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A NEW STRATIGRAPHY FOR THE GLACIAL DEPOSITS AROUND LOWESTOFT, GREAT YARMOUTH, NORTH WALSHAM AND CROMER, EAST ANGLIA, UK.

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ABSTRACT

A new stratigraphical model for the glacial deposits around Lowestoft, Great Yarmouth, North Walsham and Cromer (east of Weybourne and Edgefield) is presented, based on a combined research programme by the British Geological Survey and the Department of Geography, Royal Holloway University of London. This stratigraphical model is founded upon evidence derived from sedimentological descriptions, geological mapping and analytical lithological techniques including clast lithological analysis, derived pre-Quaternary palynomorphs and heavy mineralogy. The previously accepted 'North Sea Drift' / 'Lowestoft Formation' scheme is abandoned in favour of four formations that relate to assemblages of till units and associated outwash lithofacies, the mapping of major discontinuities, and morpho- and tectono-stratigraphical associations. The new scheme consists of the Happisburgh, redefined Lowestoft, Sheringham Cliffs and Briton's Lane formations.

INTRODUCTION

Glacial sediments in northern East Anglia have been the focus of scientific investigation since the Geological Survey originally mapped the region during the late nineteenth century (Reid, 1882; Blake, 1890). Attention has centred primarily upon stratigraphical correlation and the sedimentology of the deposits (Harmer, 1909; Boswell, 1914, 1916; Banham, 1968; Ranson, 1968; Lunkka, 1994; Hart & Boulton, 1991a), and using the tills of the region as ancient analogues for the testing of new models of glacial deposition derived from modern glacial environments (Eyles *et al*., 1989; Hart *et al*., 1990; Hart & Boulton, 1991b; Hart & Roberts, 1994; Lee, 2001).

Despite this vast quantity of published material, comparatively little quantitative data has been published with respect to the lithology of the glacial sediments. An understanding of sediment lithology, together with their standard sedimentological and structural properties is a critical component in constructing a robust and demonstratable lithostratigraphic framework (Salvador, 1994; Rawson et al., 2002), as well as for modelling sediment provenance and patterns of glaciation.

In response to this, a joint research programme examining the stratigraphy and palaeoenvironments of the glacial deposits of East Anglia was instigated by the British Geological Survey, and the Department of Geography Royal Holloway University of London. This paper presents a summary of the results of this survey in the areas of Lowestoft, Great Yarmouth, North Walsham and Cromer (Figure 1), with particular emphasis placed on outlining a new glacial stratigraphy for the region based upon an integrated stratigraphical approach utilising geological mapping, lithological and sedimentological analyses. It is envisaged that this new stratigraphy will provide a robust foundation and standard nomenclature for future research within the region, as well as offering the conceptual basis upon which presently accepted explanations for the glacial history of the region can be tested. A classic example of this is the widely accepted view that northern East Anglia was glaciated by Scandinavian ice (Cromer Tills / North Sea Drift) during the Middle Pleistocene (Perrin *et al*., 1979; Bowen *et al*., 1986; Ehlers & Gibbard, 1991; Bowen, 1999), despite no direct evidence having been published to demonstrate this (Moorlock *et al*., 2001).

The specific aims of this paper are firstly, to present a new glacial stratigraphy for the region; and secondly, to use this data to test some of the major concepts that underlie the glacial history of the region.

A HISTORY OF GEOLOGICAL INVESTIGATIONS

Stratigraphy

Previous lithostratigraphical schemes for the glacial deposits of northeast Norfolk and the Waveney Valley are shown in Tables 1 and 2 respectively. The first detailed stratigraphic investigation of glacial sediments within the area of investigation (Figure 1) coincided with the original mapping survey of the region by officers of the Geological Survey in the late nineteenth century (Reid, 1882; Blake, 1890). Working in the area around Lowestoft and

Great Yarmouth, Blake (1890) identified two tills that corresponded to the 'Lower' and 'Upper Glacials', separated by an intervening 'Middle Glacial' sand unit. In northeast Norfolk, Reid (1882) recognised a tripartite till sequence separated by a series of outwash deposits. He termed the tills the 'First' and 'Second Tills' (Cromer Till association) and the 'Boulder Clay / Stony Loam' and was able to trace them individually between Happisburgh and Mundesley before they passed northwards into the 'Contorted Drift' (Trimingham – Weybourne) (Table 1). In this area Reid argued that a stratigraphical succession was impossible to determine due to intense deformation. This melange of deformed sediments was overlain by a series of highly chalky tills deposited by British ice that were later to become known as the 'Marly Drift' (Banham, 1968; Lunkka, 1994).

Following Reid and Blake, the next major stratigraphical study undertaken in the region was that of Harmer (1909) and Boswell (1914, 1916). Their work led to the introduction of the now familiar term 'North Sea Drift' which was used to encompass the 'Cromer Till' and 'Contorted Drift' associations of Reid (1882), due to the reported occurrence of erratics and heavy minerals of North Sea and Scandinavian provenance, and their inferred stratigraphical correlation with tills of Scandinavian origin ('Lower Glacial') that underlie British tills ('Upper Glacial') within the County Durham area (Trechmann, 1916).

A notable hiatus in research occurred during the inter-war years. After the conclusion of World War II, Baden-Powell (1948, 1950) published two influential papers concerning the stratigraphy of central East Anglia and the Lowestoft area. He confirmed the sequence identified at Corton by Blake (1890) and renamed the 'Lower Glacial' and 'Upper Glacial' as 'Norwich Brickearth' and 'Chalky Boulder Clay' respectively. He also recognised two distinctive facies of 'Chalky Boulder Clay', a Jurassic-rich facies (i.e. Lowestoft-type) and a chalk-rich facies (i.e. Gipping-type), and concluded that they were deposited during separate Anglian and 'Gipping' glaciations.

During the 1960s and 1970s Banham and Ranson undertook a major research programme in northeast East Anglia. They adopted a litho- and tectono-stratigraphical approach to their investigations and constructed a similar sequence, albeit more elaborate, to that originally defined by Reid (1882) and Blake (1890) (Tables 1 and 2). Tills were renamed as the now familiar First, Second and Third Cromer Tills of the 'North Sea Drift' (Banham, 1968, 1971; Ranson, 1968a) which Banham (1968, 1975) recognised could be traced laterally into the Contorted Drift. Banham (1971) and Pointon (1978) also investigated coastal sections at Corton and replaced the term 'Chalky Boulder Clay' (Corton-type) coined by Baden Powell (1948), with 'Lowestoft Till'.

Banham's stratigraphical classification was subsequently adopted following a stratigraphical review of Quaternary deposits in the British Isles by the Geological Society (Mitchell *et al*., 1973). Two separate glaciations were assumed to have occurred during separate stadials of the Anglian Glaciation. The first of these, the Gunton Stadial, related to an initial advance of Scandinavian ice into the region that deposited the 'Cromer Tills' / 'North Sea Drift Formation'; during the second Lowestoft Stadial glaciation, the 'Lowestoft Till' was laid-down by British ice. Within the intervening Corton Interstadial, the 'Corton Beds' ('Middle Glacial' of Blake, 1890) were deposited. Subsequent work has challenged the validity of this climostratigraphical interpretation of the Anglian Glaciation, due to the presence at Weybourne of intercalated North Sea Drift and Lowestoft Till (Banham *et al*., 1975), and the reinterpretation of the Corton Beds as outwash derived from the North Sea Drift ice sheet (Bridge & Hopson, 1985; Rose, 1989).

The first detailed quantitative investigation of tills within the region was undertaken by Perrin *et al*. (1973, 1979). They used the spatial distribution of till matrix properties ($CaCO_3$, matrix texture, heavy mineralogy) to determine: (1) that all chalky tills of eastern England, namely the 'Chalky Boulder Clay' (Jurassic- and chalk-rich types) and 'Marly Drift' of north Norfolk, formed a single till sheet that was deposited by ice fanning-out over different bedrock lithologies from the Wash and Fenland Basins – this till sheet was subsequently called the Lowestoft Till after Banham (1971) and Mitchell *et al*. (1973); (2) that tills of 'North Sea Drift' and 'Lowestoft' affinities possessed different lithological properties. The original model of Perrin et al. has been elaborated and superseded by subsequent work (Rose, 1992; Fish & Whiteman, 2001).

The 1980s marked a distinctive point of divergence in approaches to stratigraphy. The lithostratigraphical and mapping approach was adopted by the British Geological Survey who had just begun mapping within the Waveney Valley. Using the sequence described at Corton by Blake (1890) and Banham (1971) as a regional stratotype, they were able to correlate stratigraphical units back to the Corton type-area via mapping, boreholes, and subsurface geometry (Bridge & Hopson, 1985; Hopson & Bridge, 1987; Arthurton *et al*., 1994). In contrast, the work of Hart and Boulton (Hart, 1987, 1990, 1992; Hart & Boulton, 1991a) and later Lunkka (Lunkka, 1988, 1991, 1994) in northeast Norfolk followed a more process-based stratigraphical rationale that, particularly in the case of the former, was strongly influenced by research in modern glacial environments. The stratigraphical scheme proposed by Lunkka (1994), although similar to that of Banham (1968) and Ranson (1968a), was considerably expanded with a total of five diamicton units – Happisburgh Diamicton (=First Cromer Till), Walcott Diamicton (=Second Cromer Till), Cromer and Mundesley Diamictons (=Third Cromer Till), and Marly Drift (=Lowestoft Till) (Table 1).

A modified version of Lunkka's stratigraphical scheme has subsequently been adopted by the Geological Society of London for northeast East Anglia in their recent reclassification of the Quaternary deposits of the British Isles (Bowen, 1999). Within this scheme, two major lithofacies associations are present: (1) the North Sea Drift Formation of Scandinavian provenance; (2) the Lowestoft Formation deposited by British Ice. However, this scheme has several problems – most notably the complexity and inaccessibility of the stratigraphical nomenclature, and the failure to resolve the fundamental problem of synchronising the successions of northeast Norfolk and the Waveney Valley.

Chronology of glaciations

The Geological Society correlation of Quaternary deposits in Britain stipulate that the region was glaciated just once during the Middle Pleistocene – an event that corresponds to the Anglian Glaciation (c. 480-430ka) (Mitchell *et al.*, 1973; Bowen, 1999), and has subsequently been generally accepted by most (Bowen *et al.*, 1986; Hart & Boulton, 1991a; Lunkka, 1994).

Several divergences from this view have occurred. Firstly, regarding whether the chalky tills of East Anglia correspond to one extensive till sheet (Lowestoft Till) that was deposited during the Anglian (Bristow & Cox, 1973; Perrin *et al.*, 1979; Rose, 1992), or whether there are several lithologically similar till sheets deposited during different Middle Pleistocene glaciations (Baden-Powell, 1948; West & Donner, 1956; Straw, 1979, 1983). Most recently, Hamblin *et al*. (2000, 2001), Lee (2003) and Clark *et al*. (2004) have argued that only the Lowestoft Till and the Second Cromer Till / Walcott Diamicton of the 'North Sea Drift' are Anglian, and that the First Cromer Till / Happisburgh Diamicton and the Third Cromer Till / Cromer / Mundesley Diamictons may relate to older and younger Middle Pleistocene glaciations respectively. This concept has been challenged by some (Banham *et al*., 2001; Preece, 2001; Whiteman, 2002), and is the focus of present research within the region. A detailed review of current evidence within this debate is beyond the scope of this paper since its primary focus is stratigraphical, however readers are directed to the above-mentioned publications, and references therein, and to Lee *et al*. (2004).

RESEARCH STRATEGY AND METHODOLOGY

Stratigraphical approach

The primary aim was to devise a robust and accessible stratigraphical scheme that conforms to modern stratigraphic protocols (Salvador, 1994; Rawson *et al*., 2002), and one that was not biased by pre-conceived or out-dated stratigraphical and palaeoenvironmental models. With this in mind, the following hierarchical stratigraphical approach was applied:

1. Field description and lithological analyses of deposits at individual sites.
2. Identification and definition of 'lithofacies' at stratotype localities / areas based on their lithological, mineralogical, sedimentological and textural properties, geometry, geomorphological context and relative stratigraphical position. This provided a practical and conceptual basis for:
    a. Correlation of lithofacies between sites;
    b. Geological mapping based on recognition of type-lithofacies – especially diamictons and some of the more identifiable sands and gravels;
3. Construction of 'members' within the stratigraphical scheme based upon the spatial correlation of lithofacies. Where possible this has utilised and adapted pre-existing stratigraphical terms (i.e. Corton Sands = Corton Sand Member).
4. Placement of 'members' within 'formations' based upon lithofacies associations and mappable disconformities. An important characteristic of the 'formation' is that it is the fundamental mapping-based unit (Salvador, 1994).

Analytical Methodologies

A range of analytical techniques was utilised to generate the data that underpins the stratigraphy. Lithofacies at individual sites were described on the basis of texture, lithology, colour (Munsell Colour value), structure (sedimentary and tectonic), geometry and the nature of lower and upper contacts (Tucker, 1996). Orientation measurements such as clast fabric (a-axis measurements), shear plane, fold and palaeocurrent determinations were also collected to provide information concerning palaeo stress-fields and palaeoflow. Lithological analyses were undertaken on bulk samples in order to quantify their lithological properties, aid stratigraphical correlation and provenance determination. Particular emphases were placed upon particle size distribution, calcium carbonate content, derived palynomorphs, clast lithological analysis of diamictons and heavy mineral analyses - sampling, processing and counting procedures follow standard recommendations (Gale & Hoare, 1991). Diamicton units were also investigated using micromorphological techniques in order to gain further understanding of their genesis and post-depositional history. Further analytical detail is provided within the relevant figure captions.

LOCATION AND GEOMORPHOLOGY OF THE RESEARCH AREA

The geographical area covered by this paper includes the stretch of coastline and adjacent hinterland areas between Weybourne in northern Norfolk, and Pakefield in northern Suffolk. It corresponds to the area in East Anglia recently mapped by the British Geological Survey as part of the Eastern England Mapping Programme and includes the following 1:50,000 sheets with accompanying memoirs and sheet explanations: Lowestoft (Sheet 176; Moorlock *et al*., 2000b), Great Yarmouth (Sheet 162; Arthurton *et al*., 1994), North Walsham and Mundesley (Sheet 148 / 132; Moorlock *et al*., 2002a) and Cromer (east) (Sheet 131; Moorlock *et al*., 2002b). Coverage of the Cromer sheet (Sheet 131) within this paper is restricted to the eastern half of the sheet, east of the line that links Weybourne and Edgefield (Figure 1). The geology of the area immediately to the west that includes Holt, the Glaven Valley and adjoining 1:50,000 Wells sheet, is not discussed within this paper. Geological investigations of this area are currently being undertaken by the authors, the results will be presented at a later date.

The southern sector of the study area encompasses the area around Beccles, Great Yarmouth and Lowestoft and the lower reaches of the River Yare and Waveney. Coastal exposures are present at Pakefield, Corton, California Gap and Scratby although their quality and accessibility are variable due to coastal defences and local cliff instability. Inland within the valley flanks, several quarries (many now disused) such as Leet Hill and Norton Subcourse provide good access to glacial deposits (Rose *et al*., 1999a; Lee, 2003). The stratigraphy within this area is further supported by extensive borehole evidence (Hopson & Bridge, 1987; Arthurton *et al*., 1994; Rose *et al*., 2002). Northwards between Scratby and Happisburgh, and inland as far west as Wroxham and North Walsham, the topography consists of a relatively low-lying till plateau incised through by the Rivers Bure and Thurne. Exposures within this area are rare, even in coastal areas where cliffs are replaced by extensive dune fields, and are largely limited to trial pits and occasional now disused brick-pits and sand pits. The valley floors consist of small rivers, marshes and dykes, the Norfolk Broads, that have been mapped as Holocene alluvium belonging to the Breydon Formation (Arthurton *et al*., 1994). Farther northwards into northeast Norfolk, the topography becomes more undulating rising gently to 100m OD in the vicinity of the Cromer Ridge between Cromer and Sheringham. Coastal sections between Happisburgh and Weybourne are generally good although beach defences and cliff falls, particularly within the south of the region around Mundesley and Trimingham, can restrict access to good sections. Additionally, several working sand and gravel quarries, and numerous partially back-filled, disused sand and gravel and brick pits exist.

A NEW LITHOSTRATIGRAPHY

The new glacial lithostratigraphy for the area studied is presented within Table 3 and their lateral equivalence in Figure 2, which also shows the simplified relationship between the previous and the new lithostratigraphical schemes. Previously applied stratigraphical terms for each of the newly-defined members are shown within summary tables for each of the formations (Tables 4, 9, 11, 13). Essentially, all of the major till and outwash units identified within the previous lithostratigraphical model (Model A) have been recognised within the new scheme (Model B) however, the major developments of the new scheme are:

1. The 'Cromer Till' and 'North Sea Drift' terminology has been abandoned in favour of a formal stratigraphical nomenclature that contains geographic and litho-genetic qualifiers.
2. Three newly-defined Formations – the Happisburgh, Sheringham Cliffs and Briton's Lane formations are presented together with a re-defined Lowestoft Formation.
3. The 'Walcott Till Member' (formerly Second Cromer Till / Walcott Diamicton) is laterally equivalent to the Lowestoft Till Member.
4. The stratigraphies of the Waveney Valley area (Great Yarmouth and Lowestoft districts) can now be directly linked to that of northeast Norfolk (North Walsham and Cromer districts).

A geological map (Figure 3) and coastal cross-section (Figure 4) show the spatial distribution of the Formations, whilst a series of correlated composite stratigraphical logs (Figure 5) outline the stratigraphy of key sites, and the spatial distribution of the major lithostratigraphical sub-divisions presented therein. Some of the data, observations and discussion presented within the following sections relate to work that is presently unpublished – papers providing more detail on particular sites and issues will be published in the near future. Reference to published data, maps and supporting literature sources is indicated.

Happisburgh Formation

The Happisburgh Formation (Table 4) consists of tills and outwash deposits that were previously assigned to the First Cromer Till (Banham, 1968; Ranson, 1968), Happisburgh Diamicton (Lunkka, 1994) or Corton Diamicton (Lee, 2001) and represent sedimentation associated with the oscillating margins of the British Ice Sheet. Cliff sections (TG 3830) to the south of Happisburgh village have been designated the stratotype area for the Happisburgh Formation since they reveal a near complete sequence that enables the stratigraphies of northeast Norfolk and northern Suffolk to be correlated (Figure 5). Of critical significance is the delineation of the First Cromer Till / Happisburgh Diamicton / Corton Diamicton into two lithologically similar units, the Happisburgh and Corton Till members, that can be separated on the basis of structure and stratigraphical position. Happisburgh Formation sediments crop out widely at the surface throughout the Lowestoft, Great Yarmouth and North Walsham districts (Figure 3), and have been traced extensively through coastal sections and boreholes as far north as Trimingham (Figures 4 and 5). They commonly overlie, and are in places sedimentologically related to, pre-glacial fluvial and marine deposits of the Bytham Formation and Wroxham Crag Formation respectively (Rose *et al*., 1999a, 2001; Lee, 2003; Lee *et al*., 2004).

Happisburgh Till Member

The Happisburgh Till Member is the basal lithofacies of the Happisburgh Formation and crops out at the base of coastal sections between Happisburgh (TG 388304) and Ostend (TG 368322), and further north between Trimingham (TG 288387) and Cromer (TG 230417). It equates to the First Cromer Till of Banham (1968) and Ranson (1968a) or the Happisburgh Diamicton of Lunkka (1994). The unit consists of a 2-7m -thick yellowish grey (2.5Y 4/1) to grey (5Y 4/1) matrix-supported diamicton, which has a sandy clay matrix texture (Figure 6), and is generally massive except for occasional contorted inclusions of chalk and sand. The clast content of the diamicton is typically less than 1% with lithologies largely derived from the reworking of pre-existing Pleistocene deposits (brown, white and chatter-marked flint; quartzose clasts) (65.0-68.1%) and chalk bedrock (15.7-22.8%) (Table 5) (Lee *et al*., 2002).

The lower contact of the unit with underlying pre-glacial Crag sediments is a sharp but irregular, sub-horizontal décollement plane formed during the subglacial accretion of the till as a deforming bed (Hart, 1987; Hart & Boulton, 1991a; Lunkka, 1994; Lee, 2001, 2003). The upper surface of the till is undulating, comprising a series of ridges and troughs that have been interpreted as a range of subglacial and ice-marginal landforms (Hart, 1987; Lunkka, 1988, 1994; Lee, 2003).

Clasts and derived palynomorphs from the till at Happisburgh and Trimingham demonstrate that the ice is of British provenance (Lee *et al*., 2002). Diagnostic British indicators include Magnesian Limestone clasts from northeastern England, a *Gryphaea arcuata* Lamarck shell from the Lias of Yorkshire, Carboniferous Limestone and coal, plus a Carboniferous palynomorph association characteristic of the Westphalian of central Scotland or northern England (Lee *et al*., 2002). The far-travelled erratic content is strongly suggestive of a source in Central Scotland with clasts of low- to medium-grade Dalradian meta-sediments, basaltic and acid porphyry and Old Red Sandstone. No diagnostic Scandinavian lithologies such as rhomb porphyry, larvikite and high-grade metamorphic erratics were observed, and all other rocks that could be attributed to Scandinavia could equally have been derived from Scotland (Lee *et al*., 2002). Detailed examination of the matrix composition further refines the source areas for the till with palynomorphs from the Lower, Middle and Upper Jurassic plus the Lower Cretaceous Speeton Clay Formation suggesting an additional input of sediment from the area of the Cleveland Basin and the adjacent offshore region (Lee *et al*., 2002; c.f. Lowestoft Till Member). This is supported by an abundance of amphibole, epidote and garnet non-opaque heavy minerals relative to total opaques (Table 6), since these heavy mineral species are diagnostic of derivation from the reworking of Palaeogene and / or Early Pleistocene sands in the North Sea (Perrin *et al*., 1979; Lee *et al*., 2004).

Ostend Clay Member

The Ostend Clay Member corresponds to the Happisburgh Clays of Lunkka (1994) and the lower parts of the Intermediate Beds of Banham (1968). Between Happisburgh (TG 388304) and Ostend (TG 368322), and Trimingham (TG 288387) and Cromer (TG 230417) it infills the upper surface topography of the Happisburgh Till Member forming a series of onlapping beds that reach a maximum thickness of 3.5m. These beds consist of stratified diamicton at the base, that grades upwards into rhythmically-laminated silts and clays with occasional isolated sand ripples, and convoluted horizons. They represent ice-marginal glaciolacustrine sedimentation.

Happisburgh Sand Member

The Happisburgh Sand Member crops out between the Ostend Clay Member and the Corton Till Member at Happisburgh (TG 390305) where it reaches a maximum observed thickness of 8m and correspond to the Happisburgh Sands of Lunkka (1994). It consists of yellowish brown (10YR 5/8) and yellow-orange (10YR 7/3) sands and rests upon the scoured upper surface of the Ostend Clay Member. Structurally it exhibits massive bedding, ripples, horizontal beds, channel structures and sporadic horizons of convolute bedding. Planar cross-beds are also common with palaeocurrent directions indicating localised flow towards the southeast. They have been interpreted as delta bottom-sets and delta top-sets (Hart, 1999; Lunkka, 1988; Lee, 2003).

Corton Till Member

This member has been mapped extensively throughout the Lowestoft, Great Yarmouth and North Walsham districts and crops out in coastal sections at Corton (TM 543979), California Gap (TG 518148) and Happisburgh (TG 390305). In its southern outcrop, it rests unconformably upon shallow marine deposits of the Wroxham Crag Formation (Hopson & Bridge, 1987; Arthurton et al., 1994; Rose et al., 2002) and has been referred to as the Norwich Brickearth (Bridge & Hopson, 1985; Hopson & Bridge, 1987), Cromer Till (Banham, 1971) or Corton Till (Arthurton et al., 1994). Further north at Happisburgh, the deposit has a gradational lower contact with the Happisburgh Sand Member (Lee, 2003). It consists of a light olive-brown (2.5Y 5/4) to olive-brown (2.5YR 4/4) matrix-supported sandy (Figure 6), clast-poor diamicton (<1%) that attains a maximum observed thickness of 3.2m. Two distinctive facies occur, firstly, at California Gap the diamicton is massive and highly consolidated and interpreted as a subglacial deformation till based largely upon its micro-scale deformational properties (Lee, 2003). Secondly, at Corton the diamicton is crudely stratified commonly exhibiting sandy stringers, dewatering structures, isoclinal fold noses showing a direction of overturn towards the southeast, and inter-stratified beds of waterlain sediment and subglacial till; it is interpreted as a series of subaqueous flow tills representing a grounding-line position (Lee, 2001) associated with a receding ice margin (Lee, 2003). An intermediate facies crops out at Happisburgh, with a massive lower facies becoming stratified progressively upwards.

Lithologically, the till is strikingly similar to the Happisburgh Till Member in terms of particle size distribution (Figure 6), calcium carbonate (Table 7) and heavy mineral content (Table 6). The clast composition is, however, different with the Corton Till Member containing higher proportions of re-worked Pleistocene lithologies such as flint, vein quartz and quartzite relative to chalk-derived clasts (Table 5) (Lee *et al*., 2002). Additional features that allow the discrimination between the two tills are the brown colouration, frequent stratified structure and lower apatite content of the Corton Till Member. Provenance-diagnostic lithologies are less abundant than within the Happisburgh Till Member, but similarities of clast and palynomorph assemblages demonstrate that the Corton Till Member is also of British derivation (Lee *et al*., 2002).

Leet Hill Sand and Gravel Member

The Leet Hill Sand and Gravel Member consists of stratified and channelled proximal glaciofluvial outwash deposits that have been mapped extensively through the Lowestoft and Yarmouth districts where it can be traced through numerous boreholes (Hopson & Bridge, 1987; Rose *et al*., 2002), as well as being exposed within coastal sections and quarries at Leet Hill (TM 384962), Pakefield (TM 537892), Corton (TM 543979) and Norton Subcourse (TM 402995) (Rose *et al*., 1999a, 2002; Lee, 2003). Reconstruction of the sub-surface geometry of these gravels using borehole evidence demonstrates that they thicken progressively westwards from Corton (up to 0.8m) to around 9m in the vicinity of Leet Hill (Hopson & Bridge, 1987). Lithologically, the gravels are rich in flint (66.4-79.8%) and quartzose (19.3-31.3%) clasts, but contain far-travelled erratics of northern provenance including Old Red Sandstone, basaltic porphyry, dolerite and Carboniferous Limestone (Table 8) (Rose *et al*., 1999a, 2002; Lee, 2003). In terms of the heavy mineral composition of the fine sand fraction, they can be distinguished from all other non-diamicton units by their high relative apatite (7.2% ± 2.8) content (Table 6). At their Leet Hill stratotype, the sands and gravels are a transitional lithofacies between underlying fluvial terrace deposits of the Bytham river (Kirby Cane Sands and Gravels) and the overlying Corton Sand Member (Happisburgh Formation) (Lee *et al*., 2004). At other localities such as Corton and Pakefield, the sands and gravels are incised down into either the Corton Till Member or shallow marine Crag deposits (Hopson & Bridge, 1987; Arthurton et al., 1994; Lee, 2003). Palaeocurrent measurements indicate that initial drainage was controlled by the pre-existing Bytham river valley topography. Upon infilling of this valley system by outwash, drainage was diverted southwards, unconstrained by topography (Rose et al., 1999a; Lee, 2001).

Corton Sand Member

The Corton Sand Member reaches thicknesses of 15m throughout the Lowestoft, Yarmouth and North Walsham districts where it is widely distributed and rests upon either the Corton Till Member as at Corton (TM 540985), California (TG 520144) and Happisburgh (TG 390303), or the Leet Hill Sand and Gravel Member at localities including Norton Subcourse (TM 402995), Pakefield (TM 537892) and Leet Hill (TM 384962). It is composed of pale yellow (2.5Y 8/4) chalky and shelly (detrital) sands that exhibit a variety of types of cross-bedding, ripples, horizontal and massive bedding, and soft-sediment deformation structures (e.g. convolute bedding, flame structures). Genetically, the sedimentology of the sands is typical of a progressively distal glaciofluvial environment during deglaciation (Hopson & Bridge, 1987; Lee, 2003). The heavy mineral composition of the sands exhibits a moderate degree of spatial variability, however they can still be readily identified across their distribution area (Table 6). Cryoturbation features and ice-wedge pseudomorphs have been reported from Corton and Burgh Castle (Ranson, 1968b; Bridge & Hopson, 1985; Arthurton *et al*., 1994), whilst a rhizogenic calcrete has been identified at Leet Hill (Candy, 2002). Elsewhere in the literature, they have been referred to as the Corton Beds (Banham, 1971) or the Corton Sands (Bridge & Hopson, 1985; Rose *et al*., 1999a, 2002).

California Till Member

The California Till Member has a localised outcrop in coastal sections within the Scratby and California Gap area (TG 521143) where it rests conformably upon the Corton Sand Member. The unit attains a maximum thickness of 13m and consists of beds of massive and faintly stratified olive brown (2.5YR 4/4) sandy diamicton (Figure 6), separated by massive and horizontal-bedded chalky sand with occasional augen-shaped lenses of fine silty-sand. Isoclinal fold noses are common and show (after correction for tilting) flow towards the south and southeast. The composition of these diamicton and sand beds is identical to that of the Corton Till and Corton Sand members respectively and suggests that these deposits form the parent material of the California Till Member. The California Till Member is interpreted as a subaqueous flow till.

Lowestoft Formation

The Lowestoft Formation (stratotype: Corton near Lowestoft – TM 5496) (Table 9) is based on the important Lowestoft Till Member of the Lowestoft and Yarmouth districts which can be correlated laterally with the Walcott Till Member of the North Walsham, Mundesley and Cromer districts (Figures 3, 4 and 5). A mappable disconformity is present between the Happisburgh and Lowestoft formations throughout the region. The spatial variation in the elevation of this disconformity suggests that between 15-25m of Happisburgh Formation material was eroded prior-to and during the onset of periglacial conditions before the arrival of ice that deposited the Lowestoft Formation.

Lowestoft Till Member

The stratotype of the Lowestoft Till Member is the coastal sections around Corton (TM 546987) near Lowestoft. From Corton, the unit formerly referred to as either the Lowestoft Till (Banham, 1971; Bridge & Hopson, 1985) or Chalky Boulder Clay (Baden-Powell, 1948, West & Donner, 1956), is mappable across the Lowestoft and Yarmouth districts where it truncates the Corton Sand Member or California Till Member. Localities where the till can be observed in section include Corton, Pakefield (TM 536884), Scratby (TG 514156), California Gap (TG 517148) and Leet Hill (TM 384962), and previously Aldeby (TM 459928). The unit is up to 4m thick, and consists of a dark grey clay-rich matrix-supported diamicton (Figure 6), that is massive in structure, and has been interpreted as a subglacial deformation till (Hart *et al*., 1990; Richards, 2000).

One of the most striking features of the till is its distinctive range of lithological properties – specifically, a moderate matrix calcium carbonate content (Table 7); palynomorphs from the matrix are almost exclusively derived from the Kimmeridge Clay Formation (Riding, 2002); a high proportion of chalk and black flint clasts are from the Chalk Group (Table 5) (Lee, 2003); the heavy mineral composition of the sand fraction contains high opaque concentrations (mainly limonite) and apatite derived from ironstone horizons within Jurassic and Lower Cretaceous mudstones (Table 10) (Lee, 2003). These lithological properties demonstrate that the ice that deposited the Lowestoft Till Member entered the region from the west crossing the Fenland Basin (Kimmeridge Clay Formation) and Chalk escarpment. This is consistent with clast fabric and shear plane measurements from Corton and Pakefield, and other published sites (West & Donner, 1956; Perrin *et al*., 1979; Rose, 1992; Fish & Whiteman, 2001; Lee, 2003).

Walcott Till Member

In the North Walsham, Mundesley and Cromer districts, the basal member of the Lowestoft Formation is the Walcott Till Member which is equivalent to the Second Cromer Till of Banham (1968) or Walcott Diamicton of Lunkka (1994). The unit crops out in coastal sections between Happisburgh (TG 380313) and Cromer (TG 234414) where it reaches a maximum observed thickness of 1.6m. Its base is marked by a décollement surface upon Happisburgh Formation sediments or shallow marine Wroxham Crag deposits (Paston – Marl Point, Trimingham). It has also been mapped in the North Walsham district where it overlies the Corton Sand Member of the Happisburgh Formation and forms a mapping continuity with the Lowestoft Till Member of the Great Yarmouth and Lowestoft areas. It consists of an olive-grey (2.5Y 5/1) to olive-brown (2.5Y 4/3) silt-rich matrix-supported diamicton (Figure 6) that is largely massive in structure. It has a moderate calcium carbonate matrix content (Table 7) and has been interpreted as a subglacial till with clast fabric and shear plane measurements indicating ice flow from the northwest (Banham, 1968, 1988; Lunkka, 1994; Lee, 2003).

The till exhibits a broadly intermediate lithology between the Happisburgh Till Member and Lowestoft Till Member: broadly equal proportions of clasts derived from Cretaceous bedrock (chalk and black flint) and reworked Pleistocene deposits (vein quartz, quartzite, other types of flint) (Table 5) (Lee, 2003); a palynomorph association that contains Pliensbachian and Toarcian (Lower Jurassic) forms derived from the Whitby Mudstone Formation, in addition to Kimmeridgian forms from the Kimmeridge Clay Formation (Riding, 1999); heavy mineral composition that contains lower quantities of opaques and non-opaque minerals such as apatite typical of the Lowestoft Till Member, relative to higher proportions of amphibole, epidote and garnet characteristic of the Happisburgh Till Member (Table 10) (Lee, 2003). In addition the Walcott Till Member contains diagnostic lithologies unique to a British provenance including several *Gryphaea* shells derived from the Lower Lias (Jurassic), and clasts of Magnesian Limestone, Carboniferous Limestone and palynomorphs from Viséan to Westphalian strata.

Oulton Clay Member

The Oulton Clay Member (Oulton Beds of Banham (1971)) rests conformably upon the upper surface of the Lowestoft Till Member beneath Corton Woods (TM 546987) where it locally crops out and reaches a maximum observed thickness of 2.2m. It is composed of horizontally-laminated light grey (2.5Y 7/2) sandy silts and grey (5Y 5/1) clays with occasional isolated light grey (2.5Y 7/1) sand lenses. It has been interpreted as a localised glaciolacustrine deposit (Pointon, 1978; Bridge & Hopson, 1985).

Pleasure Gardens Till Member (PTM)

Cropping-out above the Oulton Clay Member beneath Corton Woods (TM 546987) is a second highly localised unit, the Pleasure Gardens Till Member. The unit is up to 0.9m thick and consists of a contorted melange of Lowestoft Till Member and Ostend Member material. It has been interpreted as a flow till (Banham, 1971; Pointon, 1978). Deformation structures within the till are considered to represent sub-horizontal mixing during flow, and load-induced dewatering.

Aldeby Sand and Gravel Member

The Aldeby Sand and Gravel Member is a chalk-rich glaciofluvial sand and gravel (Table 8) derived from the ice sheet that deposited the Lowestoft Till Member. It crops out locally at Aldeby TM (459928), Leet Hill (TM 384962) and Scratby (TG 415156) and was called the Aldeby Sands and Gravels by Rose et al. (1999a).

Sheringham Cliffs Formation

The stratotype for the Sheringham Cliffs Formation is the coastal sections between West Runton (TG 1843) and Skelding Hill (TG 1443) to the west of Sheringham. Sheringham Cliffs Formation sediments correspond to the ‘Third Cromer Till’ of Banham (1968), the highly calcareous till or ‘Marly Drift’ of the Cromer area, and all associated outwash deposits (Table 11). They are exposed in coastal sections between Bacton Green (TG 334350) and Weybourne (TG 1143) and have been mapped extensively inland (Figures 3, 4 and 5).

Three tills are recognised within the West Runton and Sheringham area (Figure 5). The lower two tills are the Runton and Bacton Green Till members (Lee, 2003; Pawley *et al*., 2004) and these record a transition from subglacial to subaqueous styles of sedimentation. Eastwards towards Sheringham and Weybourne, these tills are truncated, and in places have been incorporated subglacially into the Weybourne Town Till Member (Lee, 2003; Pawley *et* *al*., 2004). This style of remobilisation and inter-mixing of the separate till units indicates that the Runton and Bacton Green Till members were still relatively water-saturated when the Weybourne Town Till Member was deposited, suggesting that all three tills were laid-down during one glacial episode (Pawley *et al*., 2004).

Mundesley Sand Member

The basal lithofacies of the Sheringham Cliffs Formation is the Mundesley Sand Member (Mundesley Sands of Banham, 1968), which rests upon the upper eroded surface of the Walcott Till Member in north Norfolk. It reaches a maximum thickness of 9m and consists of dull yellow-orange (10YR 6/3) to dull yellowish brown (10YR 5/4) stratified sands with a high abundance of detrital chalk grains within the basal few metres. Typical bedding structures include planar cross-bedding, massive bedding, horizontal bedding, climbing ripples (types A and B) and several horizons of convolute bedding. A distinctive feature of these sands is their high opaque heavy mineral concentrations – typically in the order of 60% (Table 12). They are interpreted as glaciodeltaic in origin on the basis of sedimentology and lithology. The member crops out in coastal sections between Paston (TG 325356) and Trimingham (TG 293383), from where it thins northwards towards Trimingham (TG 277392) before pinching-out beneath the Ivy Farm Laminated Silt Member at Sidestrand (TG 265398).

Ivy Farm Laminated Silt Member

The Ivy Farm Laminated Silt Member rests conformably upon the Walcott Till Member at Sidestrand (TG 268397) although towards Trimingham, these two deposits are separated by the Mundesley Sand Member. The true thickness of the member cannot be measured directly since it is truncated by several large-scale basal shear planes, however reconstructions of the undeformed profile suggest an original thickness of at least 22m. Three distinctive facies assemblages are present. (1) A basal facies upto 6m thick, which consists of rhythmically-bedded dark grey (5Y 3/1) clays and light grey (2.5Y 7/2) silts that grade upwards into a white (5Y 8/2) to pale yellow (5Y 8/2) marl. Contacts between couplets are generally sharp although some gradational-types were noted. The facies is interpreted as an ice-distal glaciolacustrine deposit. (2) Resting upon the upper eroded surface of facies 1 is a 1-1.3m thick bed of horizontally bedded and rippled fine grained light grey (2.5Y 7/1) sand that is rich in zircon (Table 12). This facies probably represents a small delta deposit. (3) An upper rhythmically-bedded silt and clay, 16m thick, that is identical to facies 1 except that it does not grade into a marl. Deposition probably occurred within a distal glaciolacustrine environment by processes of background suspension settling of fines punctuated by small turbidity events.

Runton Till Member

The Runton Till Member equates to the diamicton that can be traced along the bottom of the cliffs from East Runton (TG 198428) to Sheringham (TG 169434). Previously, this has been equated to the Third Cromer Till and Contorted Drift (Banham, 1968, 1975) or Laminated Diamicton (Hart & Boutlon, 1991b; Roberts & Hart, 2000, 2004). It consists of a dark grey (10YR 4/1) to very dark greyish brown (2.5Y 3/2) matrix-supported diamicton that contains highly attenuated lenses and laminations of sand, chalk (including rafts) and Walcott Till Member material. The matrix calcium carbonate content is low (Table 7). Genetically, it is interpreted as a subglacial deformation till (Hart & Boulton, 1991a,b; Hart & Roberts, 1994; Roberts & Hart, 2000; Lee, 2003) although detailed examinations of laminae structures within the till, have led Roberts & Hart (2004) to conclude that prior to subglacial deformation, the primary origin for much of this deposit was subaqueous.

The particle size distribution is broadly similar to the tills of the Happisburgh Formation and the Bacton Green Till Member of the Sheringham Cliffs Formation (Figure 6). The heavy mineral composition is more similar to the Walcott Till Member of the Lowestoft Formation, however, supporting the concept that ‘Walcott-type’ material was being assimilated into the Runton Till (Table 12). Further supporting evidence is the derived palynomorph content of the till, which shows an assemblage devoid of associations that can be tied to specific Jurassic and Cretaceous lithologies (Riding, 2001a). The input of fresh materials is demonstrated by the presence of chalk and black flint (20.5%) (Table 5) from local chalk bedrock, and several soft, striated ironstone clasts that are derived from the Lower Cretaceous Speeton Clay Formation and the Jurassic Redcar Mudstone Formation (Riding, 2001a).

Bacton Green Till Member

The Bacton Green Till Member is a distinctive diamicton assemblage that can be mapped and identified in coastal sections throughout north Norfolk. From its Bacton Green stratotype (TG 334347), it can be traced westwards via Mundesley (TG 304376) to Trimingham (TG 286386) where it overlies the Mundesley Sand Member. Between Trimingham (TG 281388) and Overstrand (TG 259312) it rests upon the Ivy Farm Laminated Silt Member, whereas between East Runton (TG 197427) and Sheringham (TG 171434) it exhibits a gradational lower contact with the Runton Till Member. Throughout its outcrop, it consists of beds of dark yellowish sandy brown (10YR 4/4) to dark grey (5Y 5/1) matrix-supported diamicton (Figure 6) separated by beds of light grey (2.5Y 8/1) to light yellow (2.5Y 7/4) sand. Many of these sand bodies, which can be traced laterally over several tens of metres, exhibit internal lamination, dropstones, grading and large lens-shaped structures. The till member is interpreted as a subaqueous flow till based upon its gradational lower contact with the deltaic Mundesley Sand Member, the lateral continuity of beds, dropstone structures, and variations in texture and sorting. The presence of high-angle reverse and normal faults that cross-cut the deposit, plus intense zones of folding suggest that the deposit was tectonised following deposition.

Analysis of the lithological composition of the Bacton Green Till Member, formerly called the Third Cromer Till and Contorted Drift (Banham, 1968, 1975) or Mundesley Diamicton (Lunkka, 1994), reveals that it is similar in terms of particle size distribution, clast composition (Table 5), matrix calcium carbonate content (Table 7) and heavy mineralogy (Table 12) to the Happisburgh Formation. This supports previous analyses performed by Perrin *et al*. (1979). Derived palynomorphs include associations suggesting input from Whitby Mudstone Formation (Lower Jurassic), Kimmeridge Clay Formation (Upper Jurassic), Lower Spilsby Sandstone / Sandringham Sands (Portlandian) and Speeton Clay Formation (Lower Cretaceous), probably from the area of the Cleveland Basin (Riding, 2001b; Lee, 2003). No diagnostic Scandinavian lithologies were encountered during clast counts, instead the association of Magnesian Limestone, with clasts of Dalradian metasediments, basaltic porphyry, acid porphyry and Old Red Sandstone is typically British (Lee *et al*., 2002).

Trimingham Clay Member

The Trimingham Clay Member (Trimingham Clay Member of Lunkka, 1994) crops out locally between Trimingham (TG 281388) and Overstrand (TG 259312) where it exhibits a gradational lower contact with the Bacton Green Till Member. It is up to 2.2m thick, and consists of rhythmically-laminated dark grey (5Y 4/1) clays and light grey (2.5Y 4/1) silts which exhibit sharp contacts between couplets and consistent couplet thicknesses. These lithologies represent sedimentation within a distal glaciolacustrine environment where turbidity-current activity was low.

Trimingham Sand Member

The Trimingham Sand Member (Trimingham Sands of Lunkka, 1994) crops out locally between Trimingham (TG 281388) and Overstrand (TG 259312) and occupies small undulations incised into the upper surface of the Trimingham Clay Member. It is less than 30cm thick, and composed of horizontally-bedded and massive sand with occasional ripple structures. On the limited sedimentological evidence available, the Trimingham Sand Member probably represents a small glaciolacustrine delta.

Weybourne Town Till Member

The stratotype of the Weybourne Town Till Member is Weybourne Town Pit (TG 114431) and adjacent coastal sections at Weybourne (TG 114437). It consists of a highly calcareous silt- and chalk-rich matrix-supported diamicton (Figure 6) that was deposited subglacially by grounded ice (Ehlers *et al*., 1991; Fish et al., 2000; Lee, 2003; Pawley *et al*., 2004). The Weybourne Town Till Member corresponds to the ‘Cromer Till’ variant of the ‘Marly Drift’ that was defined by Perrin *et al.* (1979) on the basis of its lithological properties, and crops out in the Weybourne-Hanworth-Trimingham area. No stratigraphical association with other ‘Marly Drift’-type tills in the Glaven Valley and western Norfolk is made. In the Weybourne area, the diamicton is highly stratified, with highly attenuated and sheared inclusions of Runton Till Member and Bacton Green Till Member material (Lee, 2003; Pawley *et al*., 2004). Further south and east, in coastal sections to the north of West Runton, Trimingham (TG 269395 & TG 279389) and in trial pits in the Hanworth area (TG 204336), the till is massive and truncates underlying lithofacies without incorporating them (Lee, 2003). The till is distinguished by an abundance of chalk-derived clasts (83.6-92.8%) (Table 5) and high matrix calcium carbonate content (Table 7). Derived palynomorphs and microfossil associations indicate input of materials derived from Toarcian-age Whitby Mudstone Formation (Lower Jurassic), Kimmeridgian-age Kimmeridge Clay Formation (Upper Jurassic), and Santonian-Campanian and Campanian-Maastrichtian zones of the chalk from the present area of the sea floor to the north and northwest (Fish *et al*., 2000; Riding, 2001a). This supports evidence derived from the measurement of shear plane orientations, fold noses and clast fabrics which indicate a direction of ice flow from the northwest (Banham & Ranson, 1965; Fish *et al*., 2000; Lee, 2003; Pawley *et al*., 2004).

Runton Sand and Gravel Member

The Runton Sand and Gravel Member corresponds in part to the Gimingham Sands of Banham (1968) and crops out in the gravitational sag basins between East Runton (TG 198428) and Sheringham (TG 173433) where the deposit rests upon the Bacton Green Till Member, Weybourne Town Member, or a series of un-named localised glaciolacustrine marls. The member is composed of planar cross-bedded, rippled, channelised and horizontally-bedded yellow (2.5Y 7/8) to olive-brown (2.5Y 6/6) sands separated by beds of massive or cross-bedded gravel that were laid down within a proximal glaciofluvial drainage system. The flint content is low (81.8%) compared to other sand and gravel Lithofacies. There is a high content of far-travelled erratics (3.7%) including Carboniferous limestone, micaceous schist, quartz-schist, granodiorite, acid porphyry and andesite, typical of a Scottish source (Table 8). No diagnostic Scandinavian lithologies were observed.

BRITON'S LANE FORMATION

The stratotype for the Briton's Lane Formation is the Briton's Lane Quarry (TG 168415), Beeston Hill (TG 168434), Sheringham. The formation consists of several coarse-grained outwash lithofacies that truncate and drape pre-existing sediments in the Cromer and Mundesley districts (Table 13; Figures 3, 4, 5) – no *in-situ* till units have been identified to date, however thrusted slabs of till have been recognised within the Briton's Lane Sand and Gravel Member within the vicinity of Sheringham and Briton's Lane Quarry. Briton's Lane Formation outwash sediments were emplaced prior-to, during and immediately following a major episode of glaciotectonic deformation associated with an ice marginal oscillation into a thick sequence of pre-existing sediments. The glaciotectonic episode formed the push moraine element of the Cromer Ridge. Their relative arrangement is determined by their morpho- and tectono-stratigraphical relationship to one another and the tectonic episode that formed the Cromer Ridge push moraine. The deposits of the Briton's Lane Formation are separated from those of the underlying Sheringham Cliffs Formation by a distinctive unconformity that can be seen within cliff sections at Beeston Hill near Sheringham. At this locality, sands and gravels of the Briton's Lane Formation (Briton's Lane Sand and Gravel Member) form the upper most stratigraphic unit within the local succession and truncate both the Bacton Green

Till Member and the Runton Sand and Gravel Member (Sheringham Cliffs Formation) that occupy the sag-basins (Lee, 2003). This demonstrates the existence of a hiatus between the deposition of the Sheringham Cliffs and Briton's Lane formations, during which the former became consolidated. However, a more complex relationship between the two formations is revealed west of Sheringham (TG 145136 – TG 115437), where the Briton's Lane Sand and Gravel Member locally crops out within a younger set of sag-basins (Pawley *et al*., 2004). This suggests a polyphase history of sag-basin development in the Weybourne area and confirms the findings of Ehlers *et al*. (1991, fig.143) who recognised 'double sand basins'. The causes of this complexity are not fully understood, but are likely to involve local variations in groundwater conditions. Of critical importance is that the Briton's Lane Formation contains evidence at least in part, for a Scandinavian provenance (Briton's Lane Sand and Gravel Member).

Stow Hill Sand and Gravel Member

This member corresponds to the Stow Hill Sands and Gravels of Lunkka (1994) and part of the Gimingham Sands of Banham (1968). It rests unconformably upon the upper surface of the Bacton Green Till Member between Bacton Green (TG 338345) and Mundesley (TG 319361), and the Weybourne Town Till Member within large tectonically-controlled synclines between Trimingham (TG 279389) and Sidestrand (TG 265397). The member consists of beds of massive, matrix-supported gravel separated by thick beds of horizontally bedded sand which are interpreted as glaciofluvial outwash. A maximum thickness of 8m has been observed in the Trimingham area where the member is in places exposed in tectonically controlled basins. Inland, the unit forms the slightly elevated topography around Paston and the Bacton Gas Terminal. Up to 92.0% (90.1-92.0%) of the clast content is flint (mainly white, brown and chatter-marked types) with a subsidiary quartzose content (6.4-6.5%), which suggests a major input of material from pre-existing glaciogenic sediments (Table 8). A lithological feature that distinguishes the unit from other sand and gravel lithofacies within the Briton's Lane Formation is the lower amphibole content (18.5% ± 1.9) (Table 14). These sands and gravels were deposited before the widespread glaciotectonic deformation associated with the formation of the Cromer Ridge.

Beacon Hill Sand and Gravel Member

The Beacon Hill Sand and Gravel Member crops out in coastal sections between Marl Point (TG 292383) and Trimingham (TG 283388), and forms the elevated topography between the coast and Gimingham. Its stratotope location is Gimingham Quarry (TG 284384) on the southern outskirts of Trimingham. The lithofacies consists of shelly, cross-bedded and rippled sands with occasional flint-rich (85.7-87.6%) gravel seams. The quartzose content is between 10.3-12.5%, whilst far-travelled exotics are rare (<1%) but ubiquitous in all samples (Table 8). Palaeocurrent measurements indicate a localised direction of flow towards the south and southeast. The sands and gravels were deposited as proximal glaciofluvial outwash within a braided channel. Intraformational horizons of involutions ('drop-soils') and frost-crack features are present within the upper horizons at Gimingham Quarry. Structurally, the lower 5m of the sands and gravels at Gimingham Quarry exhibit steeply inclined bedding (towards the north) with bedding planes that lie parallel to the axial trace within a tight, inclined southwards-verging horizontal fold. These features indicate uni-axial compression and shortening associated with a stress application from the north, whilst the upper 7m of the sands are undeformed. These sands and gravels were therefore deposited during the glaciotectonic episode that formed the Cromer Ridge, with sedimentation continuing following the northwards retreat of the ice margin.

Briton's Lane Sand and Gravel Member

The Briton's Lane Sand and Gravel Member is the thickest (up to 40m) and most spatially extensive member of the Briton's Lane Formation and forms the elevated sections of the Cromer Ridge between the Glaven Valley in the west, the stratotype area of Beeston Regis, and coastal sections between Overstrand and Cromer to the east. The member also forms some of the large sand and gravel outliers between West Runton and Weybourne including Beeston Hill (TG 168434) and Skelding Hill (TG 147135) (Pawley *et al*., 2004), and has been traced as far southwards as the Hanworth area (TG 204336) where it has been recorded in trial pits (Lee, 2003). The sedimentology of the sands and gravels at Briton's Lane Quarry suggests that they accumulated as thick gravel sheets reflecting high-energy sheet-flow deposition. The environment was that of an ice-marginal fan complex that accreted around a pre-existing thrust-stacked ridge of Bacton Green Till Member, with palaeocurrent directions indicating flow between the north and southeast. The lithology is distinctive due to the high flint content (84.5-88.6%) of which the majority is non-chatter-marked (77.7-84.5%), plus the presence of a mixed erratic assemblage comprising clasts of British and Scandinavian provenance (Table 8). Although trace quantities of Scandinavian lithologies were identified within quantitative counts, the majority were found as large cobble-sized erratics. Sedimentary erratics include both Old and New Red Sandstone; metamorphic erratics include quartz schist, graphite schist, micaceous schist and gneiss, migmatite; igneous erratics include rhyolitic tuff, basaltic porphyry, biotite-muscovite granite, andesite, quartz pegmatite, quartz and olivine dolerite, quartz diorite, feldspathic porphyry, rhomb porphyry, acid porphyry and monzo-diorite (Moorlock *et al*., 2000; Lee, 2003). Of critical importance is the first appearance of metamorphic supracrustals such as gneiss and the high temperature / high pressure migmatites, plus the quartz pegmatites and the rhomb porphyry that are distinctive of southern and central Norway (Lee *et al*., 2002).

Corton Woods Sand and Gravel Member?

The Corton Woods Sand and Gravel Member corresponds to the Plateau Gravels of Banham (1971) and Pointon (1978), and form the elevated plateau adjacent to Corton (TM 546987) where thicknesses up to 6m can be observed in coastal sections. The sands and gravels are placed within the Briton’s Lane Formation since they exhibit a similar geomorphological relationship to underlying deposits as those in northeast Norfolk. However a lithostratigraphical link between the Corton Woods Sand and Gravel Member and lithofacies in northeast Norfolk cannot by demonstrated and its inclusion within the Briton’s Lane Formation is, therefore, tentative. Bridge and Hopson (1985) in their study of the Waveney Valley concluded that the Corton Woods Sand and Gravel Member did not relate to the Lowestoft Formation. The lithofacies consists of beds of matrix-supported horizontally-bedded flint-rich (82%) gravel (Table 8) separated by beds and lenses of sorted pale yellow (2.5Y 8/4) sand. A distinctive feature of the heavy mineral composition is the mica non-opaque content (7.9% ± 4.3) which is almost exclusively glauconite, and a high but variable zircon (24.3±11.1) content (Table 14).

CRITICAL STRATIGRAPHICAL ISSUES

As stated previously, the emphasis of this paper is not just to construct a robust stratigraphy for the region, but to use the data which underpins the stratigraphy to test some of the widely-accepted models of the glacial history. Several of these issues are discussed briefly below.

Usage of the term ‘North Sea Drift’

The term 'North Sea Drift' has been abandoned as a stratigraphical term since it does not conform to appropriate stratigraphical protocols (Salvador, 1994). Specifically, a stratigraphical qualifier (i.e. North Sea) should not relate to the provenance of the sediment, but should be chosen to represent a critical site or localised area where deposits from this stratigraphical sub-division can be observed (Hamblin et al., 2001). Within the stratigraphical scheme proposed here, all glacial deposits are assigned qualifiers relating to localities and areas where these deposits can be observed in stratigraphical position.

Usage of the terms 'Norwich Brickearth', 'Contorted Drift' and 'Marly Drift'

Usage of 'Norwich Brickearth', 'Contorted Drift' and 'Marly Drift' within the new stratigraphical scheme has also been discontinued. All of these names were originally introduced simply as descriptive terms but were then erroneously adopted as formal stratigraphical terms.

The term 'Norwich Brickearth' was originally introduced to define a series of brown sandy diamictons that crop out throughout the study area and adjacent Norwich district (Cox & Nickless, 1972; Perrin *et al*., 1979), and have in places been pedogenically modified (Rose *et al*., 1999b). Both the Corton Till and the Bacton Green Till members defined here have previously been assimilated and stratigraphicalally united under the banner 'Norwich Brickearth', however both field mapping and sections from the north Norfolk coast demonstrate that they are two distinctive till units separated by the Lowestoft Formation.

The 'Contorted Drift' term was employed by Banham (1975, 1988) to describe a heterogeneous sequence of sediments in north Norfolk that exhibited a complex, polyphase, accretional history. However, it should be noted that this term includes a wide range of deposits in north Norfolk deposited and / or deformed by a variety of mechanisms: the structure of the Bacton Green Till Member is a function of the nature of sedimentary deposition (Lunkka, 1994; Lee, 2003) whereas that of the Runton Till Member is a function of subglacial glaciotectonic deformation (Roberts & Hart, 2000). The complex structure seen in coastal sections at Trimingham, the thickened till sequence within the Britons Lane Quarry borehole, and minor compressional overprints to deposits at other localities, are features caused by ice-marginal thrusting (Hart, 1990).

The term 'Marly Drift' is a term that has been used in relation to the highly chalky diamictons of north Norfolk (Perrin *et al*., 1979; Ehlers *et al*., 1987). Within the Cromer district the chalky diamicton corresponds to the Weybourne Town Till Member, however it is unclear at present how this relates stratigraphically to highly chalky tills within the Glaven Valley and west Norfolk. The possibility that there are several highly chalky tills in northern Norfolk, occurring in different stratigraphical positions and relating to different glacial episodes cannot be discounted.

Scandinavian provenance of the 'North Sea Drift' group of sediments

Analysis of clast lithologies and derived palynomorphs from the tills of the 'North Sea Drift' (i.e. Happisburgh Till Member and Corton Till Member; Walcott Till Member; Runton Till Member and Bacton Green Till Member) demonstrates that they were actually deposited by British ice flowing down the present North Sea coast of England (Lee et al., 2002; Lee, 2003) rather than from Scandinavian ice as previously considered (Bowen et al., 1986; Ehlers & Gibbard, 1991; Lunkka, 1994). Critical evidence includes:

- Absence of diagnostic Scandinavian lithologies such as rhomb porphyry, larvikite and high grade gneisses and high temperature / high pressure supracrustal lithologies (Lee et al., 2002);
- The presence of certain lithologies that are unique to Britain - especially Carboniferous Limestone and coal, Carboniferous palynomorphs; and Magnesian Limestone.

Only the Briton's Lane Sand and Gravel Member, which forms part of the youngest stratigraphical assemblage in the area – the Briton's Lane Formation, shows any evidence of a Scandinavian provenance. The Scandinavian detrital component comprises numerous clasts of rhomb porphyry, high-grade gneisses and various supracrustal lithologies, although these are mixed with more numerous erratics of British provenance (Moorlock *et al.*, 2000). Previously, such occurrences of Scandinavian lithologies, and in particular rhomb porphyry, were found on local beach foreshores (adjacent to outcrops of the Briton's Lane Sand and Gravel Member), or within ploughed fields, rather than as *in situ* occurrences within sections (Moorlock et al., 2001). It is also a problem that acid porphyries derived from the Midland Valley of Scotland were mis-identified as Scandinavian rhomb porphyry.

Re-definition of the 'Lowestoft Formation'

The redefinition of the 'Lowestoft Formation' presented here essentially follows Bowen (1999), but differs in that the Walcott Till Member (formerly Second Cromer Till or Walcott

Diamicton of the North Sea Drift) has been reassigned to the Lowestoft Formation and is stratigraphically equivalent to the Lowestoft Till Member (Table 3).

Within previous stratigraphical models, the Lowestoft Till and Walcott Till members were considered to have been deposited by co-existing British and Scandinavian Ice Sheets respectively, with the absence of Lowestoft Till in northeast Norfolk explained by the presence of Scandinavian ice in the region (depositing the North Sea Drift) that blocked the eastwards expansion of the British Ice Sheet into the north of the region (Perrin et al., 1979; Bowen et al., 1986; Rose, 1992; Fish & Whiteman, 2001). However, lithological and structural analyses of the tills of northeast Norfolk presented here and within Lee (2003) and Lee et al. (2002) (see 'Scandinavian provenance of the 'North Sea Drift' group of sediments' earlier within this section for a summary) demonstrate that these tills are of British provenance, and that the Scandinavian Ice Sheet was not actually present within the region during the deposition of the Lowestoft Till Member.

The reconstruction of the ice flow path that deposited the Lowestoft Till Member as defined within this paper, is in accord with other published evidence (West & Donner, 1956; Perrin *et al*., 1979; Rose, 1992; Fish & Whiteman, 2001), and demonstrates British ice crossing first the Kimmeridgian (Jurassic) mudstones and then the Chalk in the area of the Fenland Basin before flowing broadly westwards over northern East Anglia. Glaciodynamics would also require an additional component of more eastern ice flowing broadly southwards from the Yorkshire Basin into northern Norfolk. A till in northern Norfolk deposited by these ice flow dynamics would contain a mixture of Jurassic and Cretaceous lithologies derived from the Yorkshire Basin (including Whitby and Redcar mudstones, Kimmeridge Clay and Speeton Clay), and Cretaceous Chalk and pre-existing Quaternary sediments derived from the floor of the North Sea and northern Norfolk.

All of the tills in northeast Norfolk were deposited by ice with this flow trajectory, however stratigraphically, the Walcott Till Member is the first available till within the succession that could correlate with the Lowestoft Till Member. This is because the Corton Till Member of the Happisburgh Formation underlies both the Walcott Till and Lowestoft Till members throughout northeast Norfolk and the Waveney Valley respectively, and in addition, are separated by the lithologically-distinctive Corton Sand Member. The concept that the Lowestoft and Walcott Till members form part of the same till sheet presented here, is further supported by the field mapping between, since nowhere are the two tills seen in superposition. In summary, all of the available stratigraphical, mapping, structural and lithological evidence suggests that the Lowestoft Till and Walcott Till members were deposited from a single ice sheet. Thus the compositional differences between the two tills simply reflect different parts of this ice sheet flowing over, and entraining, different outcropping bedrock and superficial lithologies

The Weybourne Town Member (formerly Marly Drift) of this study area does not pass laterally into the Lowestoft Till Member (i.e. Perrin *et al*., 1979; Ehlers *et al*., 1991; Rose, 1992; Fish & Whiteman, 2001), but is instead separated from the Lowestoft Formation by a major disconformity and the Mundesley Sand, Ivy Farm Laminated Silt, Runton Till, Bacton Green Till, Trimingham Sand and Trimingham Clay members of the Sheringham Cliffs Formation (Lee, 2003; Pawley *et al*., 2004).

Significance of the 'Weybourne Town Till Member'

The significance of the Weybourne Town Till Member is that it represents the first stage during the glacial evolution of northern East Anglia, where pre-existing sediment cover had been removed from the Chalk surface in the present offshore area between Norfolk and Lincolnshire. During this and subsequent ice advances into northern Norfolk, ice sheets were largely flowing over and recycling predominantly chalk with minor quantities of sea-bed sediments. This would suggest that a local change in ice flow behaviour might have occurred because of a switch in the subglacial regime (i.e. drainage, rheology etc) from one that is soft-sediment controlled, to one that is locally bedrock dominated.

CONCLUSIONS

The new model for the glacial stratigraphy of the Lowestoft, Great Yarmouth, North Walsham and Cromer districts embodies four separate formations – these are the Happisburgh Formation, Lowestoft Formation, Sheringham Cliffs Formation and Briton's Lane Formation. This terminology is based upon detailed scientific evidence, but is sufficiently flexible to enable future stratigraphical discoveries to be incorporated. Geological investigations in adjacent parts of west and central Norfolk are presently on-going and it is anticipated that similar papers on these areas will be presented in the future within the Bulletin.

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Figure 1. Location of sites referred to within the paper and British Geological Survey 1:50,000 map coverage of the region. Note that this paper only covers the eastern half of Cromer sheet (Sheet 131) sited to the east of the Glaven Valley. The stratigraphy of the Glaven Valley and Holt area in the western sector of the Cromer sheet, plus that of the adjoining Wells Sheet, is currently being investigated by the authors and is beyond the scope of this paper.

Figure 2. Glacial stratigraphy of the Lowestoft, Great Yarmouth, North Walsham and Cromer districts. A – Previous stratigraphical model (based on Banham, 1968, 1971) showing the relationship between major till and sand and gravel lithofacies of the North Sea Drift (NSDF) and Lowestoft formations (LFM) in the Waveney Valley and northeast Norfolk. B – New stratigraphical model showing the re-defined major till and sand and gravel members and formations (HFM – Happisburgh Formation; LFM – Lowestoft Formation; SCFM – Sheringham Cliffs Formation; BLFM – Briton’s Lane Formation). Note that each major

lithostratigraphical unit within ‘A’ is assigned a number which corresponds to newly named members within ‘B’. Arrows indicate major discontinuities / erosion inferred from mapping.

Figure 3. Geological map of the study area adapted from 1:50,000 sheets Lowestoft (176), Great Yarmouth (162), North Walsham (148), Mundesley (132) and Cromer (131) showing the distribution of the Happisburgh, Lowestoft, Sheringham Cliffs and Briton’s Lane formations.

Figure 4. Cross section of coastal sections between Pakefield and Corton in the Waveney Valley, and Cart Gap and Weybourne in north Norfolk. Shown are the major structural elements, and the distribution of the Happisburgh, Lowestoft, Sheringham Cliffs and Briton’s Lane formations.

Figure 5. A series of composite stratigraphical logs (not to scale) from key sections and boreholes in the study area showing the distribution of members and formations. Abbreviations to stratigraphical terms – formations: HFm – Happisburgh Formation; LFm – Lowestoft Formation; SCFm – Sheringham Cliffs Formation; BLFm – Briton’s Lane Formation. Abbreviations to stratigraphical terms: HTM – Happisburgh Till Member; OCM – Ostend Clay Member; HSM – Happisburgh Sand Member; CTM – Corton Till Member; LHM – Leet Hill Sand and Gravel Member; CSM – Corton Sand Member; CaM – California Till Member; LTM – Lowestoft Till Member; WTM – Walcott Till Member; OM – Oulton Clay Member; PTM – Pleasure Gardens Till Member; AM – Aldeby Sand and Gravel Member; MSM – Mundesley Sand Member; IM – Ivy Farm Laminated Silt Member; RTM – Runton Till Member; BTM – Bacton Green Till Member; TCM – Trimingham Clay Member; TSM – Trimingham Sand Member; WM – Weybourne Town Till Member; RGM – Runton Sand and Gravel Member; SHM – Stow Hill Sand and Gravel Member; BHM – Beacon Hill Sand and Gravel Member; BLM – Briton’s Lane Sand and Gravel Member; CWM – Corton Woods Sand and Gravel Member.

Figure 6. Ternary diagram showing the particle size properties of the matrix (sand-silt-clay) of the till units within the study area. Measurement involved a combination of wet and dry sieving for the >63μm sand fraction and by the Sedigraph method for the <63μm silt and clay fractions.

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Table 3. Early-Middle and Middle Pleistocene lithostratigraphy of glacial sediments in the areas of Lowestoft, Great Yarmouth, North Walsham and Cromer. Stratotype areas and general lithofacies descriptions of each of the lithostratigraphical units are also shown.

Table 4. Stratigraphical summary table showing the members of the Happisburgh Formation. Abbreviations to sources for previous stratigraphical terms: [1]Blake (1890), [2]Arthurton et al. (1994), [3]Hopson & Bridge (1987), [4]Rose et al. (1999, 2002), [5]Lunkka (1994), [6]Banham (1968).

Table 5. Clast content of the till members within the study area. Clast counts were performed on the 4-8mm gravel fraction. Expansion of clast lithology headings: Reworked Pleistocene – brown and white flint, vein quartz, chatter-marked flint, quartzose lithologies, *Rhaxella* chert, Carboniferous chert, Greensand chert, shell, wood; Cretaceous – chalk, black flint, Carstone, glauconitic sandstone; Jurassic – sandstone, limestone (including oolitic types), ironstone, shell; Permo-Triassic – red sandstone (brick red), evaporite, Magnesian limestone; Carboniferous – coal, limestone, ironstone; Devonian – red sandstone; Scottish crystalline – Dalradian metasediments, olivine and porphyritic basalt, acid porphyry, andesite, granitoids; Northern England / Scotland – quartz dolerite / basalt, Cheviot granite; Scandinavia – rhomb porphyry, larvikite, nordmarkite, high-grade metamorphic. Key to abbreviations: Ha – Happisburgh, T – Trimingham, Hn – Hanworth, C – Corton, Be – Beeston, WT – Weybourne Town Pit, WC – Weybourne Cliffs. Source: 1 – Lee (2003), 2 – Lee *et al*. (2002), 3 – Pawley *et al*. (2004).

Table 6. Mean heavy mineral composition (at one standard deviation) of units within the Happisburgh Formation. Analysis was performed on the 63-125µm fine sand fraction which

proved the most diagnostic sub-fraction on discriminating between units. Heavy mineral separation and counting were undertaken using standard procedures (Gale & Hoare, 1991), with between 500-700 grains counted per sample.

Table 7. Calcium carbonate content of the matrix from the major till units.

Table 8. Lithological composition of outwash gravels. The 8-16mm size fraction prove the most diagnostic in terms of quantifying bulk lithology however many of the diagnostic lithologies used for provenancing are cobble-sized clasts. Abbreviation of Source: LH – Leet Hill, NS – Norton Subcourse, C – Corton, PA – Pakefield, WR – West Runton, SD – Sidestrand, PS – Paston, GQ – Gimingham Quarry, Trimingham, HA – Hanworth, BH – Beeston Hill, BL – Britons Lane, WC – Weybourne Cliffs, 1 – from Lee (2003), 2 – from Rose et al. (1999), 3 – from Pawley et al. (2004). * indicates aggregate values from multiple samples.

Table 9. Stratigraphical summary table showing the members of the Lowestoft Formation. Abbreviations to sources for previous stratigraphical terms: [1]Rose *et al*. (1999, 2002), [2]Arthurton et al. (1994), [3]Hopson & Bridge (1987), [4]Baden-Powell (1948), [5]Lunkka (1994), [6]Banham (1968, 1971).

Table 10. Mean heavy mineral composition (at one standard deviation) of units within the Lowestoft Formation. Analysis was performed on the 63-125μm fine sand fraction.

Table 11. Stratigraphical summary table showing the members of the Lowestoft Formation. Abbreviations to sources for previous stratigraphical terms: [1]Banham (1968), [2]Lunkka (1994), [3]Hart (1992) / Hart & Boulton (1991a).

Table 12. Mean heavy mineral composition (at one standard deviation) of units within the Sheringham Cliffs Formation. Analysis was performed on the 63-125μm fine sand fraction.

Table 13. Stratigraphical summary table showing the members of the Briton's Lane Formation. Abbreviations to sources for previous stratigraphical terms: [1]Banham. (1968, 1971), [2]Lunkka (1994), [3]Arthurton *et al*. (1994).

Table 14. Mean heavy mineral composition (at one standard deviation) of units within the Briton's Lane Formation. Analysis was performed on the 63-125μm fine sand fraction.

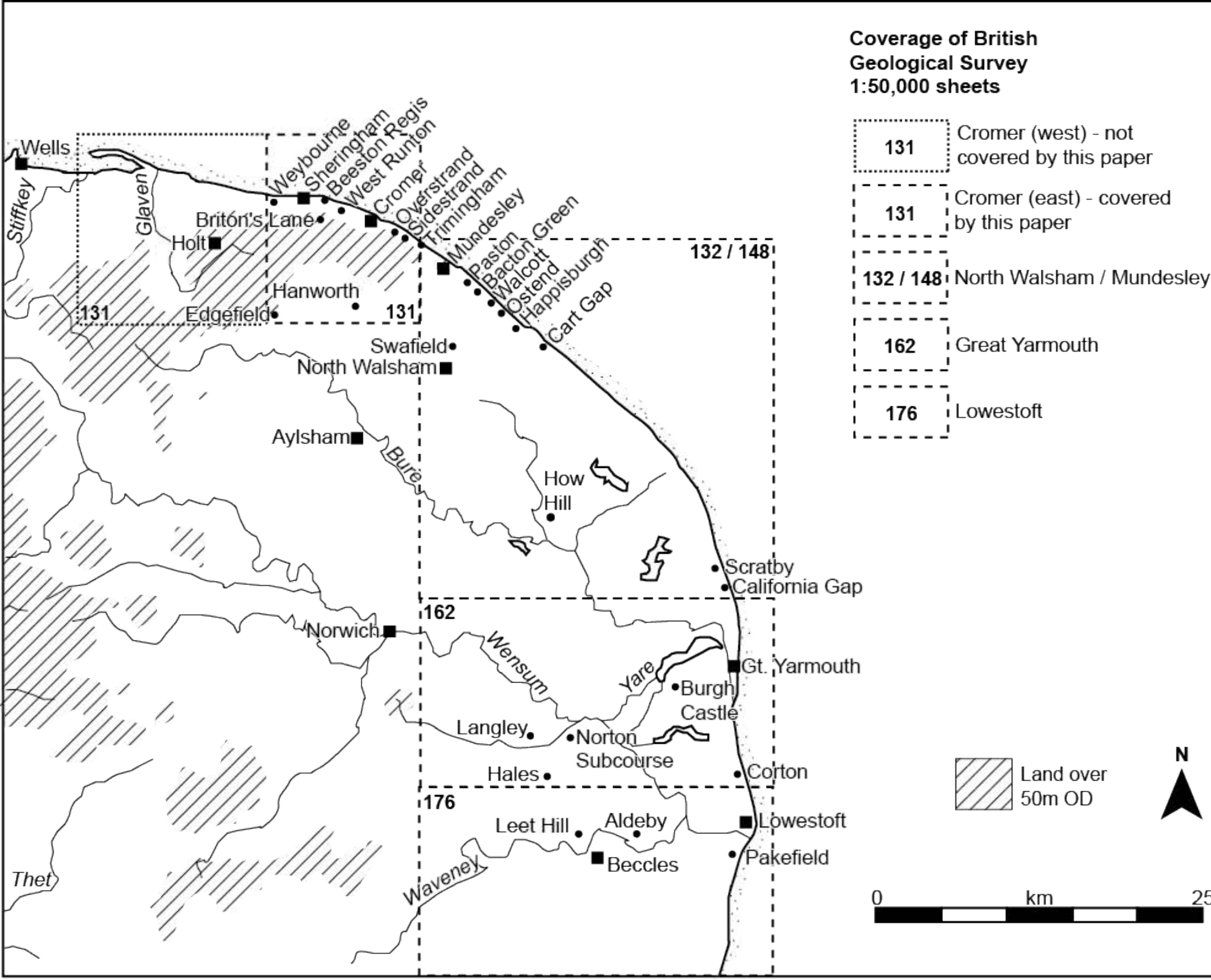
Coverage of British Geological Survey 1:50,000 sheets
131
Cromer (west) - not covered by this paper
131
Cromer (east) - covered by this paper
132 / 148
North Walsham / Mundesley
162
Great Yarmouth
176
Lowestoft
Land over 50m OD
N
0
km
25
Wells
Stiffkey
Glaven
Weybourne
Sheringham
Beeston Regis
West Runton
Cromer
Overstrand
Sidestrand
Trimingham
Mundesley
Paston
Bacton Green
Walcott
Ostend
Happisburgh
Cart Gap
Briton's Lane
Holt
Hanworth
Edgefield
131
131
132 / 148
Swafield
North Walsham
Aylsham
Bure
How Hill
Scratby
California Gap
162
Norwich
Wensum
Yare
Gt. Yarmouth
Burgh Castle
Langley
Norton Subcourse
Hales
Corton
176
Leet Hill
Aldeby
Lowestoft
Beccles
Pakefield
Waveney
Thet

FIGURE 1

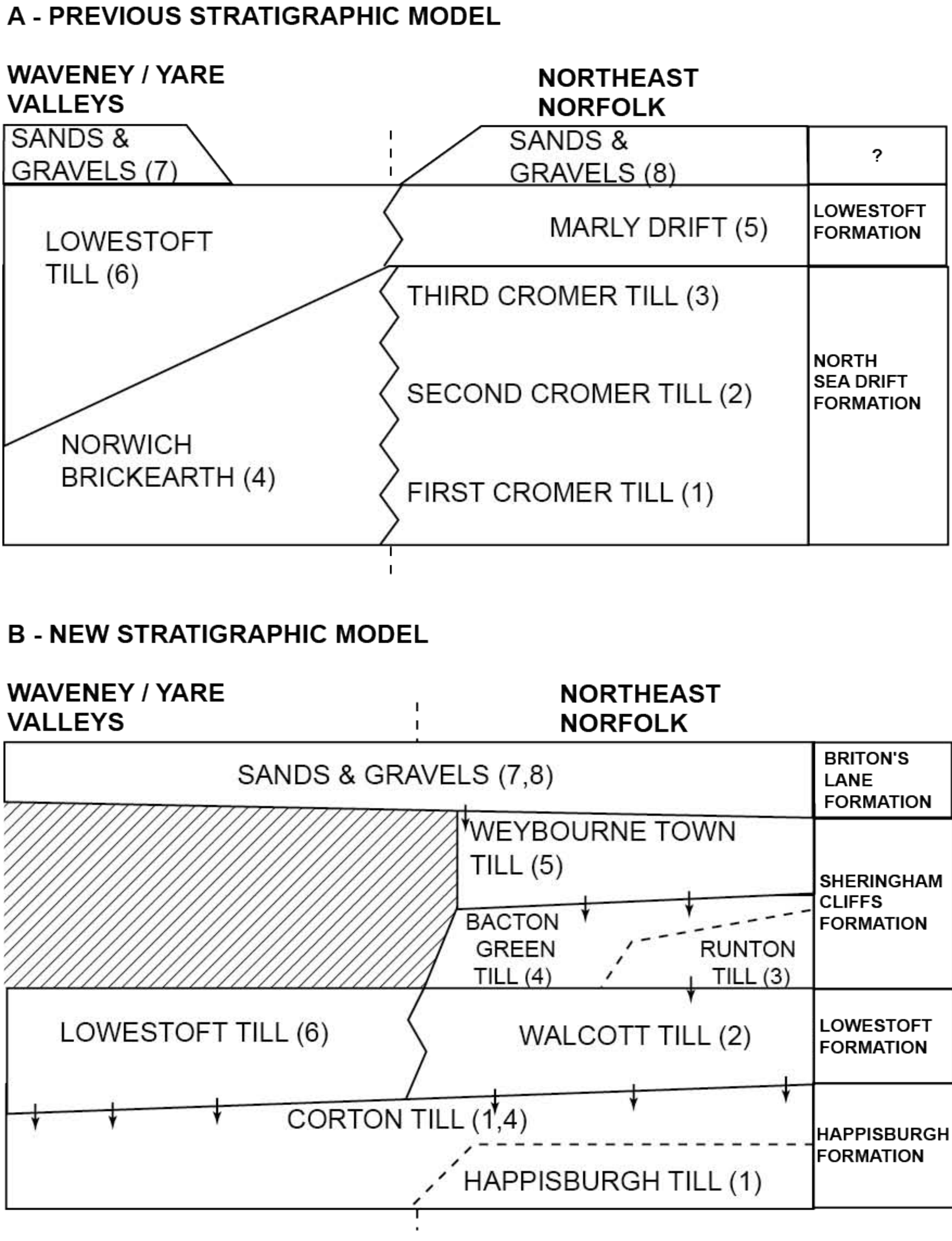
A - PREVIOUS STRATIGRAPHIC MODEL
WAVENEY / YARE VALLEYS
NORTHEAST NORFOLK
SANDS & GRAVELS (7)
SANDS & GRAVELS (8)
?
LOWESTOFT TILL (6)
MARLY DRIFT (5)
LOWESTOFT FORMATION
THIRD CROMER TILL (3)
SECOND CROMER TILL (2)
FIRST CROMER TILL (1)
NORWICH BRICKEARTH (4)
NORTH SEA DRIFT FORMATION
B - NEW STRATIGRAPHIC MODEL
WAVENEY / YARE VALLEYS
NORTHEAST NORFOLK
SANDS & GRAVELS (7,8)
BRITON'S LANE FORMATION
WEYBOURNE TOWN TILL (5)
BACTON GREEN TILL (4)
RUNTON TILL (3)
SHERINGHAM CLIFFS FORMATION
LOWESTOFT TILL (6)
WALCOTT TILL (2)
LOWESTOFT FORMATION
CORTON TILL (1,4)
HAPPISBURGH TILL (1)
HAPPISBURGH FORMATION

FIGURE 2

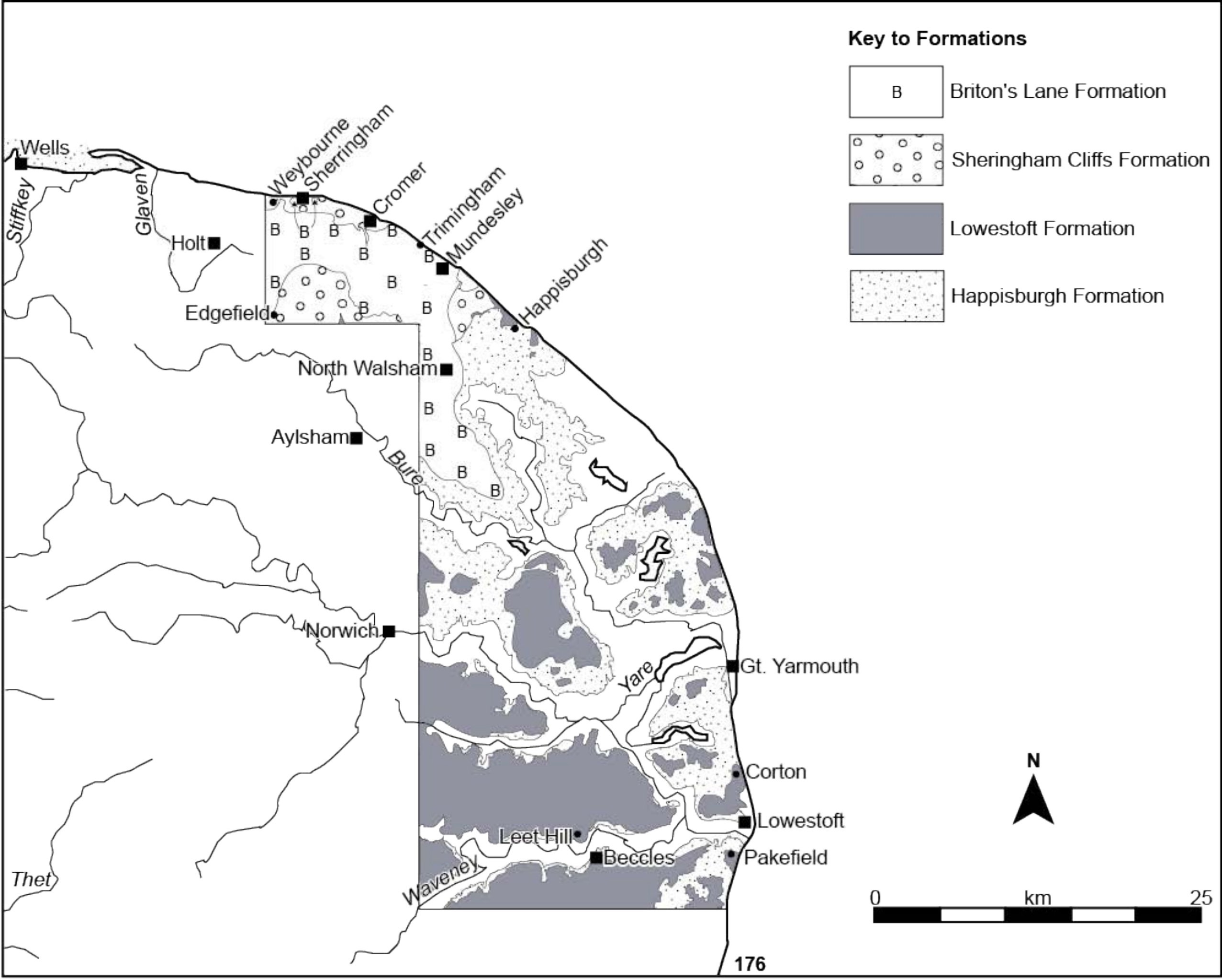
Key to Formations
B
Briton's Lane Formation
Sheringham Cliffs Formation
Lowestoft Formation
Happisburgh Formation
Wells
Stiffkey
Glaven
Holt
Weybourne
Sheringham
Cromer
Trimingham
Mundesley
Happisburgh
Edgefield
North Walsham
Aylsham
Bure
Norwich
Yare
Gt. Yarmouth
Corton
Lowestoft
Pakefield
Leet Hill
Beccles
Waveney
Thet
N
0
km
25
176

FIGURE 3

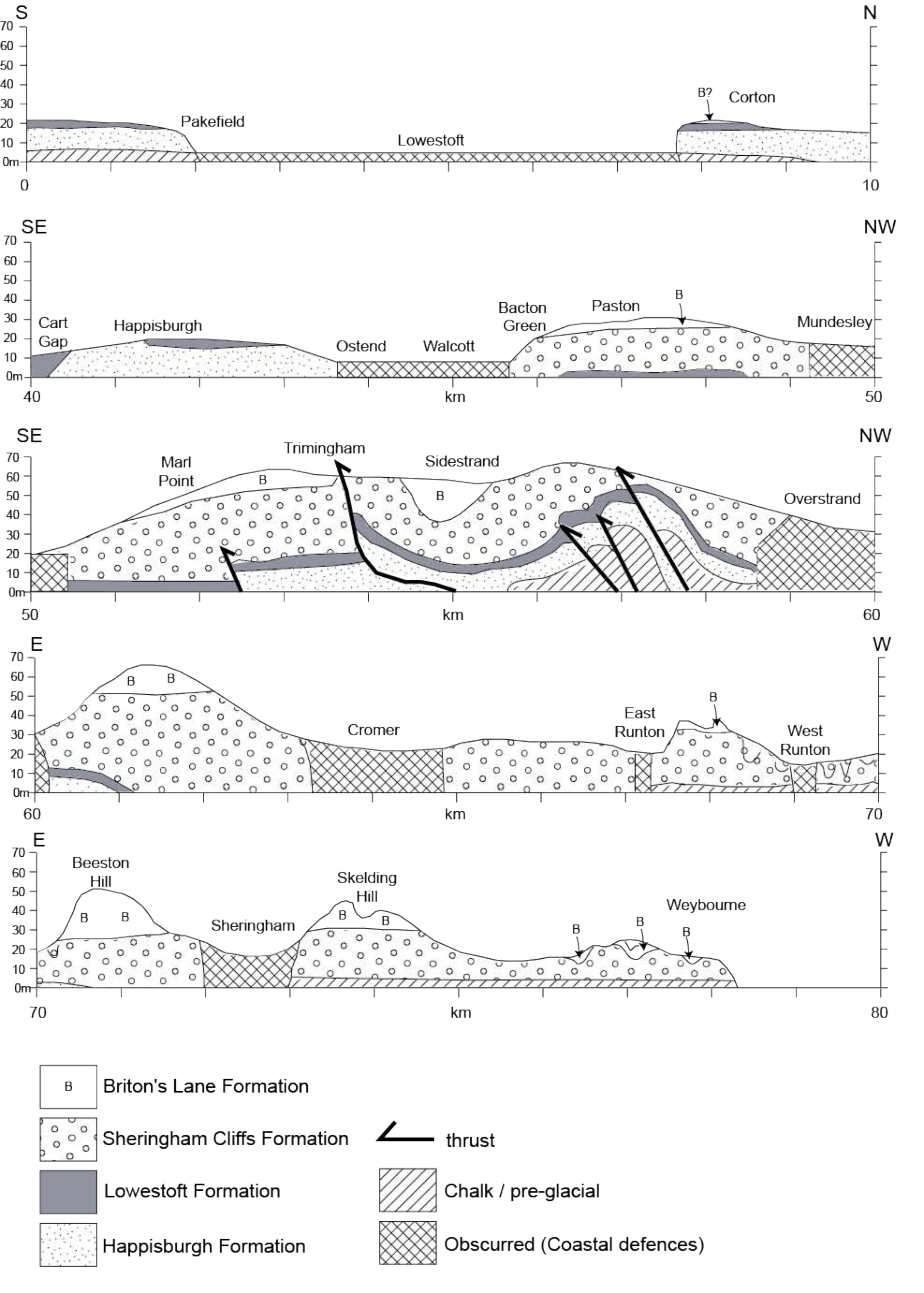
S
N
Pakefield
Lowestoft
B?
Corton
0
10
SE
NW
Cart Gap
Happisburgh
Ostend
Walcott
Bacton Green
Paston
B
Mundesley
40
km
50
SE
NW
Marl Point
B
Trimingham
Sidestrand
B
Overstrand
50
km
60
E
W
B
B
Cromer
East Runton
B
West Runton
60
km
70
E
W
Beeston Hill
B
B
Sheringham
Skelding Hill
B
B
B
B
B
Weybourne
70
km
80
70
60
50
40
30
20
10
0m
B
Briton's Lane Formation
Sheringham Cliffs Formation
Lowestoft Formation
Happisburgh Formation
thrust
Chalk / pre-glacial
Obscurred (Coastal defences)

FIGURE 4

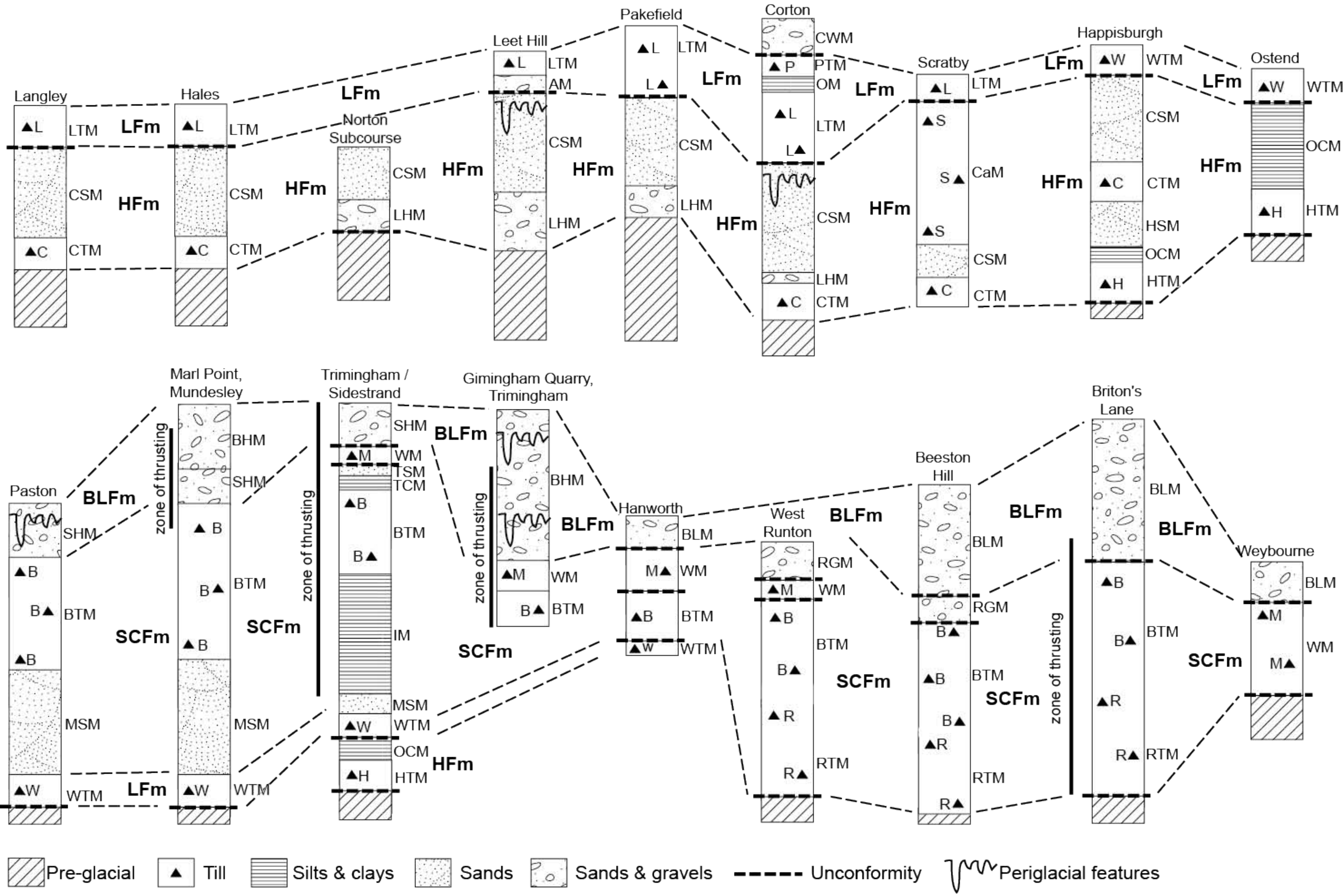
Langley
L
LTM
LFm
CSM
HFm
C
CTM
Hales
L
LTM
CSM
C
CTM
LFm
Norton Subcourse
CSM
LHM
HFm
Leet Hill
L
LTM
AM
CSM
LHM
HFm
Pakefield
L
LTM
L
CSM
LHM
HFm
LFm
Corton
CWM
P
PTM
OM
L
LTM
L
CSM
LHM
C
CTM
HFm
LFm
Scratby
L
LTM
S
S
CaM
S
CSM
C
CTM
HFm
LFm
Happisburgh
W
WTM
CSM
C
CTM
HSM
OCM
H
HTM
HFm
LFm
Ostend
W
WTM
OCM
H
HTM
HFm
LFm
Paston
SHM
B
B
BTM
B
MSM
W
WTM
BLFm
SCFm
LFm
Marl Point, Mundesley
zone of thrusting
BHM
SHM
B
B
BTM
B
MSM
W
WTM
SCFm
Trimingham / Sidestrand
zone of thrusting
SHM
M
WM
TSM
TCM
B
B
BTM
IM
MSM
W
WTM
OCM
H
HTM
HFm
Gimingham Quarry, Trimingham
zone of thrusting
BLFm
BHM
BLFm
M
WM
B
BTM
SCFm
Hanworth
BLM
M
WM
B
BTM
W
WTM
West Runton
RGM
M
WM
B
BTM
B
R
R
RTM
BLFm
SCFm
Beeston Hill
BLM
RGM
B
B
BTM
B
R
R
RTM
SCFm
BLFm
Briton's Lane
zone of thrusting
BLM
B
B
BTM
R
R
RTM
BLFm
Weybourne
BLM
M
M
WM
SCFm
Pre-glacial
Till
Silts & clays
Sands
Sands & gravels
Unconformity
Periglacial features

FIGURE 5

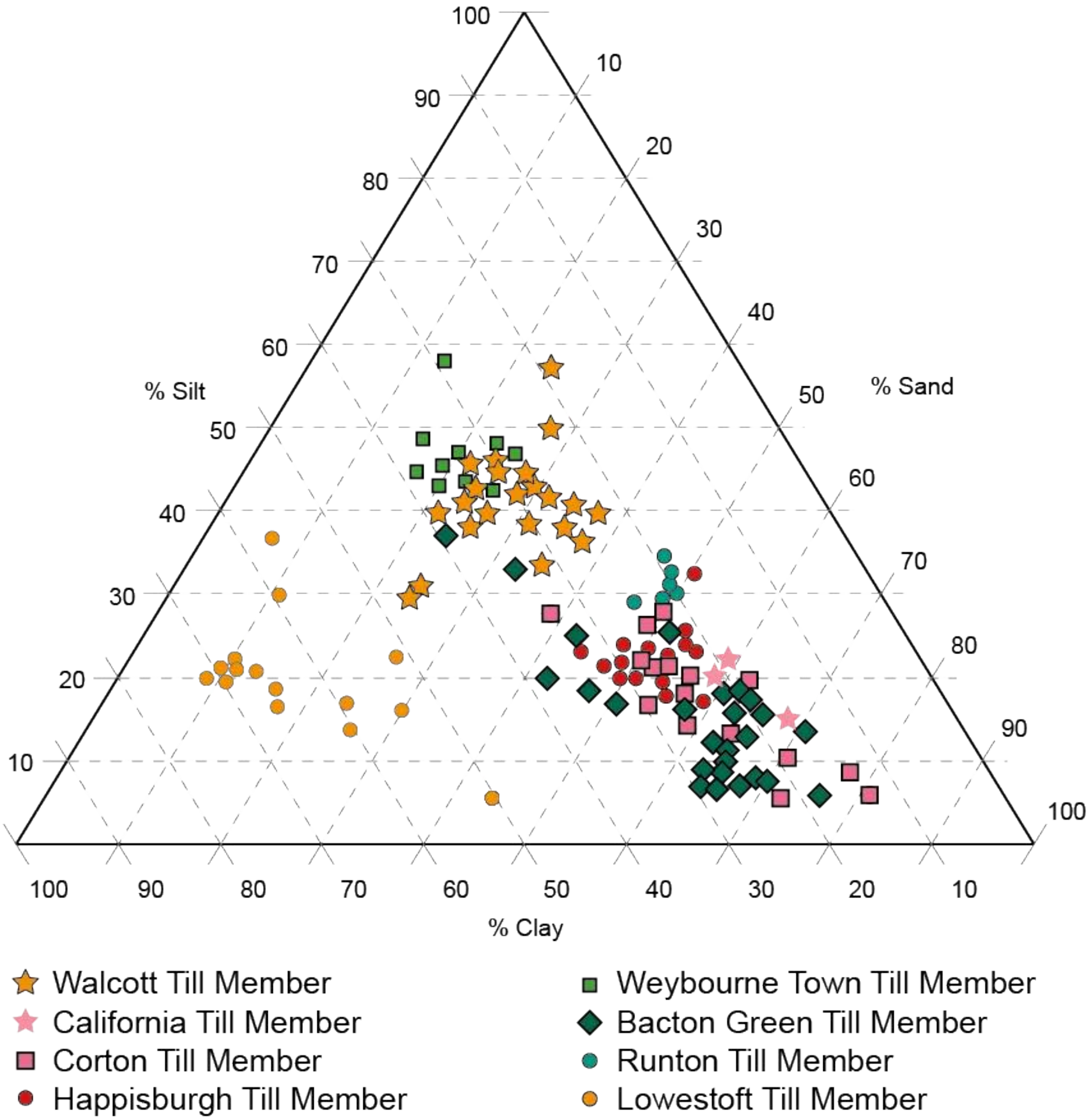
100
90
80
70
60
50
40
30
20
10
% Silt
10
20
30
40
50
60
70
80
90
100
% Sand
100
90
80
70
60
50
40
30
20
10
% Clay
Walcott Till Member
California Till Member
Corton Till Member
Happisburgh Till Member
Weybourne Town Till Member
Bacton Green Till Member
Runton Till Member
Lowestoft Till Member

FIGURE 6

REID (1882)	BANHAM (1968)	LUNKKA (1994)	
	Briton's Lane Sand & Gravels		NORTH SEA DRIFT FORMATION
Boulder Clay	Marly Drift	Marly Drift	LOWESTOFT FORMATION
Clays		Trimingham Sands & Clays	
Sands	Gimingham Sands	Stow Hill Sands	
Boulder Clay / stony loam	Third Cromer Till	Cromer & Mundesley diamictons	
Sands	Mundesley Sands	Upper Mundesley Sands	NORTH SEA DRIFT FORMATION
Second Till	Second Cromer Till	Walcott Diamicton	
Intermediate Beds	Intermediate Beds	Lower Mundesley Sands & Happisburgh Clays	
First Till	First Cromer Till	Happisburgh Diamicton	

TABLE 1

BANHAM (1971) POINTON (1978)	BRIDGE & HOPSON (1985)	
Plateau Sands and Gravels	Corton Woods Sands & Gravels	
Pleasure Gardens Till	Pleasure Gardens Till	LOWESTOFT FORMATION
Oulton Beds	Oulton Beds	
Lowestoft Till	Lowestoft Till	
Corton Beds	Corton Sands	NORTH SEA DRIFT FORMATION
	Leet Hill Sands and Gravels	
Cromer Till	Norwich Brickearth	

TABLE 2

LITHOSTRATIGRAPHY Formation / Member	STRATOTYPE AREA		LITHOFACIES
BRITON'S LANE FORMATION			
Briton's Lane Sand & Gravel Member	TG 168415	Briton's Lane, Beeston Regis	Ice-marginal fan complex
Corton Woods Sand & Gravel Member ??	TM 546987	Corton Woods, Corton	Proximal glaciofluvial outwash
Beacon Hill Sand & Gravel Member	TG 284384	Gimingham Quarry, Trimingham	Proximal glaciofluvial outwash
Stow Hill Sand & Gravel Member	TG 328353	Paston Cliffs	Proximal glaciofluvial outwash
SHERINGHAM CLIFFS FORMATION			
Runton Cliffs Sand & Gravel Member	TG 180432	Beeston Cliffs, West Runton	Proximal outwash
Weybourne Town Till Member	TG 114431	Weybourne Town Pit, Weybourne	Subglacial till assemblage – British ice advance from N / NW
Trimingham Sand Member	TG 266397	Trimingham	Local deltaic
Trimingham Clay Member	TG 266397	Trimingham	Low energy glaciolacustrine
Bacton Green Till Member	TG 334347	Bacton Green, Bacton	Subaqueous flow till – grades up from Runton Till Member
Runton Till Member	TG 180432	Beeston Cliffs, West Runton	Subglacial till – British ice advance from NW
Ivy Farm Laminated Silt Member	TG 268397	Sidestrand	Low energy glaciolacustrine
Mundesley Sand Member	TG 325356	Mundesley	Deltaic
LOWESTOFT FORMATION			
Aldeby Sand & Gravel Member	TM 384926	Aldeby	Proximal glaciofluvial outwash
Pleasure Gardens Till Member	TM 546987	Corton Woods, Corton	Flow till – subaqueous?
Oulton Clay Member	TM 546987	Corton Woods, Corton	Low energy glaciolacustrine
Walcott Till Member	TG 391304	Ostend	Subglacial till assemblage – British ice advance from NW
Lowestoft Till Member	TM 546987	Corton Woods, Corton	Subglacial till assemblage – British ice advance from W
HAPPISBURGH FORMATION			
California Till Member	TG 518149	California Gap	Subaqueous flow till
Corton Sand Member	TM 543979	Corton	Distal glaciofluvial outwash; locally tidal
Leet Hill Sand & Gravel Member	TM 384926	Leet Hill	Proximal glaciofluvial outwash
Corton Till Member	TM 543979	Corton	Subglacial till; subaqueous flow till and grounding-line fan
Happisburgh Sand Member	TG 388306	Happisburgh	Deltaic
Ostend Clay Member	TG 388306	Happisburgh	Low energy glaciolacustrine
Happisburgh Till Member	TG 389305	Happisburgh	Subglacial till assemblage – British ice advance from NW

TABLE 3

CALIFORNIA TILL MEMBER

Stratotype:	TG 518149 – California Gap
Lithofacies:	Stratified diamicton complex consisting of beds of sand (Corton Sand Member material) and brown sandy diamicton (Corton Till Member Material); fold noses and intra-formational sand lenses common
Lower contact:	Unknown
Thickness:	Maximum observed thickness of 13m at California Gap
Genesis:	Subaqueous flow till
Provenance:	British – based on association with Corton Till Member
Section outcrops:	Coastal sections between California Gap and Scratby
Previous stratigraphic terms:	None

CORTON SAND MEMBER

Stratotype:	TM 543979 – Corton Cliffs
Lithofacies:	Stratified sands with common comminuted chalk and shell grains; ice wedge casts and calcretes have also been recognised
Lower contact:	Erosive when overlying Corton Till Member, conformably when overlying Leet Hill Sand and Gravel Member
Thickness:	Commonly between 3-15m
Genesis:	Distal glaciofluvial outwash, tidal-influence in places
Provenance:	British
Section outcrops:	Coastal sections between Pakefield at Happisburgh
Previous stratigraphic terms:	[2,3]Corton Sands

LEET HILL SAND AND GRAVEL MEMBER

Stratotype:	TM 384926 – Leet Hill Quarry, Kirby Cane
Lithofacies:	Channelled and stratified sands and gravels that are rich in flint; common erratic lithologies of British provenance
Lower contact:	Conformable lower contact with underlying Bytham River deposits at stratotype; more commonly erosional contact with Corton Till Member and other pre-glacial sediments
Thickness:	Thickens westwards to upto 9m in the vicinity of the stratotype
Genesis:	Proximal glaciofluvial outwash
Provenance:	British
Section outcrops:	Coastal sections include Corton and Pakefield
Previous stratigraphic terms:	[4]Leet Hill Sands and Gravels

CORTON TILL MEMBER

Stratotype:	TM 543979 – Corton Cliffs
Lithofacies:	Brown and sandy flint-rich matrix-supported diamicton, can be either massive or faintly stratified
Lower contact:	Erosional
Thickness:	Between 0.6-3.2m
Genesis:	Variable – subglacial or subaqueous flow till
Provenance:	British
Section outcrops:	Corton, California Gap and Happisburgh
Previous stratigraphic terms:	[3]Norwich Brickearth, [2,4]Corton Till / Diamicton

HAPPISBURGH SAND MEMBER

Stratotype:	TG 388306 – Happisburgh Cliffs adjacent to lighthouse
Lithofacies:	Stratified sands with channel structures within upper horizons
Lower contact:	Erosional contact with the Ostend Clay Member
Thickness:	8m
Genesis:	Deltaic
Provenance:	-
Section outcrops:	Cliffs between Happisburgh Coastguard Station and Happisburgh lighthouse
Previous stratigraphic terms:	[5]Happisburgh Sands, [6]Intermediate Beds

OSTEND CLAY MEMBER

Stratotype:	TG 388306 – Happisburgh Cliffs adjacent to lighthouse
Lithofacies:	Stratified diamicton and sorted sediments occupying the troughs between ridges on the upper surface of the Happisburgh Till Member; grade upwards into rhythmically-bedded silts and clays with occasional ripples
Lower contact:	Conformable lower contact with Happisburgh Till Member
Thickness:	Maximum thickness of 3.5m
Genesis:	Initial deposition within small pools between till ridges, progressive expansion and coalescence into larger pools and an extensive glacial lake basin
Provenance:	-
Section outcrops:	Ostend cliffs southwards to Happisburgh lighthouse
Previous stratigraphic terms:	[5]Happisburgh Clays, [6]Intermediate Beds

HAPPISBURGH TILL MEMBER

Stratotype:	TG 389305 – Happisburgh Cliffs adjacent to lighthouse
Lithofacies:	Grey, massive matrix-supported diamicton with a sandy matrix texture and common flint and quartzose pebbles
Lower contact:	Erosive
Thickness:	2-7m
Genesis:	Subglacial deforming-bed till
Provenance:	British
Section outcrops:	Coastal sections between Happisburgh lighthouse and Ostend, and Marl Point Trimingham to Overstrand
Previous stratigraphic terms:	[6]First Cromer Till, [5]Happisburgh Diamicton

TABLE 4

Source	N	Reworked Sedimentary						Reworked Igneous and Metamorphic				
		Reworked Pleistocene	Cretaceous	Jurassic	Permo-Triassic	Carbonif-erous	Devonian	Scotland	N.England / Scotland	Scandinavia	Unknown	Unknown
SHERINGHAM CLIFFS FORMATION												
Weybourne Town Till Member												
T – 1	546	7.2	92.8	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0
WT - 1	1009	15.3	83.6	0.1	0.6	0.0	0.0	0.4	0.0	0.0	0.0	0.2
Bacton Green Till Member												
BG – 1	1824	75.0	16.7	2.0	1.8	0.0	0.0	2.3	0.2	0.0	0.0	1.8
T – 1	558	88.1	5.2	0.0	0.0	0.0	1.0	3.7	0.0	0.0	0.0	0.0
Be – 1	503	91.6	7.4	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.5
Runton Till Member												
Be – 1	1292	69.9	20.5	1.8	0.8	0.0	0.0	3.2	0.2	0.0	0.0	2.2
LOWESTOFT FORMATION												
Walcott Till Member												
Ha – 1	809	49.6	42.9	3.2	0.6	0.3	0.3	2.3	0.1	0.0	0.0	0.6
T – 1	893	39.0	59.8	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.2
Hn – 1	481	54.4	46.8	0.4	0.0	0.0	0.2	1.0	0.2	0.0	0.0	0.0
Lowestoft Till Member												
C – 1	3310	8.5	82.7	8.2	0.0	Tr	0.0	0.2	0.0	0.0	0.0	0.3
HAPPISBURGH FORMATION												
Corton Till Member												
Ha – 2	619	82.7	8.9	1.3	0.0	1.1	0.6	4.4	0.0	0.0	0.0	1.0
C – 2	1109	91.1	3.7	3.3	0.0	0.0	0.2	0.6	0.0	0.0	0.0	1.1
Happisburgh Till Member												
T – 2	769	68.1	22.8	1.7	0.4	0.4	0.4	3.5	0.8	0.0	0.0	2.1
Ha – 2	985	65.0	15.7	4.3	1.1	1.4	1.1	5.1	0.5	0.0	2.8	2.4

TABLE 5

	Happisburgh Till Member	Happisburgh Sand Member	Corton Till Member	Leet Hill Sand & Gravel Mem	Corton Sand Member	California Till Member
% Opaques	28.8 (2.3)	57.3 (7.9)	29.0 (3.1)	60.0 (8.6)	44.9 (9.8)	29.1 (2.3)
Non-opaques (% of total non-opaques)						
% Amphibole Group	40.2 (1.5)	32.8 (7.0)	39.5 (3.1)	31.8 (7.6)	39.3 (5.2)	38.4 (0.7)
% Apatite	2.7 (0.6)	1.9 (0.8)	1.6 (0.6)	7.2 (2.8)	1.7 (1.5)	1.5 (0.3)
% Epidote	23.7 (2.8)	21.6 (3.7)	23.4 (2.3)	18.2 (3.6)	22.1 (3.9)	23.0 (2.0)
% Garnet	15.6 (2.1)	21.4 (8.7)	17.4 (2.5)	17.3 (8.1)	18.3 (3.8)	18.7 (1.0)
% Kyanite	0.9 (0.4)	0.4 (0.4)	1.0 (0.4)	0.9 (0.9)	0.8 (0.6)	1.9 (0.4)
% Mica	1.5 (0.8)	2.2 (2.0)	1.9 (0.6)	2.3 (1.3)	1.8 (1.2)	3.3 (1.4)
% Pyroxene	3.4 (1.5)	2.0 (1.7)	1.3 (0.6)	2.7 (1.0)	1.4 (1.0)	1.9 (0.6)
% Rutile	0.8 (0.3)	2.8 (0.8)	1.3 (0.5)	1.5 (0.9)	1.4 (1.0)	0.9 (0.3)
% Staurolite	0.2 (0.2)	0.6 (0.2)	0.1 (0.1)	0.9 (0.6)	0.7 (0.6)	0.2 (0.2)
% Tourmaline	4.0 (1.0)	3.5 (1.0)	3.6 (1.4)	6.3 (2.5)	4.1 (1.9)	2.9 (0.6)
% Zircon	4.9 (1.5)	8.4 (1.9)	6.6 (2.2)	8.5 (5.0)	6.8 (3.6)	7.0 (1.3)
% Other	2.2 (0.8)	2.4 (1.5)	2.5 (0.8)	2.4 (1.1)	1.8 (1.3)	1.4 (0.2)
Number of samples	14	5	15	15	39	4

TABLE 6

	Mean % $CaCO_3$	**Number of samples**
Weybourne Town Till Member	68.7	11
Bacton Green Till Member	11.3	15
Runton Till Member	14.7	5
Lowestoft Till Member	32.1	20
Walcott Till Member	36.2	15
Corton Till Member	8.4	15
Happisburgh Till Member	12.3	14

TABLE 7

		Carb-onifer ous chert	**Triassic**				**Jurassic**			**Cretaceous**						**Tert-iary / Pleis.**		**Ign, Met, Sed**		
Source	n		Qtz-ite	vein qtz	schorl	**Total**	Rhax-ella Chert	sst, lst, irnst, shell	**Total**	sst, lst, irnst, shell	glauc-onitic sstn	Green-sand chert	Chalk	Flint	**Total**	ch. mkd flint	**Total Flint**	Scot / N'th-ern	Scand-inavia	**Unk-nown**
BRITONS LANE FORMATION																				
Briton's Lane Sand and Gravel Member																				
WC3	668	**0.7**	2.7	4.3	1.0	**8.0**	1.0	0.4	**1.4**	0.1	0.0	0.0	0.0	80.1	**80.2**	5.5	**85.6**	2.7	0.1	**0.7**
BL1	2141*	**0.1**	3.7	5.8	0.3	**9.7**	0.6	0.3	**0.9**	0.0	0.0	0.7	0.0	80.8	**81.5**	6.3	**87.1**	2.0	0.0	**0.0**
BL2	1863	**0.7**	8.2	1.5	0.6	**10.3**	1.3	0.0	**1.3**	5.6	0.0	0.0	0.0	57.0	**62.6**	19.9	**81.9**	4.7	0.1	**0.4**
HA1	872*	**0.0**	5.5	7.2	0.0	**12.7**	1.0	0.6	**1.6**	0.0	0.0	0.4	0.0	74.2	**74.6**	9.6	**83.8**	1.5	0.0	**0.0**
WR1	490	**0.0**	3.1	7.0	0.1	**10.2**	0.5	0.0	**0.5**	0.4	0.0	0.4	0.0	79.9	**80.7**	7.4	**87.3**	1.2	0.0	**0.2**
Beacon Hill Sand and Gravel Member																				
GQ1	1207*	**0.0**	1.1	9.7	0.2	**11.0**	0.3	0.2	**0.5**	1.2	0.0	0.9	0.0	80.1	**82.2**	6.5	**86.6**	0.3	0.0	**0.1**
Stow Hill Sand & Gravel Member																				
PS1	576	**0.0**	1.3	3.3	1.9	**6.5**	1.2	0.0	**1.2**	0.4	0.2	0.5	0.0	85.6	**86.7**	4.5	**90.1**	1.0	0.0	**0.0**
SD1	992*	**0.0**	0.8	5.4	0.2	**6.4**	0.3	0.2	**0.5**	0.0	0.0	0.6	0.0	85.4	**86.0**	6.6	**92.0**	0.3	0.0	**0.0**
SHERINGHAM CLIFFS FORMATION																				
Runton Cliffs Sand and Gravel Member																				
BH1	751	**0.0**	1.5	10.7	0.7	**12.8**	1.6	0.1	**1.7**	0.1	0.0	0.0	0.0	73.8	**73.9**	7.9	**81.6**	3.7	0.0	**0.0**
LOWESTOFT FORMATION																				
Aldeby Sand and Gravel Member																				
LH2	241	**0.4**	5.0	2.1	0.4	**7.5**	0.0	2.5	**2.5**	15.4	0.0	0.0	44.0	29.0	**88.8**	0.4	**29.4**	0.0	0.0	**0.0**
HAPPISBURGH FORMATION																				
Leet Hill Sand and Gravel Member																				
PA1	2993*	**0.2**	5.7	16.4	0.4	**22.6**	0.6	0.4	**1.0**	0.2	Tr	0.9	0.2	55.5	**56.8**	15.9	**71.4**	2.2	0.0	**0.3**
C1	902	**0.6**	4.1	15.8	0.8	**20.7**	0.0	0.6	**0.6**	0.3	0.0	0.7	0.3	61.8	**63.1**	13.7	**75.5**	0.8	0.0	**0.6**
NS1	2611*	**0.1**	10.2	17.9	0.3	**27.6**	0.2	Tr	**0.2**	0.0	0.0	0.8	0.0	59.5	**60.1**	12.0	**71.5**	0.6	0.0	**0.0**
LH2	3756*	**1.0**	7.6	11.9	0.9	**20.4**	0.6	0.3	**0.9**	1.2	Tr	0.2	3.0	58.5	**63.0**	13.3	**71.9**	0.0	0.9	**0.3**

TABLE 8

ALDEBY SAND AND GRAVEL MEMBER	
Stratotype:	TM 384926 – Aldeby Quarry, Aldeby
Lithofacies:	Chalk-rich stratified sands and gravels
Lower contact:	Erosional
Thickness:	Upto 4m
Genesis:	Proximal glaciofluvial outwash
Provenance:	British
Section outcrops:	Aldeby Quarry, Scratby
Previous stratigraphic terms:	[1]Aldeby Sands and Gravels
PLEASURE GARDENS TILL MEMBER	
Stratotype:	TM 546987 – Corton Woods, Corton
Lithofacies:	Stratified diamicton complex composed of beds of Lowestoft Till Member and Oulton Clay Member material
Lower contact:	Inter-bedded with Oulton Clay Member
Thickness:	0.9m
Genesis:	Subaqueous flow till
Provenance:	British
Section outcrops:	Limited exposure at stratotype locality
Previous stratigraphic terms:	Pleasure Gardens Till
OULTON CLAY MEMBER	
Stratotype:	TM 546987 – Corton Woods, Corton
Lithofacies:	Horizontally-laminated light grey sandy silts and grey clays with occasional isolated light grey sand lenses
Lower contact:	Conformable with Lowestoft Till Member
Thickness:	Maximum observed thickness of 2.2m
Genesis:	Glaciolacustrine
Provenance:	-
Section outcrops:	Limited exposure at stratotype locality
Previous stratigraphic terms:	[2,3]Oulton Beds
WALCOTT TILL MEMBER	
Stratotype:	TG 391304 – Ostend
Lithofacies:	Grey, massive, matrix-supported diamicton; rich in chalk clasts and matrix calcium carbonate content; intermediate opaque heavy mineral content between Happisburgh Formation tills and the Lowestoft Till Member
Lower contact:	Erosional
Thickness:	Maximum observed thickness 1.6m
Genesis:	Subglacial deforming-bed till
Provenance:	British – North Sea ice advance from the northwest
Section outcrops:	Cliffs north of Cart Gap, Happisburgh lifeboat station to Ostend, discontinuously from Paston to Overstrand
Previous stratigraphic terms:	[6]Second Cromer Till, [5]Walcott Diamicton
LOWESTOFT TILL MEMBER	
Stratotype:	TM 546987 – Corton Woods, Corton
Lithofacies:	Dark grey, clay-rich, massive, matrix-supported diamicton; rich in opaque heavy minerals, chalk clasts and matrix calcium carbonate content
Lower contact:	Erosive
Thickness:	Up to 4m
Genesis:	Subglacial deforming-bed till
Provenance:	British – Pennine ice advance from the west
Section outcrops:	Coastal sections between Pakefield and Corton Woods, also Scratby, California Gap and Leet Hill Quarry
Previous stratigraphic terms:	[1,2,3]Lowestoft Till,[4]Chalky Boulder Clay

TABLE 9

	Lowestoft Till Member	Walcott Till Member	Pleasure Gardens Till Member
% Opaques	55.8 (4.0)	36.7 (3.3)	48.0 (4.6)
Non-opaques (% of total non-opaques)			
% Amphibole Group	27.7 (2.1)	38.8 (3.3)	29.5 (1.0)
% Apatite	16.4 (6.2)	6.2 (1.0)	16.2 (1.5)
% Epidote	17.0 (2.6)	19.4 (2.0)	16.8 (1.9)
% Garnet	17.8 (4.5)	15.8 (2.9)	13.3 (0.7)
% Kyanite	0.8 (0.3)	1.1 (0.5)	0.5 (0.7)
% Mica	2.3 (1.4)	4.2 (2.4)	7.0 (3.7)
% Pyroxene	1.8 (0.4)	1.6 (0.7)	2.2 (1.1)
% Rutile	1.9 (0.4)	1.0 (0.6)	0.2 (0.2)
% Staurolite	0.3 (0.3)	0.3 (0.5)	0.7 (0.4)
% Tourmaline	4.4 (1.0)	3.3 (1.1)	3.0 (0.3)
% Zircon	8.1 (1.6)	5.3 (1.7)	7.9 (0.3)
% Other	1.6 (0.8)	3.0 (1.2)	2.6 (1.7)
Number of samples	20	15	3

TABLE 10

RUNTON CLIFFS SAND & GRAVEL MEMBER

Stratotype:	TG 180432 – Beeston Cliffs, West Runton
Lithofacies:	Stratified sands with gravel seams
Lower contact:	Sharp
Thickness:	Up to 10m
Genesis:	Proximal outwash
Provenance:	British
Section outcrops:	East Runton – Sheringham
Previous stratigraphic terms:	[1]Gimingham Sands

WEYBOURNE TOWN TILL MEMBER

Stratotype:	TG 114431 – Weybourne Town Pit
Lithofacies:	Matrix-supported chalky diamicton; locally contains inclusions of Runton Till and Bacton Green Till members
Lower contact:	Sharp and erosional; frequent décollement plane
Thickness:	Up to 6m
Genesis:	Subglacial till
Provenance:	British – North Sea ice advance from the NW
Section outcrops:	Trimingham, Gimingham Quarry, West Runton to Weybourne
Previous stratigraphic terms:	[1,2]Marly Drift

TRIMINGHAM SAND MEMBER

Stratotype:	TG 266397 – Trimingham
Lithofacies:	Stratified sands
Lower contact:	Erosional
Thickness:	Up to 30cm
Genesis:	Deltaic
Provenance:	-
Section outcrops:	Trimingham – Sidestrand
Previous stratigraphic terms:	[3]Trimingham Sands

TRIMINGHAM CLAY MEMBER

Stratotype:	TG 266397 – Trimingham
Lithofacies:	Rhythmically bedded silts and clays
Lower contact:	Gradational with Bacton Green Till Member
Thickness:	Approximately 2m
Genesis:	Distal glaciolacustrine
Provenance:	-
Section outcrops:	Trimingham – Sidestrand
Previous stratigraphic terms:	[3]Trimingham Clays

BACTON GREEN TILL MEMBER

Stratotype:	TG 334347 – Bacton Green
Lithofacies:	Stratified diamicton complex composed of beds of diamicton and sand; fold noses and augen structures (within the bedded sands) are common
Lower contact:	Gradational with either Mundesley Sand Member or Runton Till Member
Thickness:	Up to 11m
Genesis:	Subaqueous flow till
Provenance:	British
Section outcrops:	Bacton Green – Mundesley, Trimingham – Overstrand, East Runton – Sheringham
Previous stratigraphic terms:	[1]Third Cromer Till, [3]Mundesley Diamicton

RUNTON TILL MEMBER

Stratotype:	TG 180432 – Beeston Cliffs, West Runton
Lithofacies:	Highly consolidate matrix-supported diamicton; contains highly sheared inclusions of chalk (pebble to raft size), sand and Walcott Till Member material
Lower contact:	Sharp and erosional; frequent décollement plane
Thickness:	Up to 9m
Genesis:	Subglacial till

Provenance:	British – North Sea ice advance from the NW
Section outcrops:	East Runton – Sheringham
Previous stratigraphic terms:	[3]Laminated Diamicton, [1]Contorted Drift, [2]Cromer Diamicton
IVY FARM LAMINATED SILT MEMBER	
Stratotype:	TG 268397 – Sidestrand
Lithofacies:	Rhytmically-bedded clays sand silts, marl and a thin bed of sand
Lower contact:	Gradational
Thickness:	At least 22m
Genesis:	Distal glaciolacustrine
Provenance:	-
Section outcrops:	Trimingham – Sidestrand
Previous stratigraphic terms:	[3]Trimingham Member
MUNDESLEY SAND MEMBER	
Stratotype:	TG 325356 – Mundesley
Lithofacies:	Stratified sands, chalky at the base
Lower contact:	Sharp but not erosional
Thickness:	Up to 9m
Genesis:	Deltaic
Provenance:	British
Section outcrops:	Paston – Mundesley, Mundesley to Sidestrand
Previous stratigraphic terms:	[1,2]Mundesley Sands

TABLE 11

	Mundesley Sand Member	Ivy Farm Laminated Silt Mem	Runton Till Member	Bacton Green Till Member	Trimingham Sand Member	Weybourne Town Till Member	Runton Sand & Gravel M
% Opaques	60.9 (3.3)	40.0 (4.6)	41.7 (3.9)	30.0 (3.1)	43.8 (5.9)	40.2 (5.0)	51.5 (3.9)
Non-opaques (% of total non-opaques)							
% Amphibole Group	41.7 (11.0)	20.2 (3.7)	41.1 (3.4)	42.3 (5.2)	33.1 (2.4)	38.0 (8.6)	30.1 (2.1)
% Apatite	2.8 (1.2)	0.5 (0.5)	2.0 (0.4)	1.6 (0.7)	3.3 (0.4)	3.8 (1.8)	1.1 (0.2)
% Epidote	19.2 (5.2)	15.4 (1.4)	22.1 (0.4)	22.8 (4.6)	22.5 (0.5)	18.7 (3.1)	30.3 (2.9)
% Garnet	16.9 (4.4)	41.5 (5.5)	18.4 (1.7)	17.4 (3.5)	25.6 (1.8)	23.3 (7.2)	23.0 (3.8)
% Kyanite	0.7 (0.5)	0.5 (0.1)	0.4 (0.3)	0.4 (0.6)	0.5 (0.3)	0.3 (0.3)	0.4 (0.2)
% Mica	4.8 (3.4)	0.3 (0.6)	2.0 (0.4)	2.2 (1.0)	1.0 (0.6)	1.1 (0.9)	0.5 (0.3)
% Pyroxene	0.6 (1.0)	0.5 (0.9)	2.4 (0.9)	1.9 (1.2)	0.6 (0.2)	1.1 (0.6)	2.6 (0.6)
% Rutile	1.0 (0.8)	1.1 (0.7)	1.0 (0.8)	0.9 (0.4)	0.4 (0.3)	0.9 (0.6)	0.7 (0.3)
% Staurolite	0.1 (0.2)	0.5 (0.3)	0.5 (0.5)	0.5 (0.5)	0.4 (0.4)	0.6 (0.7)	0.8 (0.2)
% Tourmaline	4.5 (1.7)	2.5 (1.8)	3.3 (1.3)	3.8 (1.4)	3.2 (0.8)	2.8 (1.2)	2.5 (0.3)
% Zircon	4.1 (2.0)	16.0 (3.1)	4.9 (1.7)	5.3 (1.3)	8.8 (1.1)	7.9 (2.8)	7.5 (1.1)
% Other	3.7 (1.4)	1.2 (0.7)	1.7 (1.0)	2.0 (0.6)	0.6 (0.2)	1.5 (1.3)	0.6 (0.3)
Number of samples	9	3	5	15	3	11	4

TABLE 12

BRITON'S LANE SAND AND GRAVEL MEMBER	
Stratotype:	TG 168415 – Briton's Lane Quarry, Beeston Regis
Lithofacies:	Coarse horizontal and massive bedded flint-rich cobble-gravels
Lower contact:	Erosional
Thickness:	Up to 40m in the vicinity of Briton's Lane
Genesis:	Ice-marginal fan complex
Provenance:	Predominantly British with a minor Scandinavian component
Section outcrops:	Briton's Lane Quarry and southwards towards Hanworth, Weybourne Cliffs plus many of the sand and gravel outliers adjacent to the north Norfolk coast including Beeston Hill (Beeston Regis) and Skelding Hill (Sheringham)
Previous stratigraphic terms:	[1]Briton's Lane Sands and Gravels
CORTON WOODS SAND AND GRAVEL MEMBER	
Stratotype:	TM 546987 – Corton Woods, Corton
Lithofacies:	Horizontally-bedded flint-rich gravel separated by beds and lenses of sorted pale yellow sand
Lower contact:	Erosional
Thickness:	Up to 6m
Genesis:	Proximal glaciofluvial outwash
Provenance:	British
Section outcrops:	Elevated sand and gravel plateaux areas in the vicinity of Corton (including Corton Woods
Previous stratigraphic terms:	[1]Plateaux Sands and Gravels, [3]Corton Woods Sands and Gravels
BEACON HILL SAND AND GRAVEL MEMBER	
Stratotype:	TG 284384 – Gimingham Quarry, Trimingham
Lithofacies:	Shelly cross-bedded and rippled flint-rich sands and gravels; dropsoils and ice-wedge casts and frost cracks are present at Gimingham Quarry; lower horizons exhibit evidence (folding and large thrust faults) of shortening and compressive glaciotectonic deformation
Lower contact:	Erosional
Thickness:	Up to 12m
Genesis:	Proximal glaciofluvial outwash
Provenance:	British
Section outcrops:	Gimingham Quarry, Trimingham and adjacent coastal sections southwards towards Marl Point and Trimingham Beacon
Previous stratigraphic terms:	-
STOW HILL SAND AND GRAVEL MEMBER	
Stratotype:	TG 328353 – Paston Cliffs
Lithofacies:	Flint-rich massive gravels separated by thin horizontally-bedded sands
Lower contact:	Erosional contact Sheringham Formation till and outwash deposits
Thickness:	Up to 8m
Genesis:	Proximal glaciofluvial outwash
Provenance:	British
Section outcrops:	Coastal sections between Paston and Sidestrand
Previous stratigraphic terms:	[1]Gimingham Sands, [2]Stow Hill Sands and Gravels

TABLE 13

	Stow Hill Sand and Gravel Member	**Beacon Hill Sand and Gravel Member**	**Briton's Lane Sand and Gravel Member**	**Corton Woods Sand and Gravel Member**
% Opaques	55.7 (2.5)	52.4 (6.2)	55.1 (13.5)	51.6 (1.8)
Non-opaques (% of total non-opaques)				
% Amphibole Group	18.5 (1.9)	26.2 (9.4)	21.9 (5.8)	22.6 (10.3)
% Apatite	1.6 (0.8)	1.6 (0.8)	1.4 (1.5)	1.3 (1.7)
% Epidote	30.6 (4.1)	23.0 (5.6)	26.6 (8.2)	21.7 (2.7)
% Garnet	11.7 (3.2)	30.9 (7.5)	22.3 (9.5)	11.4 (3.3)
% Kyanite	1.1 (0.6)	0.2 (0.3)	0.9 (0.9)	0.5 (0.4)
% Mica	0.9 (0.5)	0.8 (0.9)	0.3 (0.5)	7.9 (4.3)
% Pyroxene	1.0 (0.5)	2.4 (1.0)	1.9 (0.5)	2.1 (0.5)
% Rutile	2.2 (1.2)	1.5 (0.9)	2.5 (0.6)	3.2 (0.7)
% Staurolite	0.6 (0.5)	0.6 (0.4)	0.9 (0.5)	1.3 (0.4)
% Tourmaline	5.5 (0.9)	2.1 (1.3)	4.1 (2.0)	3.4 (0.8)
% Zircon	15.0 (1.9)	10.3 (5.3)	16.8 (8.1)	24.3 (11.1)
% Other	1.4 (0.7)	0.5 (0.3)	0.3 (0.5)	0.2 (0.3)
Number of samples	7	11	16	3

Table 14.