PRESIDENTIAL ADDRESS

A new glacial stratigraphy for East Anglia

Summary of one part of the address to the Society on Saturday 12th February 2000, by Dr Richard Hamblin of the British Geological Survey.

When I started to plan three Presidential Addresses for the Society, I decided to leave East Anglia until last, as new information was appearing all the time. Of course as time went on this new information became more and more difficult to interpret! Fortunately we were able to "cut the gordian knot" during our 1999 fieldwork and I am now in a position to put forward a completely new interpretation of the pre-Devensian glacial sequences of East Anglia, and particularly northeastern Norfolk.

I have been working in East Anglia since 1991, on a mapping project led by Brian Moorlock. There have been four people in the team throughout, other members at various times being Steve Booth, Tony Morigi, Dennis Jeffery, Mike Smith and Holger Kessler. I must also mention Profesor Jim Rose of Royal Holloway, University of London, and many of his students, with whom we have had a very constructive collaboration since the early nineties. We started in Suffolk and worked northward, deliberately leaving the difficult Cromer sheet until last, and it is in the mapping of this last sheet that the glacial stratigraphy has finally been resolved.

The sequence of tills

In recent years it has come to be accepted that all the pre-Devensian glacial deposits of East Anglia are Anglian in age, and these have been divided into two formations, most recently termed the North Sea Drift Formation and Lowestoft Formation (Bowen *et al*., 1999). These are derived from two distinct ice sheets, the 'Scandinavian Ice Sheet', which entered the area from the north or north-north-east, and the 'British Eastern Ice Sheet', which entered from the west. In general it can be said that the deposits of the North Sea Drift Formation are derived from the former ice sheet, since they are characterised by a suite of igneous and metamorphic erratics from the Olslofjord region, while the deposits of the Lowestoft Formation are derived from the latter ice sheet, and contain erratics derived from the Mesozoic outcrops to the northwest, principally the Chalk and Kimmeridge Clay. However, it has generally been believed that the two ice sheets co-existed (Hart and Boulton, 1991).

In northeast Norfolk, three tills were recognised within the North Sea Drift (Table 1; Banham, 1968, 1988), of which the middle one was noticeably more calcareous than the others. The Lowestoft Formation in the area was termed "Marly Drift" as it was formed almost wholly of reconstituted Chalk. During the late 1980s and early 1990s, Jane Hart and Juha Pekka Lunkka worked on the coast sections as part of their PhD studies (Hart and Boulton, 1991; Lunkka 1994). Unfortunately, in view of the contorted nature of the deposits, they were unable to agree on the stratigraphy, but I believe that I have correctly correlated their respective nomenclatures with that of Banham in Table 1.

When the BGS team set out to re-survey the Cromer sheet we were not anticipating erecting a new stratigraphy; we started at the western end of the area where we believed the deposits would be least contorted, and assumed that as we worked eastward, we would move off the Lowestoft Till onto the lower formation. However, this was not to be the case – as we crossed the area, the Lowestoft Till passed beneath gravels which we found to be associated with the Third Cromer Till. Furthermore, study of boreholes across the eastern part of the sheet demonstrated that the Lowestoft Till appeared to pass eastward into the Second Cromer Till. Comparison of the lithologies and provenance of the Lowestoft and Second Cromer tills subsequently confirmed that they were indeed the same unit, and we realised that there are in fact only three major tills in the succession, not the four shown in Table 1. Our new proposed stratigraphy is shown in Table 2: the First, Second and Third Cromer tills become the Happisburgh, Walcott and Hanworth till members of the Corton, Lowestoft and Overstrand formations.

The present account will largely consider the till members - there are also complex sequences of related sands, gravels and lacustrine clays related to each till member. Now that the relationships of the deposits are understood, we are better able to identify individual tills in the field, and we can say more about the sedimentology and provenance of each of them.

Banham (1968, 1988)	Hart and Boulton (1991)	Lunkka (1994)a
Lowestoft Till = Marly Drift		Lowestoft Till Formation, Marly Drift Member
Third Cromer Till	Walcott Diamicton Member	Cromer Diamicton Member, Mundesley Diamicton Member
Second Cromer Till	Eccles Diamicton Member	Walcott Diamicton Member
First Cromer Till	Happisburgh Diamicton Member	Happisburgh Diamicton Member

Table 1. Pre-Devensian stratigraphic sequences of northeastern Norfolk according to Banham, Hart and Lunkka.

Overstrand Formation	Hanworth Till Member
Lowestoft Formation	Walcott Till Member
Corton Formation	Happisburgh Till Member

Table 2. A new stratigraphy for the pre-Devensian tills of northeast Norfolk. Only the names of the formations and till members are shown; outwash sands and gravels and lacustrine deposits also occur within each of the three formations.

The three till sheets

The oldest, the Happisburgh Till, is a massive sandy till, reddish brown weathering pale yellow in colour, and generally 3-5m thick. It includes both lodgement and waterlain tills, and is poor in both carbonate (<2%) and megaclasts (most clasts <32mm). The clasts are dominantly flint, vein quartz and quartzite, but include Scandinavian rhomb porphyries, mica schists, gneiss and granitic rocks. The source of most of the material is clearly the North Sea and Scandinavia. However, examination of the derived micropalaeontology of the till by our colleague Jim Riding proved interesting. Jurassic palynomorphs were rare, arguing against the contemporary presence of the British Eastern Ice Sheet, but Carboniferous spores were extremely common, including a definite Westphalian input. There are no Carboniferous outcrops between Norway and Norfolk, and secondary derivation via the North Sea is unlikely as this would be accompanied by a varied asemblage including Jurassic forms. Consequently the only source would be northeastern Britain: either the ice sheet touched the shores of northeastern Britain before swinging south to Norfolk, or it was joined by a tributary glacier from that direction.

The Walcott Till is a stiff blue-grey chalky flinty till, which compared to the Happisburgh Till has higher clay and silt content, lower sand content, and more opaque heavy minerals. It contains 23-43% of carbonate (Lunkka, 1994), as does the Lowestoft Till in its main outcrop (Perrin et al., 1979). It is megaclast-rich, dominated by chalk clasts but also including angular flint and Jurassic limestone, mudstone and fossils, and a little quartzite and vein quartz. The micropalaeontology is dominated by spores of Carboniferous (Visean to Westphalian) and Jurassic (mainly Kimmeridgian) age. Clearly the source is eastern Britain, with little if any input from the North Sea and none from either Scandinavia or Scotland.

The Hanworth Till is a massive, very sandy till with the same Scandinavian and North Sea provenance as the Happisburgh Till, but overall it contains more megaclasts, with rounded flints and Scandinavian erratics commonly larger than 10cm. It varies in thickness more than does the Happisburgh Till, ranging up to more than 10m thick, and unlike the Happisburgh Till, it locally includes large quantities of very local Chalk. This may be in the form of rafts of pure Chalk, or else as ground-up, reconstituted chalk or "Marly Drift". It was this marly drift within the Overstrand Formation which in the past has been mistaken for Lowestoft Till, leading to the mistaken conclusion that the Lowestoft Formation overlay the North Sea Drift. During the Society's visit in 1995, rafts of Chalk up to more than 500m long were seen in the cliffs at West Runton.

The famous "contorted drift" of the northeast Norfolk coast (Reid, 1882; Hart and Boulton, 1991; Hart and Roberts 1994), formed by isoclinal folding within the till as a result of very high pore water pressures maintaining the till in an almost liquid state, is restricted to the Hanworth Till on the coast. Farther south it is a massive, undeformed till. Thrusting is also associated with the Overstrand Formation, and particularly fine thrusts were seen at Sidestrand on the Society's visit. Indeed it appears that the Happisburgh and Walcott tills are always massive and only deformed by horizontal shearing, while the "contorted drift", thrusting and formation of large rafts of Chalk are restricted to the Hanworth Till Member.

The glacial chronology

Traditionally the North Sea Drift and Lowestoft formations were both considered to be Anglian in age, and were therefore assigned to Oxygen Isotope Stage 12 [OIS 12] (Bowen *et al.* 1999). However, our new stratigraphy yields little support for the assumption that the Scandinavian and British Eastern ice sheets co-existed, and the possibility must be considered that the three formations now proposed may relate to chronologically separate ice advances.

The Lowestoft Formation does appear to be significantly younger than the Corton Formation. There is a strong unconformity between them, with the Lowestoft Formation resting on a deeply eroded topography cut in the Corton Formation in southeast Norfolk. The Lowestoft/Walcott till is much less weathered than the Happisburgh Till, which weathers to form the "Norwich Brickearth" (Rose et al. 1999). Also the Lowestoft Till incorporates clasts of calcrete derived from the underlying Corton Formation (Hopson and Bridge 1987), implying a sufficient time gap between the two formations to allow calcrete to form within the Corton Formation. The Overstrand Formation also appears to be significantly younger than the Lowestoft Formation: it rests upon a deeply eroded topography cut in the Lowestoft Formation, and it shows examples of "constructional geomorpholgy". That is to say, there are landforms associated with the Overstrand Formation which reflect the construction or deposition of the deposits, rather than their erosion. These include the Cromer Ridge, a gravel ridge over 100m high formed at the proximal end of a major sandur, the Blakeney Esker

A large raft of Upper Chalk within chalk-rich "Contorted Drift" of the Hanworth Till (Overstrand Formation) exposed in the sea cliffs at West Runton.

(visited by the Society in 1995), and a series of kames in the Glaven Valley, southeast of the Blakeney Esker.

The freshness of the Overstrand Formation and its associated geomorphological features imply that it is younger than Anglian, as such constructional features are not normally associated with the British Anglian deposits, either in East Anglia or the Midlands. However it is not likely to be Devensian, as it is entirely unlike the Devensian Holderness Formation which can be seen in Norfolk between Hunstanton and Morston, west of Blakeney. It thus corresponds to the intervening "Wolstonian" glaciation, correlating with the Saalian in the Netherlands and Germany. This is now ascribed to OIS 6, and glacial deposits of this age are now recognised in several areas of Eastern England. These include the gravels and tills of the Welton-le-Wold Formation in Lincolnshire (Bowen *et al.*, 1986), the Basement Till at Bridlington (Catt, 1991), and the outwash gravels of the Tottenhill member of the Nar Valley Formation in Norfolk (Gibbard *et al.*, 1991, 1992, Lewis & Rose, 1991). Since this was a major glaciation in the Netherlands, it would be expected that a major suite of glacigenic deposits would be found in Norfolk.

The Corton and Lowestoft formations would be ascribed to the "Anglian" Glaciation, but although this is ascribed to OIS 12 by Bowen *et al.* (1999), there is increasing evidence that it includes at least two distinct glaciations. Mike Sumbler's work on the terraces of the rivers Thames and Thame implies that glaciations occurred in the Midlands in both OIS 10 and 12 (Sumbler, 1995), and Alan Brandon's work on the Trent supports this (Foster *et al.*, 1999). In East Anglia, Uranium/Thorium dating on interglacial deposits from Tottenhill, Norfolk (Rowe *et al.*, 1997) and from Marks Tey, Essex (Rowe *et al.*, 1999) respectively imply glaciations during stages 10 and 12. It is thus tempting to date the Corton and Lowestoft formations as OIS 12 and 10 respectively. However, the Tottenhill and Marks Tey tills are both of the Lowestoft type, unlike the Happisburgh till in northeast Norfolk. Also Sumbler (1995) indicates that it was the earlier (OIS 12) glaciation which diverted the river Thames, and hence was a more far-travelled glaciation than that in OIS 10, whereas in northeast Norfolk, it appears that the Walcott Till extended farther south, with the Corton Formation being relatively local. Thus an alternative possibility is that the Walcott Till/Lowestoft Formation in north-east Norfolk relates to OIS 12, and the Corton Formation to an earlier cold period, perhaps OIS 14. However, the possibility still remains that both formations date from OIS 12, possibly separated by an interstadial. The dating of the Corton Formation may soon be constrained by work on small mammals in the "Unio Bed" underlying the Happisburgh Till at Sidestrand (Preece and Parfitt, 2000), but it is difficult to see how the age of the Walcott Till can be finally confirmed as OIS 10 or 12 unless further interglacial sites are found to constrain it.

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