality sampled lies on 1:50000 British Geological Survey Sheet 207 (Ipswich) at National Grid Reference TM 1130 5040. The samples have been registered as BGS onshore micropalaeontological samples MPA 47704, 48006 and 48007.

MPA 47704 Uppermost College Farm Silty Clay – a c.0.5m thick dark-grey clay

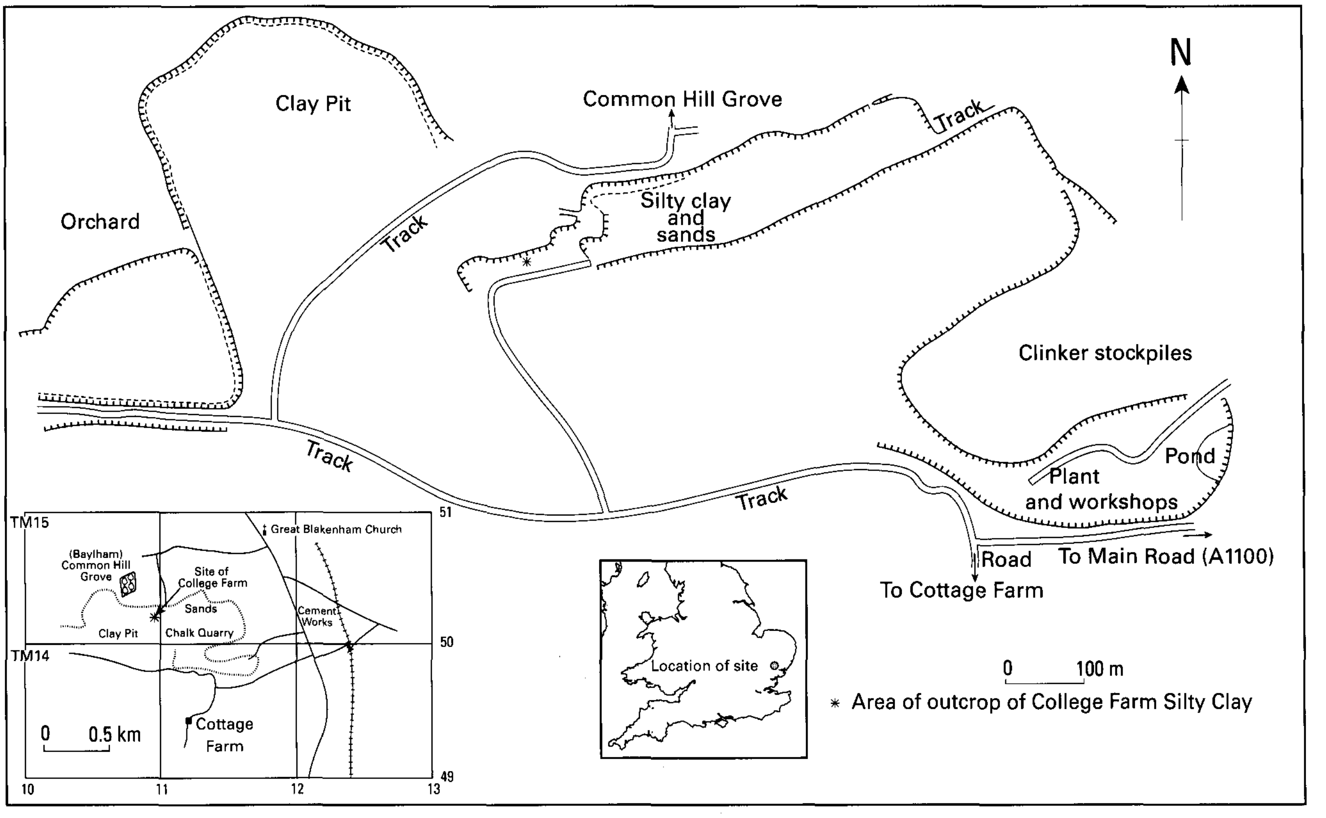

Fig. 1. Location and plan of the quarry at Great Blakenham, Suffolk, England.

MPA 48006 Midway College Farm Silty Clay – fine-grained sand with thin clay beds

MPA 48007 Basal College Farm Silty Clay – a c.0.2m thick clay bed in micaceous sand

This paper follows the convention of the British and Dutch geological surveys in taking the base of the Praetiglian pollen stage as a practical marker for the Pliocene-Pleistocene boundary. This boundary is approximately coincident with a major global palaeoclimatic change and the Gauss/Matuyama magnetic epoch boundary (Suc et al., 1997). On this basis the College Farm Silty Clay is assigned to the Early Pleistocene. However, an alternative internationally ratified Pliocene/Pleistocene boundary based on the stratotype at Vrica, Italy is dated at about 1.8MA (Berggren et al., 1995; Gradstein & Ogg, 1996). Using this definition the College Farm Silty Clay would be classified as Late Pliocene.

Stratigraphical sequence

The oldest Pleistocene deposits at Great Blakenham are preserved in shallow depressions on an irregular Chalk surface. These were called the Crag 'Stone-bed' by Markham (1972). The succeeding Creeting Formation comprises two distinctive units, the Creeting Sands Member and the overlying College Farm Silty Clay Member (Allen, 1984). Throughout much of the quarry the College Farm Silty Clay is overlain unconformably by fluvial sands and gravels of the Kesgrave Group (Whiteman & Rose, 1992) with the Valley Farm Palaeosol at their surface (Rose & Allen, 1977) and then Lowestoft Till. At the point where the samples were collected the College Farm Silty Clay was overlain directly by Lowestoft Till. Similarity in facies types later led Zalasiewicz & Mathers (1985) (Table 1) to correlate the Creeting Sands Member with the Chillesford Sand Member of the Norwich Crag Formation, and the overlying College Farm Silty Clay Member with the Chillesford Clay Member of the Norwich Crag Formation.

The Crag 'Stone-bed' is a lag deposit of flint and phosphatic nodules and phosphatised bones infilling hollows in the Chalk surface up to 0.25 m deep and 1.5 m in diameter. The overlying Creeting Sands are up to about 11 m thick and are composed of well-sorted, fine- to medium-grained micaceous sands with several matrix supported, poorly sorted gravelly sand beds and a small amount of silty clay. Primary structures range from ripples, through planar and trough cross-sets (up to 1.3m thick) to horizontally bedded units (up to 1.6m thick) (Allen, 1984; Gibbard et al., 1996). Overall, laterally extensive, horizontal beds predominate. Silty clay occurs in variable

Table 1. Lithostratigraphy, chronostratigraphy and correlation of the deposits at Great Blakenham. The Units at Great Blakenham and correlated chronostratigraphy that are the subject of this study are shown in bold. Other items in the table are to show other deposits recorded at Great Blakenham and stratigraphic context.

Lithostratigraphic units at Great Blakenham	Regional Lithostratigraphy§+ Glacial and Fluvial	Soil	Marine and Coastal#+	Regional Chronostratigraphy Britain#	Netherlands	Oxygen Isotope Stage*	Age and Environment
Lowestoft Till Formation	Lowestoft Formation			Anglian	Elsterian		Lowland glaciation/ diverted R. Thames
						12	c. 0.45 Ma
Kesgrave Group with Valley Farm Soil at top	Colchester and Cromer Forest-bed Formations	Valley Farm Soil	Wroxham Crag Formation	hitherto defined as Cromerian and Beestonian	'Cromerian Complex'		Truncated high energy River Thames
						21	c. 0.90 Ma
	Sudbury and Cromer Forest-bed Formations		Wroxham Crag Formation	hitherto defined as Pastonian and pre-Pastonian	'Bavel Complex' Menapian Waalian Eburonian		Extensive, high energy River Thames
						57	c. 1.70 Ma
Creeting Formation	Nettlebed Formation		Norwich Crag Formation: Chillesford Clay Member	Baventian	Tiglian TC4c		
College Farm Silty Clay Member			**Chillesford Sand Member**	**Antian/ Bramertonian**	**Tiglian TC3**		**Low energy River Thames, coastal lagoon and estuary**
Creeting Sands Member					Tiglian TC1-2		
						~77	c. 2.05 Ma

§ After Zalasiewicz & Mathers, 1985; # After Gibbard et al., 1996 and West, 1980; * After Funnell, 1996; +After Rose et al., 2001

amounts, but increases in frequency upwards, and is represented as curled flakes, as thin seams in simple and wavy types of flaser bedding, or as thicker seams within interlayered bedding (Allen, 1984; Gibbard et al., 1996). The sands within the uppermost 5-6 m of the Creeting Sands are coarser than those beneath, indicating higher energy levels and possibly associated with shallower water conditions.

According to Allen (1984) and Gibbard et al. (1996) the horizontal nature of the bedding, with primary structures typical of the lower and transitional flow regimes, and with flaser and interlayered bedding becoming more important upwards, indicate an aggrading environment such as a sand flat changing to a mixed flat, with curled flakes of silty clay indicating desiccation due to periodic sub-aerial exposure of the surface. These authors suggest that the occasional gravelly sands may reflect storm events or powerful flows from nearby rivers.

The overlying College Farm Silty Clay Member is up to 3.75m thick and occurs as a sequence of grey horizontal laminae and beds up to 1.2m thick, interbedded with well-sorted sand, or as interlayered sand and silt laminae forming co-sets up to 1m thick. Small-scale loading and water escape structures occur relatively frequently (Allen, 1984; Gibbard et al., 1996). Plant detritus is common at some horizons. The individual silty clay beds are generally massive, though the upper ones tend to be brecciated in places and oxidised to strong brown (7.5YR5/8). The member is present only locally in the quarry; east and west of the sampled section it thins and is replaced by flaser and lenticular laminae.

Palaeobotany

The first palynological work on the sediments at Great Blakenham was undertaken by Holyoak (in Allen, 1984). Field (1992) reported on the plant macrofossils of the site. A more thorough palaeobotanical study was reported on by Gibbard et al. (1996).

Indigenous palynomorphs

The early work by Holyoak (in Allen, 1984) provided one undiagnostic pollen spectrum. The later study by Gibbard et al. (1996) revealed the presence of a single uniform *Pinus-Picea-Alnus-Empetrum* pollen assemblage. Throughout the sequence, the pollen of *Pinus* is dominant with subsidiary amounts of *Alnus* and *Picea*. Other tree taxa are *Betula* and *Tsuga*, with occa-

Table 2. The quantitative distribution of indigenous and reworked palynomorphs in three samples from the College Farm Silty Clay Member at Great Blakenham, Suffolk, England. The taxa are listed alphabetically within five groupings. The numbers in the cells refer to the absolute numbers of the representative taxon, genus etc. per microscope slide. A question mark refers to specimens for which the identifications are deemed equivocal. Three dots (...) indicate the absence of the respective morphotype. The respective ages of the reworked palynomorphs are indicated, where appropriate, by capitalized abbreviations in parentheses:- C = Carboniferous, MJ = Middle Jurassic, UJ = Upper Jurassic, K = Cretaceous, M = Mesozoic (undifferentiated).

MPA 48007	MPA 48006	MPA 47704	PALYNOMORPHS
			Indigenous dinoflagellate cysts
...	...	10	*Achomosphaera andalousiensis* Jan du Chêne 1977
...	...	25	*Brigantedinium* spp.
...	3	11	Dinoflagellate cysts – indeterminate
...	...	2	*Lejeunecysta oliva* (Reid 1977) Turon & Londeix 1988
...	...	47	*Operculodinium centrocarpum* (Deflandre & Cookson 1955) Wall 1967 sensu Wall & Dale 1966
...	...	?1	*Selenopemphix quanta* (Bradford 1975) Matsuoka 1985
...	...	2	*Selenopemphix nephroides* Benedek 1972
...	?1	31	*Spiniferites* spp.
...	...	2	*Tuberculodinium vancampoae* (Rossignol 1962) Wall 1967
			Reworked dinoflagellate cysts
...	...	2	Chorate dinoflagellate cysts – indeterminate
...	...	11	*Cleistosphaeridium* sp.
...	...	7	*Cribroperidinium globatum* (Gitmez & Sarjeant 1972) Helenes 1984 (UJ)
...	...	1	*Crussolia deflandrei* Wolfard & Van Erve 1981 (UJ)
...	...	2	*Gonyaulacysta jurassica* (Deflandre 1938) Norris & Sarjeant 1965 (M/UJ)
...	...	1	*Leptodinium mirabile* Klement 1960 (UJ)
...	...	1	*Palaeoperidinium cretaceum* Pocock 1962 (K)
...	...	1	*Pareodinia* sp.
...	...	1	*Scriniodinium crystallinum* (Deflandre 1938) Klement 1960 (M/UJ)
			Miscellaneous palynomorphs
6	...	...	*Botryococcus*
...	...	29	Foraminiferal test linings
2	...	27	Fungal debris
...	...	4	*Pediastrum* spp.
1	...	1	*Tasmanites* sp.
			Indigenous miospores
...	...	7	*Chenopodium*
...	...	7	Compositae pollen
...	...	27	*Ericipites* spp.
...	...	5	*Deltoidospora* spp.
3	...	...	Gramineae pollen
...	...	6	*Inaperturopollenites hiatus* (Potonié) Pflug & Thomson 1953
4	...	324	*Laevigatosporites* spp.
...	...	3	*Liquidambar*
...	...	4	*Lycopodiumsporites*
8	4	473	*Pinus* spp. (bisaccate pollen)
2	8	6	Pollen – indeterminate
...	...	3	Spores - indeteterminate
...	...	45	*Stereisporites* spp.
...	...	5	Tricolpate pollen
			Reworked miospores
...	...	2	*Callialasporites dampieri* (Balme 1957) Sukh Dev 1961 (M)
...	...	2	*Callialasporites microvelatus* Schulz 1966 (M)
1	?1	3	*Callialasporites turbatus* (Balme 1957) Schulz 1967 (M)
...	...	3	Carboniferous spores - indeterminate (C)
...	...	4	*Cerebropollenites macroverrucosus* (Thiergart 1949) Schulz 1967 (M)
...	2	10	*Classopollis classoides* (Pflug 1953) Pocock & Jansonius 1961 (M)
...	...	1	*Cyathidites minor* Couper 1953
...	...	7	*Cingulisporites* spp. (C)
...	...	5	*Densosporites* spp. (C)
...	...	67	*Lycospora pusilla* (Ibrahim 1932) Schopf *et al.* 1944 (C)
...	...	1	*Vitreisporites pallidus* (Reissinger 1950) Nilsson 1958 (M)

sional records of *Quercus*, *Tilia*, *Carpinus*, *Abies*, *Acer* and *Corylus*. The pollen of *Empetrum* are well represented at all levels; at one horizon together with Ericales. Gramineae, Chenopodiaceae and plants of calcareous meadow and disturbed ground are sporadically present. The spores of Filicales are present throughout.

This assemblage is consistent with a well-vegetated landscape with a cover of predominantly coniferous woodland in which *Pinus* and *Picea* were the main components. *Alnus* and *Betula* were locally important, possibly in damper areas. Acid heathland was present as evidenced by abundant *Empetrum* as well as Ericales and *Sphagnum*. Dry calcareous grassland and disturbed ground occurred nearby. The presence of Chenopodiaceae strongly suggests saltmarsh or tidal litter horizons.

Although not examined in detail for indigenous pollen, the recently collected BGS samples generally support the findings of Gibbard et al. (1996). In addition to the indigenous pollen, the uppermost of the BGS samples contains indigenous dinoflagellate cysts (Table 2) which are indicative of marine conditions of deposition. Their occurrence is significant as Gibbard et al. (1996) stated that they were unable to comment on the quality of the water because of the absence of diatoms or calcareous fossils.

The indigenous dinoflagellate cyst flora is of low species diversity (Table 2) but of distinct Quaternary aspect (Harland, 1977, 1983, 1992; Head 1998). By far the most common species is *Operculodinium centrocarpum*; other forms present include *Achomosphaera andalousiensis*, *Brigantedinium* spp., *Lejeunecysta oliva*, *Selenopemphix nephroides*, *Spiniferites* spp. and *Tuberculodinium vancampoae* (Table 2). The assemblage is comparable to those recorded previously from the Early Pleistocene of East Anglia (Head 1994, 1996, 1998). Head's studies have demonstrated that earlier work on dinoflagellate cysts in the southern North Sea Basin contained errors of identification, due largely to the fact that, as knowledge progressed, some species were able to be subdivided into several distinct new species. The original identifications commonly led to either conflicting or incorrect interpretation of palaeoenvironment. A summary work of Head (1998) corrected many of these errors and revised the palaeoenvironmental interpretations. The assemblage of indigenous dinoflagellate cysts in the College Farm Silty Clay is consistent with a temperate, neritic palaeoenvironment.

Plant macrofossils

Gibbard et al. (1996) found plant macrofossil assemblages to be dominated by waterside, damp-ground and aquatic taxa, indicative of a still or low energy waterbody bounded by reed-swamp. An earlier report of the macrofossils in the College Farm Silty Clay (Field, 1992) provided the first record of the water fern *Azolla tegeliensis* in the British Isles.

Derived palynomorphs

Gibbard et al. (1996) recorded the presence of derived palynomorphs in the College Farm Silty Clay but did not provide details.

Examination of the BGS samples revealed the presence of palynomorphs of Carboniferous, Jurassic, and Cretaceous age (Table 2) although in the two lower samples they were very rare. No recycled Lower Palaeozoic or Palaeogene palynomorphs were recognised. The reworked Carboniferous spores are common and dominated by *Lycospora pusilla*. Others in lower proportions include *Cingulisporites* and *Densosporites*. The overwhelming majority of the reworked dinoflagellate cysts are Jurassic. They include *Cribroperidinium globatum*, *Crussolia deflandrei*, *Leptodinium mirabile* and *Scriniodinium crystallinum*; all of these are characteristic of the Upper Jurassic. *Crussolia deflandrei* is a lowermost Oxfordian marker, *Scriniodinium crystallinum* ranges from the Upper Callovian to the lowermost Kimmeridgian, *Leptodinium mirabile* is Oxfordian-Kimmeridgian and *Cribroperidinium globatum* is characteristic of the Kimmeridgian (Riding & Thomas, 1988, 1992, 1997). The most stratigraphically restricted form is *Crussolia deflandrei*, which unequivocally indicates a derivation from the Weymouth Member of the Oxford Clay Formation (formerly Upper Oxford Clay). *Leptodinium mirabile* and *Scriniodinium crystallinum* were reworked from the succession between the Oxford Clay and Kimmeridge Clay formations. *Cribroperidinium globatum* was most probably derived from the Kimmeridge Clay Formation. Pollen, such as *Callialasporites* spp. and *Cerebropollenites macroverrucosus*, with a range from the Middle Jurassic to the Cretaceous was also encountered. However, in the absence of Cretaceous miospores, this pollen is considered to be representative of the Middle/Late Jurassic interval.

A single specimen of *Palaeoperidinium cretaceum* was recorded (Table 2). The range of this species is mid-Barremian to Late Cretaceous (Costa & Davey, 1992). It is most common in the Barremian to Albian interval, however, and was therefore probably derived from the Lower Greensand or Gault formations (or equivalents).

Discussion

Allen (1984) considered that the association of the College Farm Silty Clay with interbedded sands with characteristics similar to those in the underlying Creeting Sands supported an intertidal mud flat environment of deposition for the silty clay. Gibbard et al. (1996) argued, on sedimentological evidence, that the College Farm Silty Clay could have been deposited in any one of several environments in a situation marginal to, and succeeding, a sand flat in which the underlying Creeting Sands accumulated. However, when the floral evidence was considered also, they concluded (Gibbard et al., 1996, 1998) that deposition was in a shallow lagoon-like pool receiving small streams. They suggested that the sediment was deposited predominantly in a freshwater body lacking any substantial outlet to the sea, and fringed with marsh and reed-swamp with alder and birch woodland growing locally.

Our new finding of indigenous marine dinoflagellate cysts in the clay conflicts with the latter interpretation. Clearly, there must have been access to the sea, yet the presence of much land derived pollen confirms a close proximity to the shore. The interlayered bedding in the Great Blakenham sequence is typical of conditions near the high water mark in estuaries. It is also known that marine palynomorphs may be present in modern estuaries up to the tidal limit (Farr, 1989).

Indigenous dinoflagellate cysts have been recorded from only one of our samples, from the uppermost part of the sequence. The rather restricted assemblage suggests the possibility of less than open marine conditions such as might be expected in an estuary. The absence of indigeneous cysts in the lower samples might suggest that suitable marine conditions were present only during deposition of the upper part of the College Farm Silty Clay. However, in the two lower samples, reworked dinoflagellate cysts and indigenous pollen are sparse or absent, suggesting that conditions for the preservation of palynomorphs may have been unfavourable and that this could account for the absence of any indigenous dinoflagellate cysts. Indeed, Holyoak (in Allen, 1984) noted that nearly 25 per cent of the pollen grains in his samples were badly corroded and unidentifiable.

The recycled palynomorphs demonstrate that the College Farm Silty Clay contains material derived from formations ranging in age from Upper Palaeozoic to Mesozoic. Two possible means of transport for derived palynomorphs in similar East Anglian Crag clays were considered by Riding et al. (1997) – fluvial transport from outcrops in southern and western Britain, or southerly directed long-shore drift from outcrops in northern Britain adjacent to the western margin of the Crag Basin. The latter process was rejected for four reasons. Firstly, transport within the marine environment would have led to a greater dilution by contemporary marine forms. Palaeogene palynomorphs would also be expected to be present due to coastal erosion of relatively local Palaeogene provinces and they are absent. Secondly, the wash and backwash of sediment by wave action is a highly aggressive process (Komar, 1976) that is likely to have destroyed the palynomorphs by abrasion between other materials and oxidation while on their long journey from northern Britain. Thirdly, there is some evidence that long-shore drift off southern East Anglia in Crag times was to the north since clasts of Welsh volcanic rocks are present in the youngest marine Crag of north Norfolk (Rose et al., 1996, Rose et al., 2000). These could only have been transported by the River Thames to the south-western margin of the Crag Basin and transported northwards by long-shore drift and tidal current processes. Funnell (1996) also favoured a northerly current direction during the deposition of the Norwich Crag. Fourthly, long-shore drift would also have been expected to homogenise the assemblage of derived palynomorphs, such that similar species spectra would be found in all samples. In practice at sites where multiple samples have been analysed there is commonly a marked vertical variation in reworked palynomorph assemblages (Riding et al., 1997). The variation occurs on two scales; on a broad scale the proportions of Carboniferous, Jurassic and Cretaceous palynomorphs vary greatly between adjacent vertical samples, and on a finer scale the source formations of the derived Jurassic palynomorphs commonly differ between samples. This is more consistent with pulses of sediment input, such as would be expected within a fluvial environment, where vertical variation can be attributed to differential erosion of bedrock formations within the catchment area (Riding et al., 1997). However, this latter effect could not be observed at Great Blakenham due to the small number of samples analysed.

Analysis of the Chillesford Clay has shown that, in addition to Upper Palaeozoic and Mesozoic palynomorphs, it also contains Silurian acritarchs (Riding et al., 1997) which must have been reworked and transported from Wales or the Welsh borders. This suggests sediment input from an Early Pleistocene major river flowing from the Lower Palaeozoic Silurian rocks in western Britain, through the Upper Palaeozoic Carboniferous rocks and across the Mesozoic formations of southern-central and eastern England to the western margin of the Crag Basin (Riding et al., 1997). These authors concluded that this river was the early River Thames following the model of Hey and Brenchley (1977) and subsequently Whiteman and Rose (1992) and Rose et al. (1999) (Fig. 2).

The correlation of the Chillesford Clay with the College Farm Silty Clay on lithological criteria (Zalasiewicz & Mathers, 1985) is enhanced by the presence of derived Palaeozoic and Mesozoic palynomorphs in both members which demonstrates that both members received sediment input from distant sources. Given that the two members lie geographically within about 25km of each other, along an easterly line, it is not unreasonable to suggest that the sediment in the College Farm Silty Clay was also transported by the early River Thames (Fig. 2).

The Chillesford Clay was assigned to the Baventian/pre-Pastonian a Stage (Zalasiewicz et al., 1991). Biostratigraphical correlation with the Netherlands succession suggests that this stage is equivalent to Tiglian Substage TC4c (Gibbard et al., 1991, Fig. 8).

There are, however, significant differences between the in-situ pollen assemblages in the Chillesford Clay and the College Farm Silty Clay. The latter assemblage contains a much higher frequency of tree taxa. Gibbard et al. (1996) concluded that the assemblage from the College Farm Silty Clay is intermediate between the deciduous tree-rich assemblages of the Antian-Bramertonian Stage and the shrub and grass dominated assemblages of the Baventian Stage. It is possible, therefore, that the age of the College Farm Silty Clay is intermediate between the Bramertonian and Baventian-type assemblages.

Gibbard et al. (1996) concluded that on balance the College Farm Silty Clay represents a late temperate phase of the Antian-Bramertonian Stage. The discovery of *Azolla tegeliensis* in the College Farm Silty Clay (Field, 1992) strengthens this correlation as the remains of this plant appear to be restricted to deposits of Early to Middle Tiglian age (i.e. the sediments must pre-date Substage TC4b; De Jong, 1988). Gibbard et al. (1996) preferred a Tiglian TC3 Substage age for the College Farm Silty Clay. The indigenous dinoflagellate cysts in the BGS sample reflect a temperate climate, which is consistent with such a correlation. The correlation is enhanced by the relative geographical position of the deposits at Great Blakenham compared to the Chillesford Clay some 25km to the east. As temperatures declined during the Baventian cold period, it is probable that the coastline regressed eastwards as more water became locked in polar ice; thus during the deposition of the slightly younger Chillesford Clay the estuary would have been farther east than during the deposition of the College Farm Silty Clay.

The large difference in topographic height between the clay deposits at Great Blakenham (c.+50 m OD) and Chillesford (c.+25 m OD) may be explained by post-depositional subsidence in the southern North Sea and associated tectonic uplift in Eastern England during the Late Pliocene and Early-Middle Pleistocene (Hamblin et al., 1997; Gibbard et al., 1998; Rose et al., 2002).

Originally (Gibbard et al., 1996) reported the palaeomagnetic polarity of the College Farm Silty Clay as normal, which posed problems with a correlation with the Tiglian TC3 Substage, but the polarity has since been remeasured and found to be reversed (B. Maher, personal communication to Gibbard et al., 1998) which is fully compatible with the above interpretation.

The deposition of the College Farm Silty Clay co-

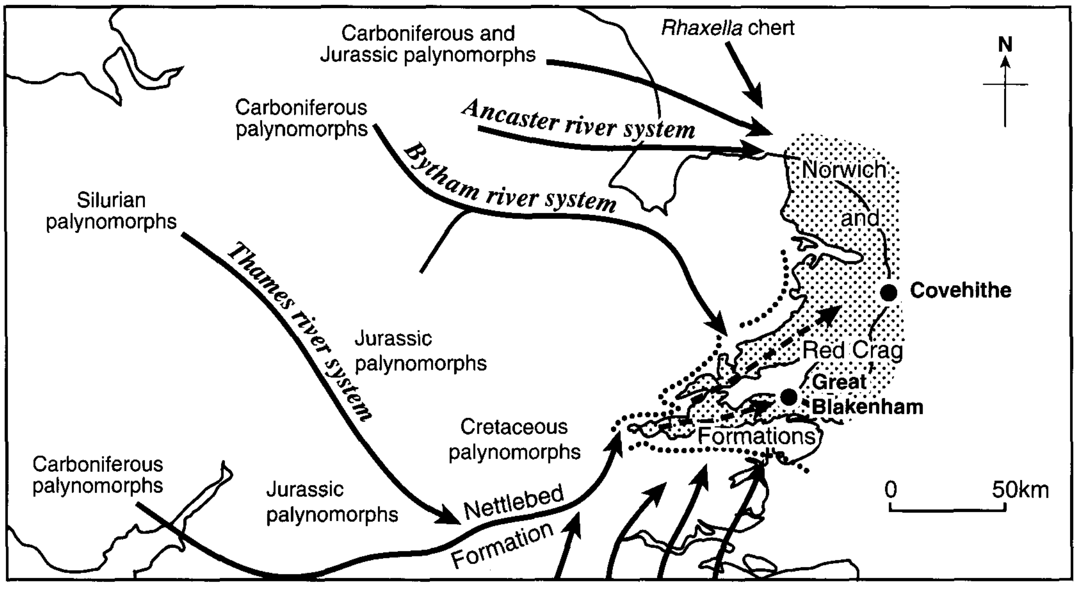

Fig. 2. The palaeogeography at the time of the formation of the College Farm Silty Clay Member at Breat Blakenham. The Figure shows the extent of the Early Pleistocene marine sediments in eastern England and the trajectories of the rivers that contributed sediment to these deposits.

incided with the period when the River Thames deposited the flint-rich Nettlebed Formation gravels along the southern slopes of the Oxfordshire Chilterns (Rose et al., 2001). During this period the suspended fraction of the river load was being transported through the entire length of the system, as demonstrated by the presence of Silurian acritarchs and Carboniferous and Mesozoic palynomorphs in the Chillesford Clay, but the bedload material derived from these distant sources was still confined to the upper reaches of the catchment (Rose et al., 2000, 2001) (Fig. 2). It was only later that indicator clasts of Welsh volcanic rocks and abundant pebbles of vein quartz and quartzite, from the higher reaches of the catchment, first made their appearance in East Anglia (Rose et al., 2000, 2001).

Conclusions

The College Farm Silty Clay was deposited during the Tiglian TC3 Substage in an estuarine environment at the western margin of the Southern North Sea Crag Basin. The presence of indigenous dinoflagellate cysts in the upper part of the member is indicative of a marine influence, but the rather restricted assemblage suggests an estuarine rather than a fully-open marine environment. It is believed that the lack of indigenous dinoflagellate cysts in the two samples from the lower part of the member results from unfavourable conditions for their preservation, although their absence could indicate a non-marine depositional environment.

Derived palynomorphs reveal that the College Farm Silty Clay and the nearby Chillesford Clay both received material from a wide range of Palaeozoic and Mesozoic formations in western and southern Britain. The early River Thames is considered to have been the transporting medium. A lack of derived Palaeogene, Pliocene or Early Pleistocene palynomorphs suggests that the College Farm Silty Clay received relatively little reworked material through marine processes operating at the western margin of the Crag Basin.

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