PRESIDENTIAL ADDRESS

The later Crags and associated fluvial deposits of 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.

I have been working in East Anglia since 1991, on a mapping project led by Brian Moorlock. There have been up to four people in the team, other members at various times being Steve Booth, Tony Morigi, Dennis Jeffery, Mike Smith and Holger Kessler. I must also mention Professor 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. Many of the analyses presented in this address are theirs. When I joined the project we were surveying the Saxmundham (191) and Lowestoft (176) 1:50,000 sheets in Suffolk, and we later moved north to survey the North Walsham (148), Mundesley (132) and Cromer (131) sheets in Norfolk (Figure 1).

The Quaternary of East Anglia falls broadly into three major divisions: the marine Crag Group, a series of pre-Anglian fluvial formations which drained into the Crag sea, and finally the glacial and post-glacial deposits which were formed from the Anglian Stage onwards. The Crag Group is divided into four formations: from the oldest these are the Coralline, Red, Norwich and Wroxham Crag formations. The Coralline Crag is Pliocene, while the others are Early Pleistocene (Table 1). They were deposited on the western margin of the North Sea basin, which was subsiding and variably deforming throughout the period. The Crags are dominantly composed of glauconitic, micaceous sands, commonly shelly, with units that are rich in gravel, and frequent interbedding of silts and clays.

Red Crag and Norwich Crag

Our work in Suffolk largely involved resurveying the Red and Norwich Crags (Hamblin, *et al.*, 1997; see therein for further references), as well as the overlying glacial deposits. In the past, many divisions of these Crags have been proposed, but as lithostratigraphical units, most have not stood the test of field mapping. However, our colleagues Steve Mathers and Jan Zalasiewicz, working in Essex and southern Suffolk, were able to distinguish in the field between the coarse, shelly sands of the Red Crag and the well-sorted, fine-grained sands of the overlying Norwich Crag. They subdivided the Red Crag into Sizewell and Thorpeness members, on borehole evidence, and the Norwich Crag into Chillesford Sand and Chillesford Clay members, both of which are mappable units (see Table 1).

The Red Crag rests unconformably upon the Coralline Crag and oversteps onto Palaeogene deposits and Upper Chalk. Our own surveys in northern Suffolk confirmed the validity of the Red and Norwich Crag formations, and revealed a further unconformity at the base of the Norwich Crag, which similarly oversteps the Red Crag to rest upon the Palaeogene deposits and Upper Chalk. This is the sub-Antian/Bramertonian unconformity shown in the cross-sections on Figure 2, which are based on borehole evidence. From a study of the contours on the bases of the two formations, and building on the work of Bristow (1983) in mid-Suffolk, we concluded (Hamblin et al., 1997) that the Red Crag was formed in a series of NE-SW marine basins, most likely controlled by contemporaneous faulting, while the Norwich Crag is represented by a thin but widespread sheet of tidal flat and coastal sediments with less evidence for tectonic effects.

Our mapping demonstrated that the Chillesford Clay outcrop does not extend very far north of Aldeburgh, but farther north, a series of interbedded clays, sands and gravels of approximately the same age (Baventian stage) occur around Easton Bavents and Covehithe (Figure 3). All these clays are very silty, with silt and sand laminae, lenticular bedding,

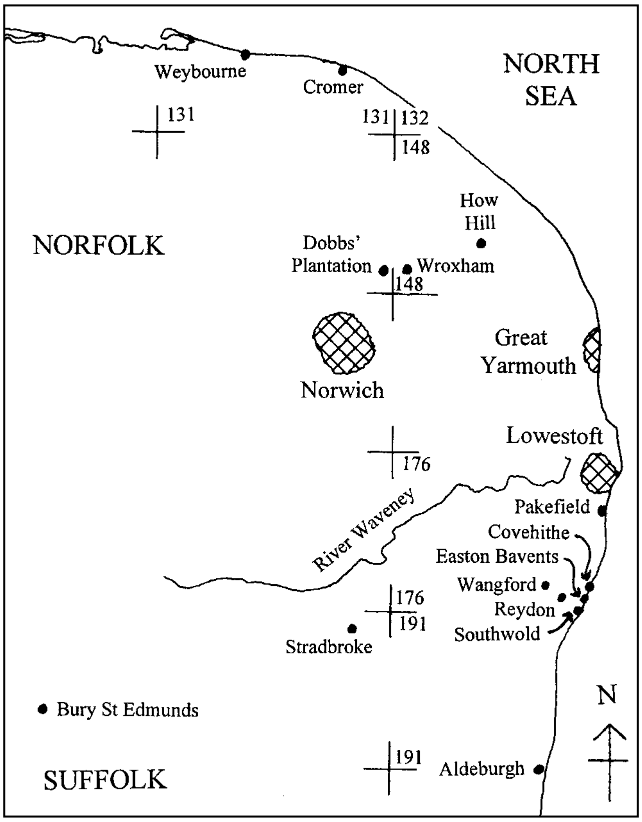

Figure 1. Locality map. All places cited in the text are shown, along with the limits of 1:50,000 map sheets 131 (Cromer), 132 (Mundesley), 148 (North Walsham), 176 (Lowestoft) and 191 (Saxmundham).

Table 1. Lithostratigraphy of the Crag Group and equivalent fluvial formations, and the English stages of the Early Pleistocene, modified after Hamblin *et al*, 1997.

<table>
<tr><th rowspan="2">Stage</th><th rowspan="2" colspan="2">Lithostratigraphy of the Crag Group</th><th colspan="3">Fluvial Formations</th></tr>
<tr><th></th><th></th><th></th></tr>
<tr><td>Cromerian</td><td rowspan="4" colspan="2">Wroxham Crag Formation</td><td rowspan="4">Kesgrave Formation</td><td rowspan="10">Bytham Formation</td><td rowspan="10">Cromer Forest-bed Formation</td></tr>
<tr><td>Beestonian</td></tr>
<tr><td>Pastonian</td></tr>
<tr><td>Pre-Pastonian</td></tr>
<tr><td>Baventian</td><td rowspan="2">Norwich Crag Formation</td><td>Westleton Beds, Chillesford and Easton Bavents clays</td><td rowspan="6">Nettlebed Formation</td></tr>
<tr><td>Antian/Bramertonian</td><td>Chillesford Sand</td></tr>
<tr><td>Thurnian</td><td rowspan="3">Red Crag Formation</td><td></td></tr>
<tr><td>Ludhamian</td><td>Thorpeness Member</td></tr>
<tr><td>Pre-Ludhamian</td><td>Sizewell member</td></tr>
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ripple-drift cross lamination, plant remains, marine molluscs and foraminifera, and desiccation polygons; these last two elements indicate that the clays range from shallow marine to supratidal in origin. As a guide to the provenance of these clays, our colleague Jim Riding studied their derived micropalaeotology (Riding *et al.*, 1997). In the Chillesford Clay he recorded Silurian acritarchs, Westphalian spores and Jurassic miospores and dinoflagellate cysts. The Easton Bavents clays were dominated by Jurassic miospores and dinoflagellate cysts, and Carboniferous spores. This dominance of relatively ancient derived microflora demonstrated that the clays were not deposited in an open sea environment, since in such a situation, material derived from river transport would be swamped by contemporary marine forms and by Quaternary, Tertiary and Cretaceous forms derived from the bed of the North Sea. Hence, we concluded that the clays formed in tidal river estuaries or lagoons.

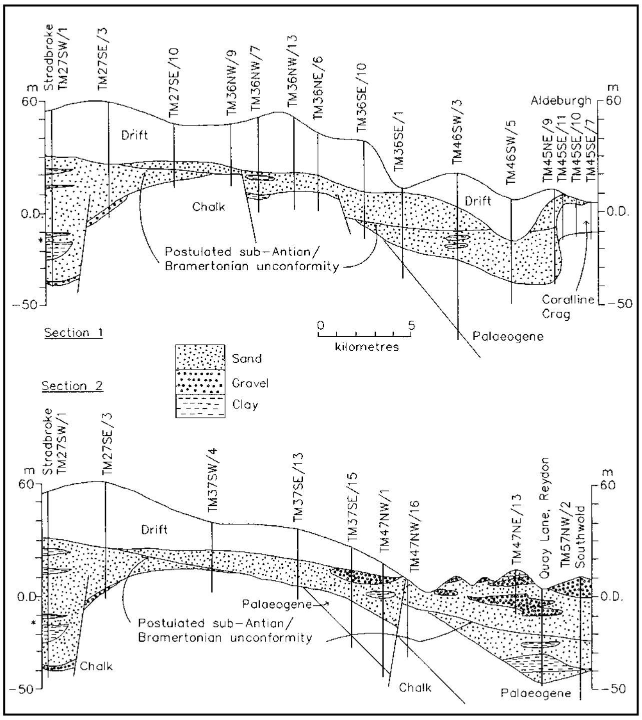

Figure 2. Generalized cross-sections through the Red and Norwich Crag formations from the Stradbroke Borehole to Aldeburgh and Southwold, after Hamblin *et al.* (1997). Vertical exaggeration x100. Boreholes are labelled with BGS registration numbers. The asterisks mark the Ludhamian : Pre-Ludhamian boundary in the Stradbroke Borehole. The base of the Antian/Bramertonian sediments has only been proved at Aldeburgh; at Reydon it has been taken at the top of proven Thurnian strata.

The contemporary rivers

At this point it is necessary to consider the rivers that drained eastwards into the Crag sea (Figure 4). The deposits of the proto-Thames are represented by the Nettlebed Formation and the Kesgrave Formation (Rose et al., 1976; see Rose *et al.* 1999 for further references). The Nettlebed Formation gravels comprise 98% flint and only 0.7% quartz and quartzite, but the later Kesgrave Formation gravels contain 20-30% quartz and quartzite, up to 3% Greensand chert and up to 1% acid volcanics. The latter demonstrate that the river flowed from Wales. The proto-Thames followed a more northward route to the sea than the present-day river, later being diverted into its present course by the advance of the Anglian ice sheet. Hence, bearing in mind the age of the derived microflora in the Chillesford Clay, it is probable that the Chillesford Clay represents the estuary (in Baventian times) of the proto-Thames, with the Silurian acritarchs being transported from the Welsh Borders and the Carboniferous and Jurassic forms from the English Midlands.

Farther north than the proto-Thames, the Bytham River (Rose, 1987, 1994; Hamblin and Moorlock, 1995) flowed from the West Midlands and southern Pennines, across the area now occupied by Fenland, crossing the Chalk outcrop at Bury St. Edmunds and then following roughly the line of the present River Waveney. The river was destroyed when the Anglian ice advance buried its catchment. The gravels of the Bytham River are rich in quartz and quartzite (20-70%) as well as flint (30-80%). Compared to the Kesgrave gravels they contain a higher proportion of quartzite than quartz, with much of the quartzite, derived from the Kidderminster Conglomerate of the English Midlands, being red and brown in colour. They also contain up to 4% of Carboniferous chert from the Pennines, and traces of Spilsby Sandstone from south Lincolnshire and north-west Norfolk, but no acid volcanics or Greensand chert. In view of the derived micropalaeotology of the Easton Bavents clay, with Jurassic and Carboniferous forms but no Silurian, we believe that the clays around Easton Bavents formed at the Bytham River estuary.

The gravels interbedded with the clays around Easton Bavents are termed Westleton Beds, and are coarse, well-sorted, clast-supported gravels formed almost wholly of high-sphericity, well-rounded to sub-angular chatter-marked flints. They contain marine molluscs and whale vertebrae, implying a marine origin, and occur in 10m-thick cross-sets, dipping towards the south-east (Mathers and Zalasiewicz, 1996; see therein for earlier references). The gravels represent a complex of regressive beach-face gravel banks, thrown up by the sea as it retreated south-eastwards. Taken in connection with the estuarine clay bodies it is probable that the clays formed in a shifting complex of muddy lagoons and quiet estuaries protected to seaward by the shoreface gravel banks: in a modern context, if the gravels represent Dungeness, the clays would represent Romney Marsh. The gravels would not be expected to yield any micropalaeontological evidence of derivation, but the non-flint clasts (up to 4% of the total) include quartzite and quartz from the Kidderminster Conglomerate of the English Midlands, "spicular" flints from the Chalk of Lincolnshire, and Rhaxella chert from the Corallian Group of North Yorkshire. This agrees with our interpretation of the clays as occupying the estuary of the Bytham River. The low proportion of non-flint clasts of the Westleton Beds compared to that of the surviving river gravels suggests that the latter formed at a later period in the development of the river than the (Baventian) Westleton Beds, after increased downcutting had led to a higher yield of pebbles from the Midlands.

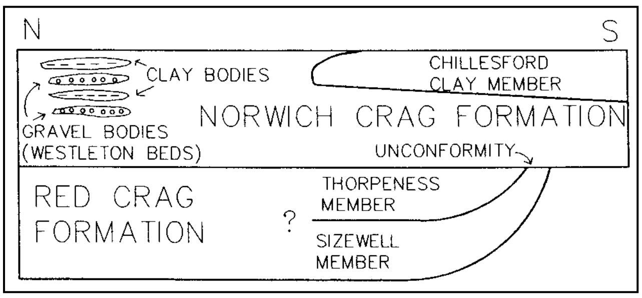

Figure 3. Diagrammatic relationships between the lithostratigraphic components of the Red and Norwich Crag formations from around Aldeburgh to around Southwold, after Hamblin et al (1997).

The stages of the Quaternary (Table 1) were derived largely from the micropalaeontological work of Richard West and Brian Funnell in the 1960s (see Hamblin *et al.* 1997 for references). Using pollen assemblages and foraminifera, they subdivided the Quaternary on climatic grounds, separating warm stages (Ludhamian, Antian/Bramertonian, Pastonian) and cold stages (Pre-Ludhamian, Thurnian, and Baventian/Pre-Pastonian). The regressions and transgressions within the Crag Group can apparently be related to these climatic changes, suggesting a relationship with glacio-eustatic changes in sea level. The Red Crag Formation ends with a regression during the cold Thurnian, while the Norwich Crag starts with a transgression during the warm Antian and ends with a regression in the cold Baventian, resulting in deposition of the estuarine clays and the beach-face Westleton Beds. Mathers and Zalasiewicz (1996) recorded deeper-water sediments overlying the Westleton Beds at Reydon, indicating a further transgression, but this will be discussed later; meanwhile, it is necessary to again consider the rivers draining into the Crag sea.

Our surveys of the Saxmundham and Lowestoft sheets, coupled with Jim Riding's work on the Chillesford and Easton Bavents clays, confirmed the paths of the proto-Thames and Bytham rivers as shown in Figure 4. However, contemporary wisdom at the time held that these rivers had only followed these routes late in their history, immediately before the Anglian transgression. At an earlier stage they were believed to have followed a more northward route still, joining together in northern Suffolk and continuing to cross the present-day coast near Cromer in North Norfolk. Our claim (Hamblin and Moorlock, 1995) that they had never flowed farther north than is shown in Figure 4 brought forth a spirited response from Rose *et al.* (1996a), including a very useful map of numerous sites in Norfolk that yielded gravels of Kesgrave or Bytham lithology.

This worried us at the time, could we have been wrong all along? We reasoned that we must be right: since we were convinced of the routes of the two rivers during the Baventian, we could see no reason why the Thames should later move to a more northward route. The answer emerged soon after from our studies in Norfolk, since by now we had started surveying the North Walsham sheet. We visited several of the sites listed by Rose et al.

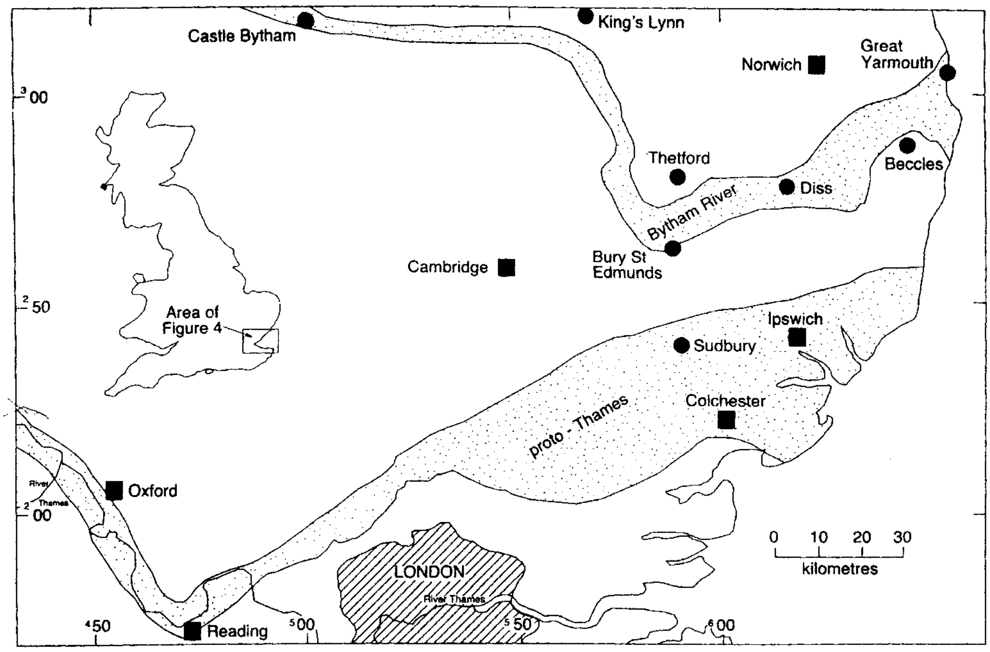

Figure 4. Courses of the pre-Anglian proto-Thames and Bytham rivers, modified from Hamblin and Moorlock (1995).

(1996a), although many were no longer exposed, and arranged with Jim Rose and his students for trial pits at How Hill (Figure 1) (Rose et al. 1996b). We discovered that almost all of the gravels in question were in fact marine, rather than fluvial. This meant that they did not belong to the Kesgrave or Bytham formations, which are by definition fluvial, but are a part of the Crag Group. We established the name Wroxham Crag Formation to cover this new unit, which differed from the Norwich Crag in that its gravel fraction contained a high (>10%) non-flint component, compared to the low (<4%) non-flint component of the Norwich Crag (Westleton Beds). We reasoned that the distinctive Kesgrave and Bytham gravel fraction of the Wroxham Crag had entered the sea at the river mouths in Suffolk and had been transported north by longshore drift or coastal currents.

The How Hill trial pits yielded more interesting information on the river systems. The gravels analysed were 52-69% flint, 22-39% quartz and quartzite, and up to 7.7% Carboniferous chert, 0.6% Rhaxella chert, 2.1% Greensand chert, and 0.3% igneous. The ratio of quartzite to quartz worked out at 1.25:1, and the quartzites were dominantly white or colourless, both of which features are more typical of the Kesgrave than the Bytham gravels. This was surprising for a deposit so far north. However, the percentages of Carboniferous and *Rhaxella* chert, derived from the Pennines and North Yorkshire, was far higher than in either the Kesgraves or Bythams, and we take this to indicate a major input from a further river flowing from that direction. Input from this "Northern River", rather than a high Kesgrave input, would be the explanation for the high proportion of white and

Figure 5. Bedded sands and gravels of the Westleton Beds exposed in the cliffs at Dunwich.

colourless quartzites. It thus appears that during the Early Pleistocene, East Anglia was traversed by three major rivers flowing from west to east, the proto-Thames, the Bytham and this “Northern River”, which is now named the Ancaster River (Clayton, 2000).

We believe that the fluvial deposits of the Cromer Forest-bed Formation (sensu stricto) in Northeast Norfolk, in which the "West Runton Elephant" was uncovered, were deposited by the Ancaster River, or possibly a right-bank tributary.

Wroxham Crag and Norwich Crag

Further evidence concerning the relationship of the Wroxham and Norwich Crags was obtained by trial pits at Dobbs’ Plantation (Figure 1), a site previously excavated by the Geological Society of Norfolk (Cambridge, 1978a,b). Cambridge recorded the bivalve Macoma baltica, indicative of the Pre-Pastonian stage, coming in about a metre above the base of the section, suggesting that here Pre-Pastonian Wroxham Crag might be resting upon earlier Norwich Crag. Our initial excavations at the site revealed only one gravel band, in the upper part of the sequence. On analysis this proved to contain (in the 8-16mm fraction) 82% flint, 12% quartz and quartzite, 6% Crag ironstone, 0.4% Carboniferous chert and 0.2% igneous and metamorphic rock, confirming that it did indeed belong to the Wroxham Crag Formation. Fortunately, we found a basal gravel in the Crag resting upon Upper Chalk at Old Hall Farm, Wroxham, only a kilometre away from Dobbs’ Plantation, and on analysis this revealed (in the 16-32mm fraction) 90% flint and only 1.1% quartz and quartzite. This is typical of the Norwich Crag, since the Westleton Beds at Wangford yielded 1.17% quartz ands quartzite in the 16-32mm fraction. Thus in the Wroxham area, the Wroxham Crag rests upon thin Norwich Crag.

The Wroxham Crag may be observed in cliff sections along the north Norfolk coast, from Weybourne eastwards, and always resting directly on the Upper Chalk. It is typically dominated by gravel, with a large percentage of quartz and quartzite as well as well-rounded flints (Briant et al., 1999). Beds of marine bivalves, including Macoma baltica, are common. At Weybourne the Crag rests upon soliflucted Upper Chalk, with rounded clasts of chalk and angular flints embedded in a sandy chalk paste. Since this solifluction deposit must be older than the Pre-Pastonian Wroxham Crag, it was most likely formed during the Baventian cold period, implying that this area was land at that time, just before the Wroxham Crag transgression.

Having established the Wroxham Crag Formation in Norfolk, we returned to further investigate the Suffolk sections, since we had not suspected the existence of the Wroxham Crag when we wrote Hamblin *et al.* (1997). At Reydon and Covehithe, Mathers and Zalasiewicz (1996) recorded offshore sands and gravels overlying the beach-face Westleton Beds, implying a further transgression. We examined the gravel overlying the Westleton Beds at Covehithe, and found that it did indeed contain large quantities of vein quartz and quartzite. Thus we conclude that the transgression following formation of the Westleton Beds is in fact the Wroxham Crag transgression, demonstrating that the Wroxham Crag is present from the north coast of Norfolk at least as far south as northern Suffolk. Also, since the formation rests on a relatively late unit of the Norwich Crag (Baventian Westleton Beds) at Covehithe, on much earlier Norwich Crag (?Antian) at Dobbs’ Plantation (only about a metre above the base of the formation), and on Upper Chalk at Weybourne, it can be seen that the unconformable base of the Wroxham Crag cuts down to rest on steadily older strata towards the north or north-west.

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