BRITISH GEOLOGICAL SURVEY
Mineralogy & Petrology Group

Technical Report No. WG/96/1

CHARACTERISATION OF QUATERNARY SEDIMENTS FROM EAST ANGLIA

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Date

24th February 1997

Classification

Open

Subject index

Cromer Till

Geographical index

East Anglia

Bibliographic reference

Mitchell, CJ, Bloodworth, AJ
& EJ Evans(1996)
Characterisation of Quaternary sediments
from East Anglia
Technical Report WG/96/1

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EXECUTIVE SUMMARY

This report describes the mineralogical investigations of Quaternary sediments, mainly Cromer Till, collected from East Anglia. The main aim of the work was to characterise the mineralogical and physical properties of the till samples to facilitate correlation between tills from different localities. The clast composition of the samples was determined using a binocular microscope and the mineralogy of the matrix was determined using X-ray diffraction and thermogravimetry. Calibration charts were used to quantify the amount of quartz and calcite present. Cumulative frequency graphs were plotted from the particle-size data to determine the mean, median, standard deviation and skewness. Also ternary sand/silt/clay diagrams were plotted.

The Cromer Till samples typically contained 2% gravel (mainly flint, sandstone, quartz and chalk), 45% sand, 31% silt and 22% clay. The Starston Till contained 12% gravel (mainly flint), 46% sand, 16% silt and 26% clay. The 'Clay' from Sea Palling contained 1% gravel (mainly flint), 10% sand, 78% silt and 11% clay. The Lowestoft Till samples had different particle-size distributions and the gravel consisted mainly of chalk.The Crag Clay samples contained 1% gravel (mainly sandstone), 11% sand, 49% silt and 39% clay. The Blue Clay samples contained virtually no gravel, 4% sand, 59% silt and 37% silt. The Holocene sample contained 1% gravel (mainly flint), 21% sand, 39% silt and 39% clay.

The $CaCO_3$ contents and particle-size distributions of the Cromer Till samples were compared with published data (Lunkka, 1994). Based upon this comparison the samples were tentatively classified as either Walcott Diamicton, Happisburgh Diamicton or Norwich Brickearth. The 'Blue Clay' samples were also tentatively classified as Crag Clay.

Recommendations for further work include detailed logging and sampling of coastal sections; collection of large samples for more accurate clast analysis ; and heavy mineral analysis.

British Geological Survey
Mineralogy & Petrology Group Report No. WG/96/1

CHARACTERISATION OF QUATERNARY SEDIMENTS FROM EAST ANGLIA

CJ Mitchell, AJ Bloodworth & EJ Evans

1. INTRODUCTION

This report describes the mineralogical investigations of samples of Quaternary sediments collected from East Anglia (Figure 1). These were mainly Cromer Till (Corton Formation), plus other till and clay samples. A field trip was carried out in November 1993 with SJ Booth (Southern & Eastern England Group) and 39 samples were collected, of which 25 were identified for characterisation (Table 1). A further 12 samples were subsequently submitted by land survey staff for characterisation.

The main aim of the work was to characterise the mineralogical and physical properties of the till and clay samples to facilitate correlation between fine grained tills from different localities, but focusing upon the Cromer Till. Several till bodies in the region, such as the Starston Till, have been equated with the Cromer Till and this investigation aimed to establish whether or not these correlation's are viable mineralogically.

The particle-size distribution of the samples was determined by a combination of sieve screening and X-ray Sedigraph. The mineralogy of the samples was determined by a combination of binocular microscopy, for the clasts, and X-ray diffraction (XRD) and thermogravimetric analysis (TGA), for the matrix. This work was carried out in support of the East Anglian regional mapping programme.

2. METHODOLOGY

2.1. Sample preparation

Each sample (Figure 2) was split by coning and quartering, with approximately a quarter retained as a reference and the remainder used for the characterisation. This was 'sloughed' (i.e. soaked in water) overnight in order to aide dispersion of the clay-rich matrix. Dispersion was completed by agitating the sample using a reciprocal shaker. The sample suspension was then wet screened using the sieve series 2 mm,

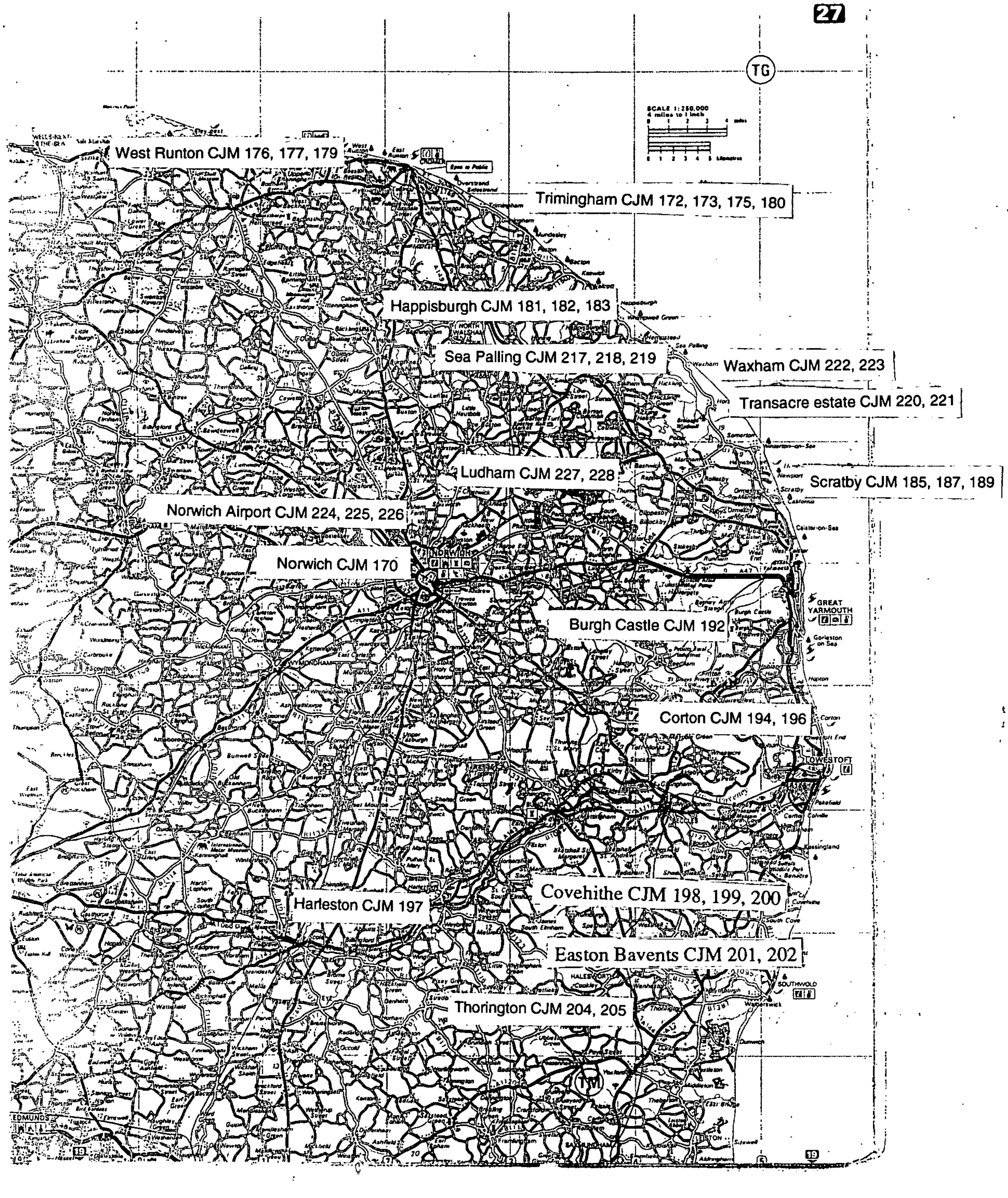

Figure 1. Location map

Table 1. Sample List

Collectors number (CJM)	Grid reference (TG)	Sample description and locality
170	219 115	Norwich Brickearth, Upper Hellesden, Norwich
172	275 391	Lower Diamicton, Cromer Till, Trimingham
173	275 391	Lower Diamicton, Cromer Till, Trimingham
175	275 391	Lower Diamicton, Cromer Till, Trimingham
176	188 431	Laminated Diamicton, Cromer Till, West Runton
177	188 431	Massive Diamicton, Cromer Till, West Runton
179	188 431	Massive Diamicton, Cromer Till, West Runton
180	275 391	Upper Diamicton, Cromer Till, Trimingham
181	384 314	Lower Diamicton, Cromer Till, Happisburgh
182	384 314	Lower Diamicton, Cromer Till, Happisburgh
183	384 314	Laminated Diamicton, Cromer Till, Happisburgh
185	518 149	Upper Leaf, Cromer Till, California Cliffs, Scratby
187	518 149	Basal Cromer Till California Cliffs, Scratby
189	518 149	Lowestoft Till, California Cliffs, Scratby
192	482 043	Leaf, Cromer Till, Welcome Quarry, Burgh Castle
194	547 965	Cromer Till, Corton
196	547 965	Lowestoft Till, Corton
197	2480 8410	Starston Till, Harleston
198	525 816	Crag Clay, Cove Hithe
199	525 816	Cromer Till ?, Cove Hithe
200	525 816	Cromer Till ?, Cove Hithe
201	517 789	Blue Clay, Eastern Bavents
202	517 789	Lower Blue Clay, Eastern Bavents
204	420 729	Upper Blue Clay, ARC Quarry, Thorington
205	420 729	Lower Blue Clay, ARC Quarry, Thorington
217	4265 2738	'Clay', Sea Palling
218	4265 2738	Top of Cromer Till ?, Sea Palling
219	4265 2738	Bottom of Cromer Till ?, Sea Palling
220	4834 2000 to 4850 2205	Lowestoft Till or Norwich Brickearth ?, Transacre Estate (ditch section)
221	4834 2000 to 4850 2205	Cromer Till ?, Transacre Estate (ditch section)
222	435 267	Holocene ?, Broiler House Field, Waxham Hall Farm
223	4405 2659	Cromer Till ?, Waxham (beach exposure)
224	212 134	D2, 1.5m deep, Norwich Brickearth, Norwich Airport
225	212 134	D3, 2.2m deep, Norwich Brickearth, Norwich Airport
226	212 134	D4, 3.0m deep, Norwich Brickearth, Norwich Airport
227	3980 1835	Till capping (Lowestoft or Cromer ?), near Ludham
228	3980 1835	Till capping (Lowestoft or Cromer ?), near Ludham

600 μm and 425 μm and the >425 μm residues were dried and retained for examination by binocular microscope.

The <425 μm suspension was dried and split into two sub-samples. The larger split (about three-quarters) was retained mainly as a reference although a small portion was ground to provide a powder suitable for determination of the bulk mineralogy (by XRD and TGA). The remainder of the <425 μm material was re-dispersed and wet screened, using 212 μm and 63 μm sieves. The <63 μm suspension was sub-sampled for particle-size analysis by X-ray Sedigraph. The remainder of the <63 μm suspension was used to produce <2 μm fractions (by sedimentation) for determination of the clay mineralogy (by XRD).

2.2 Mineralogy

2.2.1. Clast analysis

The >425 μm fractions were examined using a binocular microscope to determine their modal mineralogy (Table 2).

2.2.2. Matrix analysis

The bulk mineralogies of the <425 μm fractions were determined by XRD, using a Phillips PW 1700 X-ray diffractometer, operating with Co-Kα radiation at 45 kV and 40 mA and scanning over a range of 3 - 50°2θ. The diffraction traces were interpreted with reference to the JCPDS database and semi-quantitative mineral proportions were assigned according to peak intensity (Table 3).

The quartz contents of the <425 μm fractions were determined using a calibration chart. This was produced by 'spiking' a sample with known amounts of pure quartz and plotting the increase in X-ray intensity of the quartz main line against percentage addition. The quartz content of the samples was then determined from the calibration chart using the X-ray intensity of the main line quartz peak.

The calcite contents of the <425 μm fractions were also determined using a calibration chart. The calcite contents of selected samples were determined using thermogravimetric analysis. These were then plotted against the X-ray intensity of the calcite main line. The calcite contents of the samples were then determined from the calibration chart using the X-ray intensity of the main line calcite peak (Figure 3) and these can be compared with published data (Figure 4).

The mineralogy of the <2 μm fraction, the clay mineralogy, was also determined by XRD. Oriented clay mounts were prepared by vacuum filtration of 80 mg of clay (dispersed in distilled water) onto porous ceramic discs. These were analysed as for bulk mineralogy and scanned over an angular range of 1.5 - 32°2θ. The diffraction traces were interpreted with reference to the JCPDS database. Quantitative clay mineral compositions were estimated from a calibration chart derived from the analysis of standard mixtures of illite, smectite and kaolinite (Table 4). The clay mineralogies of these samples were plotted on a ternary diagram (Figure 5).

2.3. Particle-size distribution

The particle-size analysis of the samples (outlined in 2.1.) was carried out with reference to BS1377: Part 2: 1990. Wet sieving was carried out to ensure thorough dispersion of the fine-grained material and to remove clay from coarser particles. The <63 μm fractions were analysed using a Micromeritics X-ray Sedigraph to determine the particle-size distribution down to 0.5 μm.(Table 5).

Particle-size characteristics were determined using statistical methods. Cumulative frequency charts were plotted from the particle-size distribution data (Appendix A). From the cumulative charts, the mean , median, standard deviation and skewness were determined. The following graphical methods (Folk, 1974) were applied:

$$\text{Mean} = (D_{16} + D_{50} + D_{84}) / 13 \qquad \text{Median} = D_{50}$$

$$\text{Standard Deviation} = [(D_{84} - D_{16}) / 4] + [(D_{95} - D_5) / 6.6]$$

$$\text{Skewness} = [(D_{16} + D_{84} - 2D_{50}) / 2 (D_{84} - D_{16}] + [(D_5 + D_{95} - 2D_{50}) / 2 (D_{95} - D_5)]$$

Where, Dx = particle-size value (phi units, ϕ) at x cumulative percent; and Particle size (phi units, ϕ) = -log2 (particle size, mm).

The standard deviation is a measure of the degree of sorting or uniformity of the sample. Skewness gives an indication of the proportion of coarse or fine material in a sample relative to a gaussian distribution. Qualitative descriptions can be applied to these values using the classifications devised by Folk (1974), which are as follows:

Std Dev (sorting) (ϕ)	Verbal description	Skewness	Verbal description
0 - 0.35	Very well sorted	+1.0 - +0.3	Strongly fine-skewed
0.35 - 0.5	Well sorted	+0.3 - +0.1	Fine-skewed
0.5 - 0.71	Moderately well sorted	+0.1 - -0.1	Near-symmetrical
0.71 - 1.0	Moderately sorted	-0.1 - -0.3	Coarse-skewed
1.0 - 2.0	Poorly sorted	-0.3 - -1.0	Strongly coarse-skewed
2.0 - 4.0	Very poorly sorted		
4.0 +	Extremely poorly sorted		

It is conventional to sub-divide till into a fine fraction (<2 mm) and a coarse fraction (>2 mm). Till with <40% coarse fraction is defined as "matrix dominant" and its particle-size data are best expressed on a ternary sand / silt / clay diagram (Sladen & Wrigley, 1984). The Cromer Till samples are plotted with data from Lowestoft Till samples (Inglethorpe, 1995) for comparison in Figure 6. Also the Cormer Till samples can be compared with published data (Figures 7 and 8). The ternary particle-size distribution plots for all of the East Anglian samples are given in Appendix B.

3. RESULTS

3.1. Cromer Till

A summary of the mineralogical and particle-size data from the East Anglian Cromer Till samples is given in Table 7.

These results indicate that the Cromer Till has a clast component (>2 mm) which is mainly flint, sandstone, quartz and chalk, with a minor amount of shell fragments, pyrite, limestone, siltstone and porphyry. The coarse matrix (2 mm to 425 μm) is mainly composed of quartz, sandstone, flint and chalk and minor amounts of shell, coal, iron oxide, pyrite and siltstone. The sandstone present in the Cromer Till occurs as three broadly defined types, as follows: i) Grey, buff to reddish-brown, rounded to occasionally sub-angular, and fine to medium grained; ii) Dark-grey to black, sub-angular, and medium grained; iii) Rusty reddish-brown, irregular in shape, and medium grained. The flint occurs as grains that are either light-grey, brown to white, and angular to occasionally rounded, or dark-grey to black and rounded. The quartz occurs as grains that are mainly colourless to light-brown and rounded, occasionally sub-angular.

The fine matrix (<425 μm) is predominantly composed of quartz, with minor feldspar and calcite, and a trace of mica and kaolinite. The <2 μm fraction is composed of equal proportions of smectite, illite and kaolinite.

The Cromer Till samples contained on average 2% gravel (>2 mm), 45% sand (2 mm - 63 μm), 31% silt (63 - 2 μm) and 22% clay (<2 μm). The mean particle size is 27 μm and the median is 77 μm. The standard deviation is 2.4 ϕ (very poorly sorted) and the skewness is 0.5 (strongly fine-skewed).

3.2. Possible Cromer Till

3.2.1. Starston Till, Harleston

The clast component of the samples is mainly flint, with a trace of quartz and sandstone. The coarse matrix is mainly quartz, with a small amount of flint, sandstone and iron oxide and a trace of feldspar. The fine matrix is predominantly composed of quartz and a trace of feldspar and kaolinite. The flint is mainly light to dark grey and angular in shape, although a small proportion is black and rounded. The sandstone is rusty reddish-brown, rounded to sub-angular and fine to medium grained. The quartz is grey to colourless and rounded in shape. The <2 μm fraction is composed of roughly equal proportions of the following clay minerals (ranked in order of abundance) : kaolinite > smectite > illite.

The till sample contained 12% gravel, 46% sand, 16% silt and 26% clay. The mean particle-size is 40 μm, the median is 230 μm, the standard deviation is 2.9 ϕ (very poorly sorted) and the skewness is 0.9 (strongly fine-skewed).

3.2.2. 'Clay', Sea Palling

The clast component of this sample is mainly composed of grey to brown coloured, rounded flint, with a small amount of grey, angular, medium grained sandstone. The coarse matrix is mainly quartz, plus small amounts of flint and sandstone. The fine matrix is mostly quartz, with minor feldspar and trace amounts of mica and kaolinite. The <2 μm fraction contains equal proportions of smectite, illite and kaolinite.

The sample contained 1% gravel, 10% sand, 78% silt and 11% clay. The mean particle-size is 18 μm, the median is 22 μm, the standard deviation is 1.6 ϕ (poorly sorted) and the skewness is 0.3 (fine-skewed).

3.3. Lowestoft Till

The clast component of the two samples is mainly chalk, with a small amount of sandstone, flint and quartz, and a trace of shell fragments. The flint is light to dark grey or brown and angular. The sandstone occurs as two types: i) light grey, rounded to sub-angular and fine to medium grained, or ii) rusty reddish-brown, irregular in shape and medium grained. The coarse matrix is mainly chalk, quartz and sandstone, with a small amount of flint and trace amounts of shell fragments and coal. The fine matrix consists predominantly of quartz, plus major calcite, minor feldspar and pyrite, and trace amounts of mica and kaolinite. The < 2 μm fraction is mostly composed of kaolinite, major illite and minor smectite (present in the mixed layer clay mineral, illite-smectite).

The particle size distribution and characteristics of the two Lowestoft Till samples is markedly different. The 'coarse' sample from Scratby contained 8% gravel, 36% sand, 34% silt and 22% clay. The mean particle size is 26 μm, the median is 67 μm, the standard deviation is 2.3 ϕ (very poorly sorted) and the skewness is 0.5 (strongly fine-skewed). The 'fine' sample from Corton contained 4% gravel, 10% sand, 43% silt and 43% clay. The mean particle-size is 5 μm, the median is 3.7 μm, the standard deviation is 2.6 ϕ (very poorly sorted) and the skewness is -0.3 (coarse-skewed).

3.4. Crag Clay

The clast component of this sample is mainly rusty reddish-brown, irregularly shaped, medium grained sandstone. The coarse matrix is also mainly sandstone, but with trace amounts of quartz and flint. The fine matrix consisted predominantly of quartz, minor feldspar and a trace of calcite and kaolinite. The <2 μm fraction contains equal proportions of smectite, illite and kaolinite.

The sample contains 1% gravel, 11% sand, 49% silt and 39% clay. The mean particle-size is 3.5 μm, the median is 3.8 mm, the standard deviation is 2.5 ϕ (very poorly sorted) and the skewness is 0.03 (near-symmetrical).

3.5. Blue Clay

The samples of Blue Clay proved to have a clast component mainly composed of flint, sandstone and quartz. The flint is grey and angular to rounded, the sandstone rusty reddish-brown, angular and medium grained and the quartz colourless and rounded. The coarse matrix is mainly sandstone and quartz, with a small amount of flint and a trace of iron oxide. The fine matrix consists predominantly of quartz, minor feldspar and traces of mica and kaolinite. The <2 μm fraction is composed of roughly equal proportions of the following clay minerals (ranked in order of abundance) : smectite > illite > kaolinite.

The Blue Clay contains on average virtually no gravel, 4% sand, 59% silt and 37% clay. The mean particle-size is 3.3 μm, median 4.8 μm, standard deviation 2.0 ϕ (very poorly sorted) and the skewness ranges from 0.5 (strongly fine-skewed) to -0.1 (coarse-skewed).

3.6. Possible Holocene

The clast component of this single sample is mainly composed of flint, with a small amount of iron oxides and trace amounts of quartz and sandstone. The flint is grey to brown and rounded, the sandstone dark brown, irregularly shaped and the quartz colourless to light brown and rounded. The coarse matrix is mainly quartz and sandstone, with a small amount of iron oxides. The fine matrix is mostly quartz, with major feldspar and trace amounts of mica and kaolinite. The <2 μm fraction is composed of roughly equal proportions of the following clay minerals (ranked in order of abundance) : kaolinite > illite > smectite.

The sample contains 1% gravel, 21% sand, 39% silt and 39% clay. The mean particle-size is 13 μm, the median is 70 μm, the standard deviation is 2.9 ϕ (very poorly sorted) and the skewness is 0.7 (strongly fine-skewed).

4. DISCUSSION

The Cromer Till (also locally known as the 'Norwich Brickearth' or the 'North Sea Drift') occurs in the north-eastern part of East Anglia and is best exposed in the coastal cliff sections of northern Norfolk and Suffolk, between Lowestoft and Weyborne (Ehlers *et al*, 1991). It is a lodgement till within the Corton Formation, part of the Anglian Stage of the Pleistocene. It is reddish-brown or grey diamict (or till) of sandy and silty clay or clayey silt lithology. The proportion of sand varies between till units and fine sand may occur as lenses or laminae giving the till a laminated appearance. Average particle-size distribution for tills from the Lowestoft - Corton area gave 5% gravel (>2 mm), 52% sand (2 mm to 63 μm) and 43% silt (63 to 2 μm) and clay (<2 μm) (Arthurton et al, 1994).

In comparison with the Lowestoft Till the Cromer Till contains fewer clasts (Hart & Boulton, 1991), with a smaller proportion of chalk and flint, and a higher proportion of quartz and quartzite (from reworked Triassic sands and gravels). A small percentage of erratics also occur, including Scandinavian-derived rhomb porphyry and larvikite as well as mica-schists, gneisses and granitic rocks (Hart & Boulton, 1991). The Scandinavian erratics are believed to be restricted to the Corton Formation and younger sediments. The proportion of erratics is said to increase towards the coast. A typical clast composition (-8 +4 mm fraction) would comprise the following: 54% flint, 24% vein quartz, 8% quartzite plus a small amount of chalk, shell and igneous material (Cox *et al*, 1989)

The Cromer Till can locally be sub-divided into various sub-groups, including the 'Norwich Brickearth' and the 'Contorted Drift'. The former occurs as a decalcified till between Norwich and the coast to the east, e.g. around Scratby. The latter occurs between Sheringham and Cromer, especially at West Runton, where the till is dramatically deformed - possibly due to sub-glacial glaciotectonic deformation. Hart and Boulton (1991) suggest that the Cromer Till can be divided into two main glacial advances over north Norfolk. The first advance from the north deposited the 'Happisburgh Diamicton' and the second advance from the north deposited the 'Walcott Diamicton'. Lunkka (1994) suggests that, based on sedimentological evidence, the Cromer Till can be divided into four diamictons namely the Happisburgh, Walcott, Mundesley, and Cromer Diamictons. The mineralogical and particle-size data from the Lunkka (1994) paper provide a useful comparison with the data produced during the current investigation. The $CaCO_3$ contents can be seen in Figures 3 and 4 and the particle-size data can be seen in Figures 7 and 8. Clay mineralogy does not appear to provide a useful means of discrimnating between till units.

A tentative classification of the till samples has been attempted, based on the mineralogical and particle size data in Lunkka (1994).

<u>Walcott Diamicton</u> CJM 176, 180, 182 & 183

The Walcott Diamicton typically has a silty matrix (the silt proportion is greater than the sand proportion), it is often stratified and has a high $CaCO_3$ content (25 to 45%). The samples listed all have high silt contents (average 50%) and high $CaCO_3$ contents (average 30%). Also samples 176 and 183 were seen to be stratified in the field.

Happisburgh Diamicton CJM 172, 173, 175, 177, 179 & 181

The Happisburgh Diamicton typically has a sandy matrix (the sand proportion is greater than the silt proportion), a small $CaCO_3$ content (5 to 10%) and relatively few clasts. The samples listed all have high sand contents (average 53%), $CaCO_3$ contents of approximately 10% and relatively few clasts (average >2mm is 1.3%).

Norwich Brickearth CJM 170, 185, 187, 192, 194, 199, 200, 221, 223, 224, 225, 226, 227 & 228

The Norwich Brickearth is typically a sandy clay that contains virtually no $CaCO_3$. The samples listed all contain virtually no $CaCO_3$. Also most of the samples have a relatively high sand content (average 53%).

Crag Clay CJM 198, 201, 202, 204 & 205

The Crag Clay sample from Cove Hithe has a low sand and gravel content, and a high silt content (silt proportion greater than clay proportion). The samples of 'Blue Clay' from Eastern Bavents and Thorington also have a low sand and gravel content and high silt contents. All the samples contain virtually no $CaCO_3$. It is thought likely the 'Blue Clay' samples are unweathered Crag Clay.

Lowestoft Till CJM 189 & 196

These samples contain a high proportion of chalk clasts which is typical of Lowestoft Till.

Miscellaneous samples

CJM 197

The sample of Starston Till has particle-size characteristics and mineralogy (high sand content and no $CaCO_3$) similar to the samples classified as Norwich Brickearth.

CJM 217, 218 & 219

These clay samples from Sea Palling were thought likely to be Cromer Till. However their particle-size characteristics are very similar to those of the Crag Clay. Samples 217 and 218 contain no $CaCO_3$ so they could possibly be Crag Clay. Sample 219 contains approximately 10% $CaCO_3$ so it could possibly be Cromer Till.

CJM 220

This sample from Transacre estate was tentatively labelled 'Lowestoft Till or Norwich Brickearth ?'. It has a high $CaCO_3$ content (33%) similar to the Lowestoft Till samples collected from Scratby and Corton (33% and 30% $CaCO_3$ respectively). Also a large proportion of the >2 mm clasts are chalk. However the particle-size characteristics and clay mineralogy of this sample suggest it is Cromer Till, possibly Happisburgh Diamicton. Further samples would need to be analysed to provide a more conclusive classification.

5. CONCLUSIONS

1. A total of 37 samples were collected for evaluation of their physical and mineralogical characteristics. The samples were tentatively classified, according to their properties, into several till types.

2. The Cromer Till samples were divided into several units:

- Walcott Diamicton. The till samples typically have a silty matrix, with the proportion of silt greater than that of sand. Also they have a high $CaCO_3$ content. Some of the samples display characteristic lamination.
- Happisburgh Diamicton. The till samples typically have a sandy matrix, with the proportion of sand greater than the silt and a $CaCO_3$ content of approximately 10%.

- Norwich Brickearth. The till samples typically have a relatively high sand content and contain virtually no $CaCO_3$.

3. The Crag Clay samples have a low sand and gravel content, a high silt content and contain virtually no $CaCO_3$.

4. The Lowestoft Till samples contain a high proportion of chalk clasts.

5. Miscellaneous. The Starston Till is tentatively classified as Norwich Brickearth. The samples from Sea Palling are tentatively classified as either Crag Clay (217 & 218) or Cromer Till (219). Some doubt remains as to the classification of sample 220 from Transacre Estate. It may be Lowestoft or Cromer Till.

6. RECOMMENDATIONS

A detailed logging and sampling programme of coastal drift sections is recommended, for example at Trimingham where a thick sequence of till exists, with the collection of large samples (5 - 10 kg) specifically for clast analysis. Statistically valid clast analysis requires the identification of approximately 300 to 500 clasts per sample. Heavy mineral analysis would also aide the classification of till samples.

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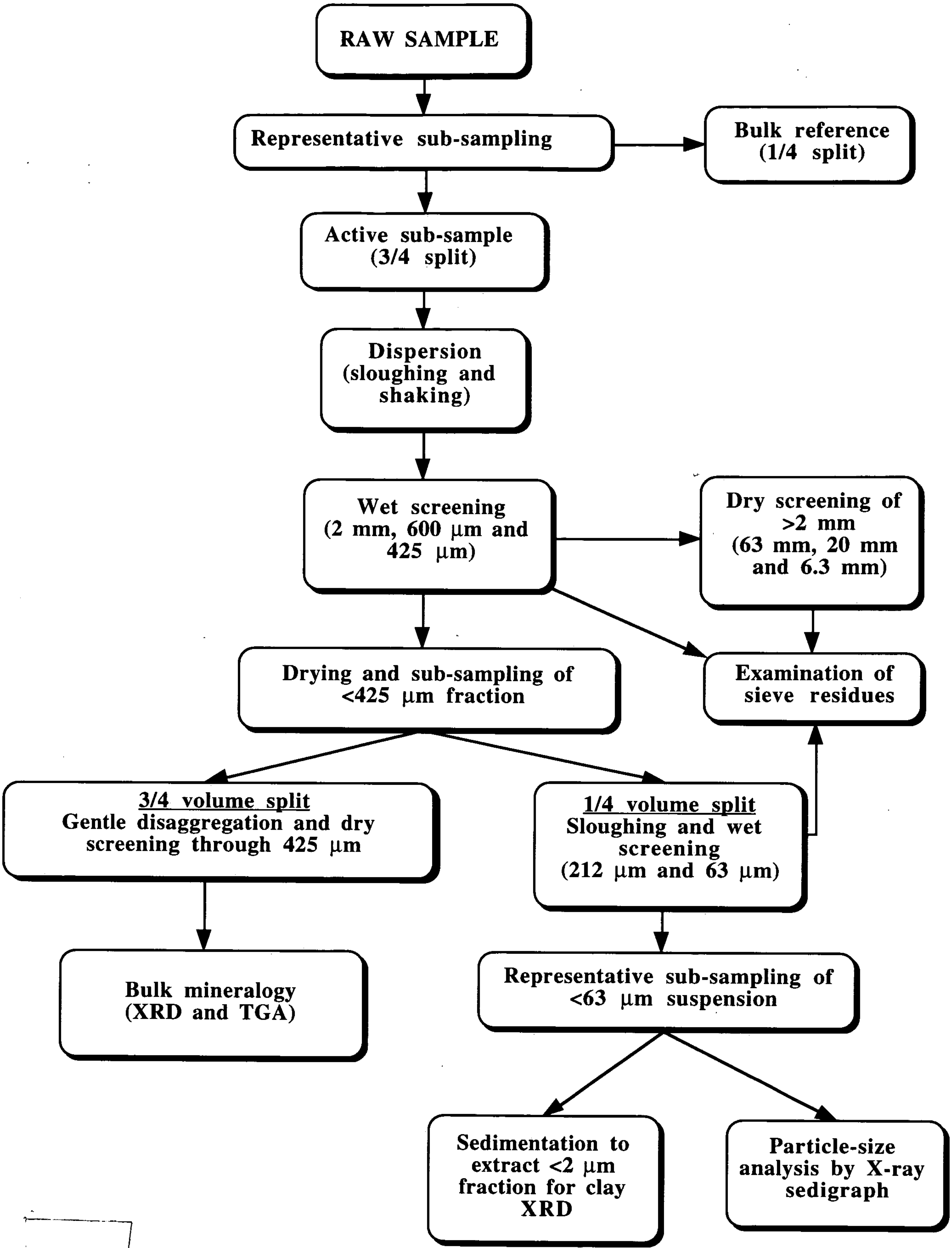


Figure 2. Sample preparation flowsheet for East Anglian till samples

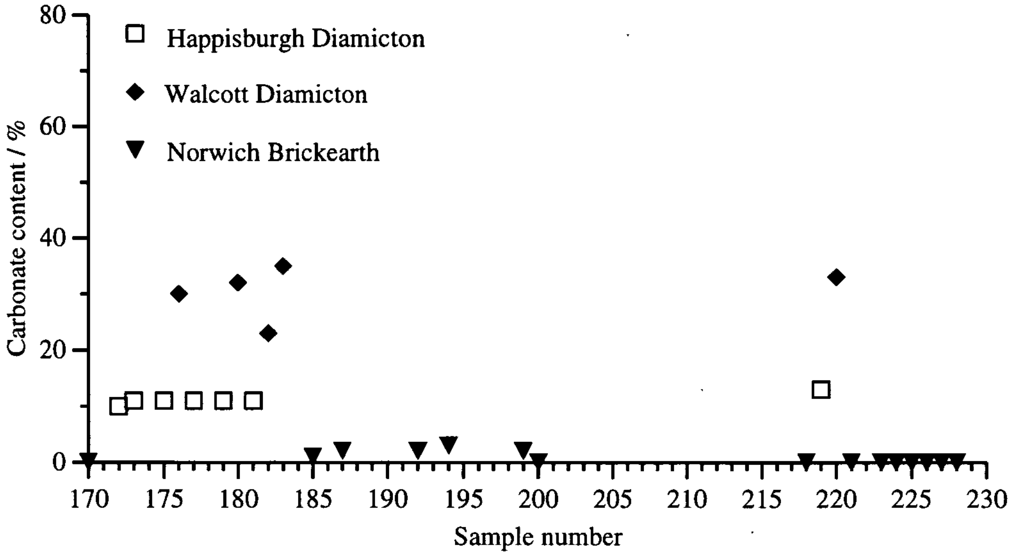


Figure 3. Calcium carbonate content (<425 μm) of the Cromer Till samples

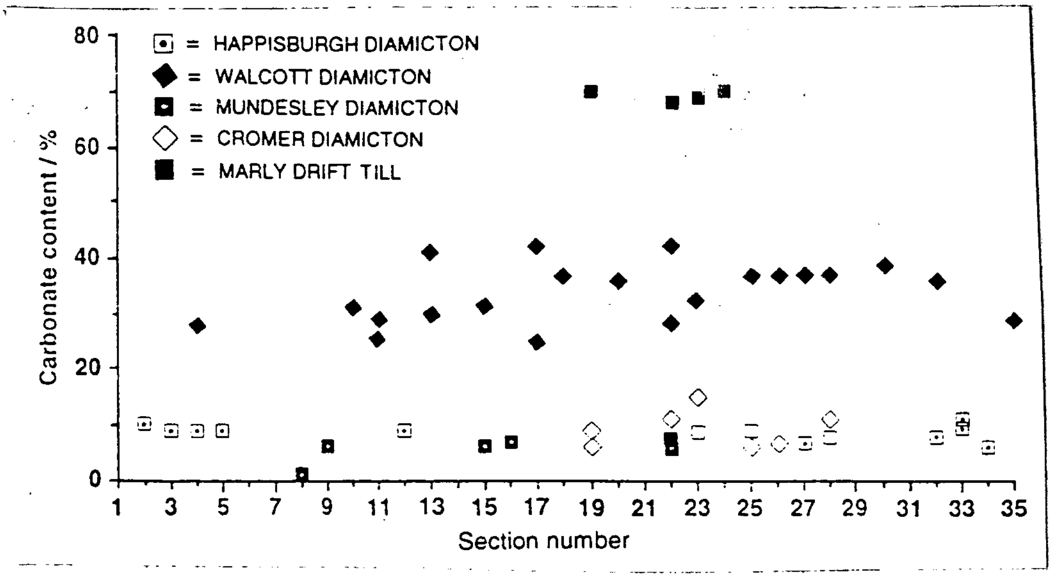


Figure 4. Calcium carbonate content (<2 mm) of the Cromer Till samples (Lunkka, 1994)

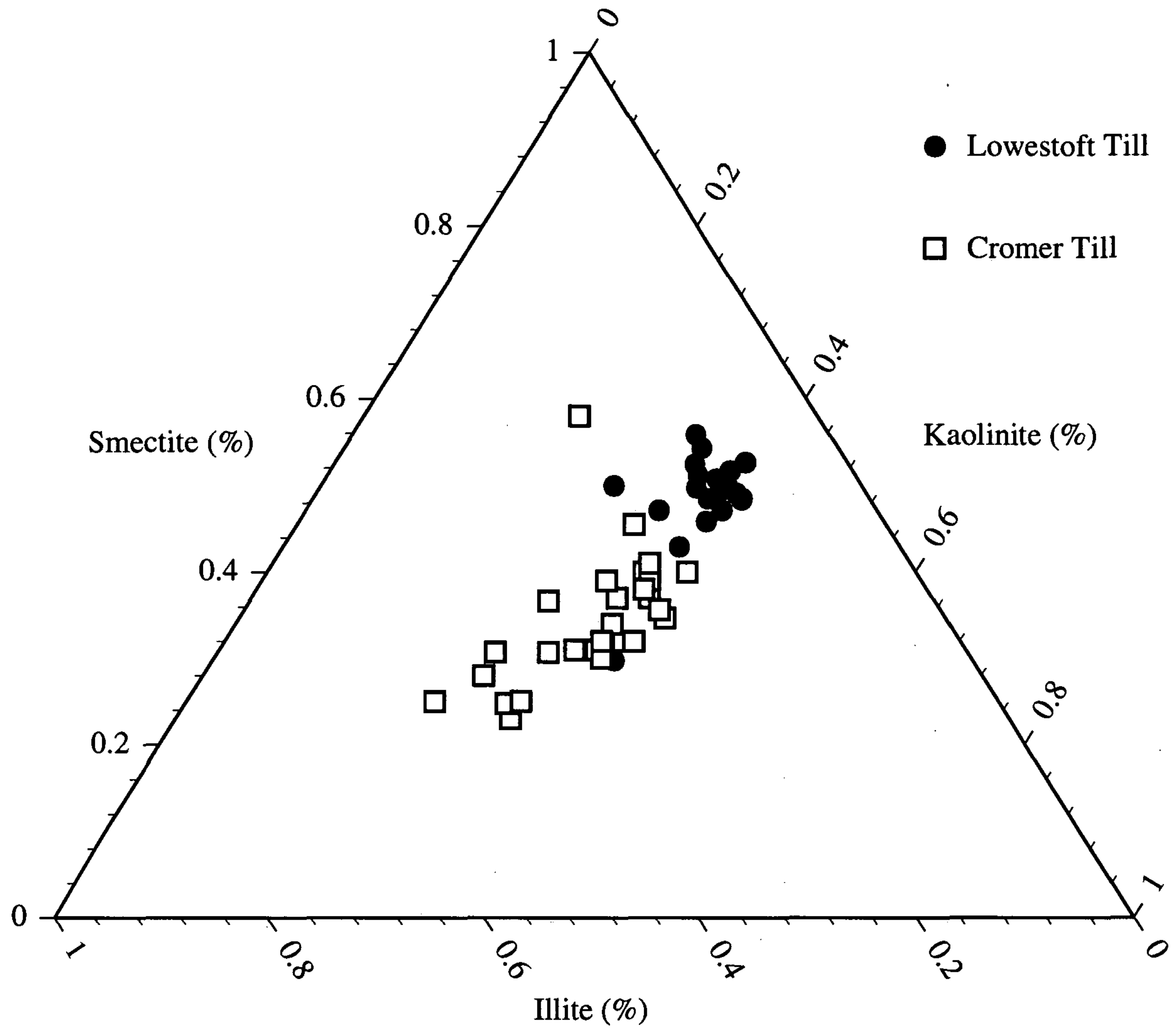


Figure 5 Clay mineralogy of Cromer Till and Lowestoft Till, East Anglia
(Lowestoft data from Inglethorpe, 1994)

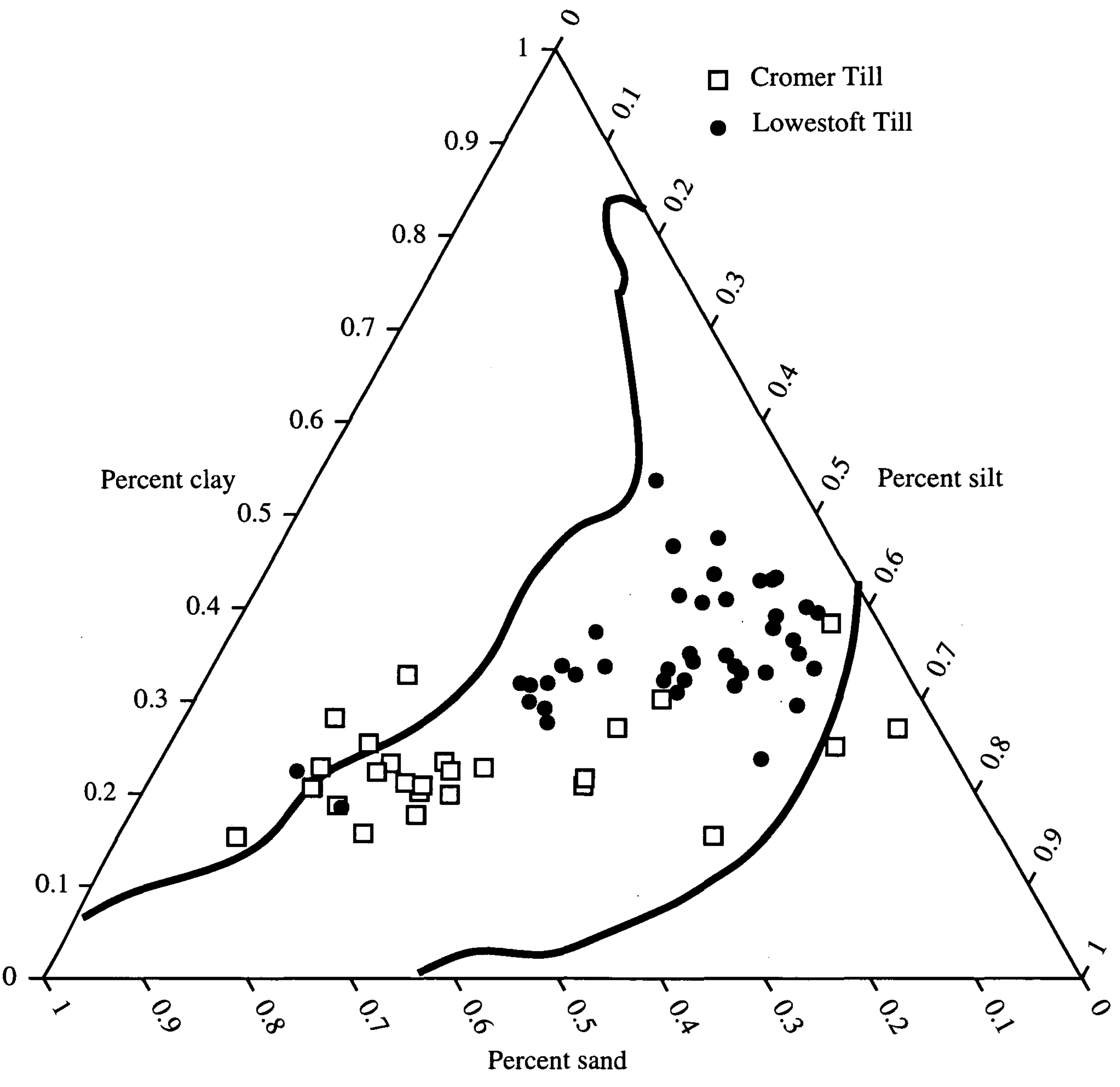


Figure 6 Ternary particle-size distribution plots for Cromer and Lowestoft Till, East Anglia (Lowestoft data from Inglethorpe, 1994)

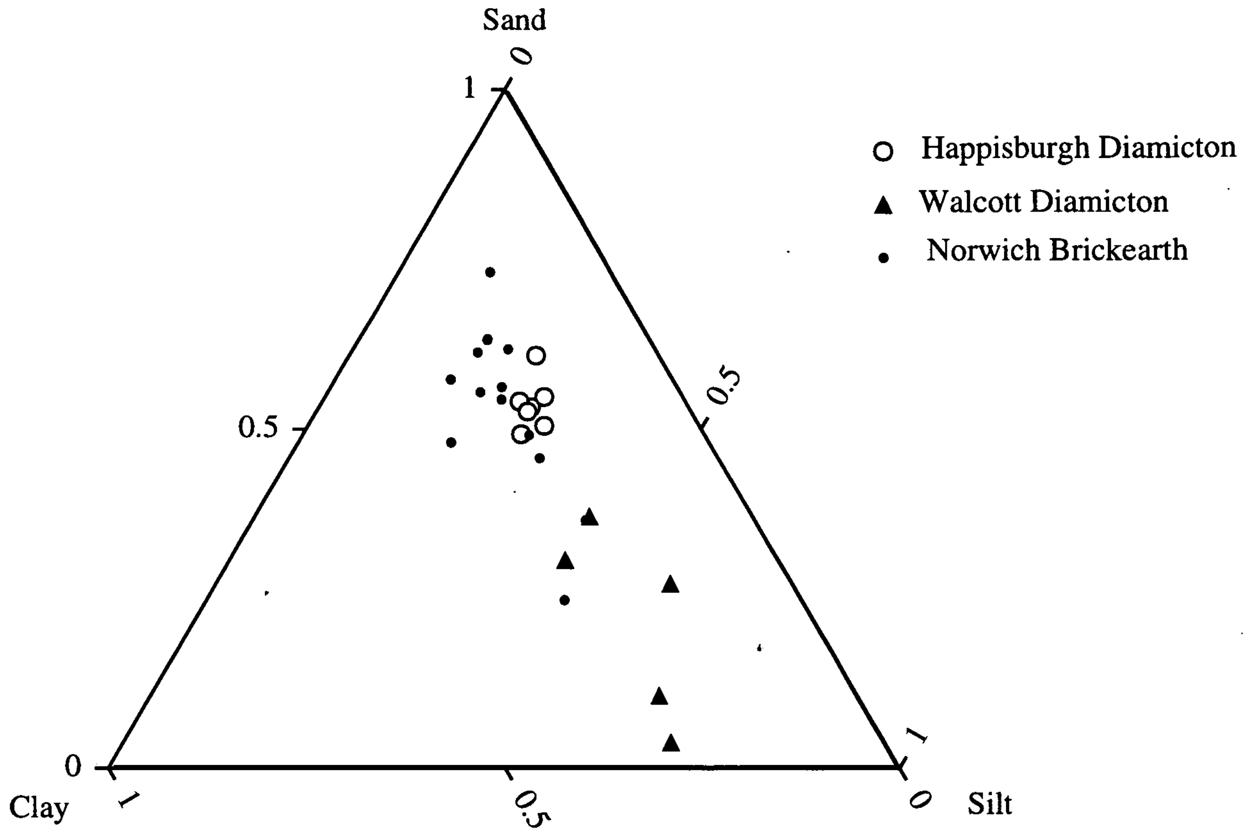


Figure 7 Ternary plot of the particle-size distribution (<2 mm) of the Cromer Till,East Anglia

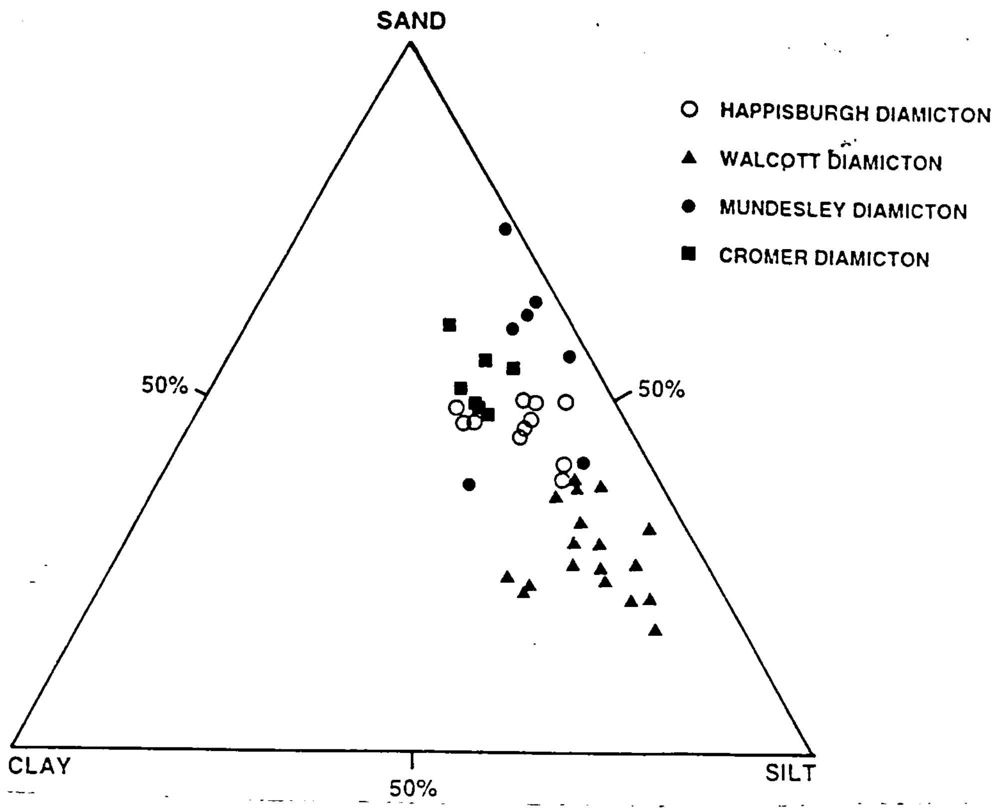


Figure 8 Ternary plot of the particle-size distribution (<2 mm) of the Cromer Till, East Anglia (Lunkka, 1994)

Table 2. Modal mineralogy of >425 μm fraction (clast content), East Anglia Till

Sample (CJM)	Fraction	Modal analysis (particle percentage) Flint	Chalk	Quartz	Sandstone	Fe oxide	Other
Cromer Till							
Upper Hellesden, Norwich							
170	>2 mm	60		30	10		
	2 mm - 600 μm	30		50	20		
	600 - 425 μm	5	2	90		3	
Trimingham							
172	>2 mm	50	20				Shell (30)
	2 mm - 600 μm	25		50	15	2	Shell (3) ; Coal (3) ; Pyrite (2)
	600 - 425 μm	10	3	80	4	3	Pyrite (1)
173	>2 mm	25	5	30	15		Shell (20) ; Pyrite (5)
	2 mm - 600 μm	25	5	60	2	1	Shell (5) ; Coal (1) ; Pyrite (1)
	600 - 425 μm	5	2	90	2		
175	>2 mm	35	15	30	10		Shell (10)
	2 mm - 600 μm	15	20	60	3		Shell (2)
	600 - 425 μm	3	5	90		2	
180	>2 mm	30	30	10	30		
	2 mm - 600 μm		25	50	25		
	600 - 425 μm	1	5	90	4		
West Runton							
176	>2 mm	5	95				
	2 mm - 600 μm	15	30	40	15		
	600 - 425 μm	3	10	80	5		Coal (2)
177	>2 mm	30	15	20	25		Shell (10)
	2 mm - 600 μm	20	20	40	3		Shell (15) ; Coal (2)
	600 - 425 μm	2	2	80	15		Shell (1)
179	>2 mm	80	5	5	5		Shell (5)
	2 mm - 600 μm	5	15	60	10		Shell (10)
	600 - 425 μm	5	5	90			
Happisburgh							
181	>2 mm	35	10	20	25		Shell (10)
	2 mm - 600 μm	10	10	60	5		Shell (10) ; Coal (5)
	600 - 425 μm		4	90			Coal (4) ; Pyrite (2)
182	>2 mm	50	25		25		
	2 mm - 600 μm	2	5	80	3		Coal (10)
	600 - 425 μm			80	10	10	
183	>2 mm	35		30	35		
	2 mm - 600 μm		5	60	30		Shell (5)
	600 - 425 μm	4		90	4		Coal (2)

Table 2. Modal mineralogy of >425 μm fraction (clast content), East Anglia Till

Sample (CJM)	Fraction	Flint	Chalk	Quartz	Sandstone	Fe oxide	Other
Cromer Till							
California Cliffs, Scratby							
185	>2 mm	50		50			
	2 mm - 600 μm			50	50		
	600 - 425 μm			65	35		
187	>2 mm	35		30	35		
	2 mm - 600 μm	5		60	35		
	600 - 425 μm			80	20		
Welcome Quarry, Burgh Castle, Nr Great Yarmouth							
192	>2 mm	75			25		
	2 mm - 600 μm	10		50	40		
	600 - 425 μm			90	10		
Corton							
194	>2 mm	65	5	25			Limestone (5)
	2 mm - 600 μm	10		80	10		
	600 - 425 μm	5		90	5		
Covehithe							
199	>2 mm	10			90		
	2 mm - 600 μm	5		5	90		
	600 - 425 μm			40	60		
200	>2 mm	80		5	15		
	2 mm - 600 μm	3		60	30	5	Coal (2)
	600 - 425 μm			90	5	5	
Sea Palling							
218	>2 mm				100		
	2 mm - 600 μm			5	95		
	600 - 425 μm	5		15	80		
219	>2 mm				100		
	2 mm - 600 μm			10	90		
	600 - 425 μm			19	80		Coal (1)
Transacre Estate							
220	>2 mm	25	60	15			
	2 mm - 600 μm	5	15	80			
	600 - 425 μm	2	3	95			
221	>2 mm	70		25	3		Siltstone (2); Rhomb Porphyry (1)
	2 mm - 600 μm	10		80	10		
	600 - 425 μm	5		95			
Waxham							
223	>2 mm	40		20	39		Rhomb Porphyry (1)
	2 mm - 600 μm	10		80	19		Siltstone (1)
	600 - 425 μm			95	5		

Table 2. Modal mineralogy of >425 μm fraction (clast content), East Anglia Till

Sample (CJM)	Fraction	Flint	Chalk	Quartz	Sandstone	Fe oxide	Other
Cromer Till							
Norwich Airport							
224	>2 mm	50		10	40		
	2 mm - 600 μm	5		80	15		
	600 - 425 μm			95	5		
225	>2 mm	50		5	40	5	
	2 mm - 600 μm	5		80	15		
	600 - 425 μm			95	5		
226	>2 mm	70		10	20		
	2 mm - 600 μm	5		80	15		
	600 - 425 μm			99	1		
Ludham							
227	>2 mm	50		5	40		Coal (5)
	2 mm - 600 μm	10		80	10		
	600 - 425 μm			95	5		
228	>2 mm	40		10	50		
	2 mm - 600 μm	5		75	20		
	600 - 425 μm			95	5		
? Cromer Till							
Starston Till, Harleston							
197	>2 mm	90		5	5		
	2 mm - 600 μm	25		45	20	10	
	600 - 425 μm			80	5	10	Feldspar (5)
'Clay', Sea Palling							
217	>2 mm	90			10		
	2 mm - 600 μm	10		80	10		
	600 - 425 μm	5		90	5		
Lowestoft Till							
California Cliffs, Scratby							
189	>2 mm	10	75	5	10		
	2 mm - 600 μm	5	40	20	30		Shell (5)
	600 - 425 μm	5	30	35	30		
Corton							
196	>2 mm	2	75	2	20		Shell (1)
	2 mm - 600 μm	20	45	10	10		Shell (5) ; Coal (10)
	600 - 425 μm	10	30	50			Coal (10)

Modal analysis (particle percentage) columns: Flint, Chalk, Quartz, Sandstone, Fe oxide, Other.

Table 2. Modal mineralogy of >425 µm fraction (clast content), East Anglia Till

Sample (CJM)	Fraction	Modal analysis (particle percentage) Flint	Chalk	Quartz	Sandstone	Fe oxide	Other
Crag Clay							
Covehithe							
198	>2 mm				100		
	2 mm - 600 µm			5	95		
	600 - 425 µm	5		5	90		
Blue Clay							
Easton Bavents							
201	>2 mm						
	2 mm - 600 µm	20		60	20		
	600 - 425 µm			90	5	5	
202	>2 mm	90			10		
	2 mm - 600 µm			30	70		
	600 - 425 µm			40	60		
ARC Quarry, Thorington							
204	>2 mm				100		
	2 mm - 600 µm			50	50		
	600 - 425 µm			30	70		
205	>2 mm	50		50			
	2 mm - 600 µm			30	70		
	600 - 425 µm			18	80	2	
? Holocene							
Waxham							
222	>2 mm	75		5	5	15	
	2 mm - 600 µm			20	50	30	
	600 - 425 µm			80	10	10	

Table 3 Mineralogy of <425 μm fraction (matrix), East Anglia Till

Sample (CJM)	Quartz	Feldspar	Mica	Calcite	Kaolinite	Pyrite
Cromer Till						
Upper Hellesden, Norwich						
170	**** (91)	**	*	nd	nd	nd
Trimingham						
172	**** (81)	**	*	** (10)	*	nd
173	**** (83)	**	*	** (11)	*	nd
175	**** (87)	**	*	** (11)	*	nd
180	**** (65)	**	*	*** (32)	*	nd
West Runton						
176	*** (44)	**	*	*** (30)	*	nd
177	**** (79)	**	*	** (11)	*	nd
179	**** (81)	**	*	** (11)	*	nd
Happisburgh						
181	**** (83)	**	*	** (11)	*	nd
182	**** (37)	**	*	*** (23)	*	nd
183	*** (46)	**	*	*** (35)	*	nd
California Cliffs, Scratby						
185	**** (84)	***	*	* (1)	*	nd
187	**** (78)	***	*	* (2)	*	nd
Welcome Quarry, Burgh Castle						
192	**** (89)	**	*	* (2)	*	nd
Corton						
194	**** (92)	**	*	* (3)	*	nd
Covehithe						
199	**** (89)	**	*	* (2)	nd	nd
200	**** (68)	**	*	nd	*	nd
Sea Palling						
218	*** (37)	**	*	nd	*	nd
219	*** (47)	**	*	** (13)	*	nd
Transacre Estate						
220	*** (38)	**	*	*** (33)	*	nd
221	**** (77)	**	*	nd	*	nd
Waxham						
223	**** (64)	**	*	nd	*	nd
Norwich Airport						
224	**** (79)	**	*	nd	*	nd
225	**** (81)	**	*	nd	*	nd
226	**** (78)	**	*	nd	*	nd
Ludham						
227	**** (77)	**	*	nd	*	nd
228	**** (79)	**	*	nd	*	nd

N.B. The proportion of minerals present are given in a 4 star ranking, relative to their peak intensity on an XRD trace. The ranking is as follows : **** = Dominant (> 50 wt %), *** = Major (20 - 50 wt %), ** = Minor (7 - 20 wt %) and * = Trace (<7 wt %)
The figures in brackets are weight percentages.

Table 3 Mineralogy of <425 μm fraction (matrix), East Anglia Till

Sample (CJM)	Quartz	Feldspar	Mica	Calcite	Kaolinite	Pyrite
? Cromer Till						
Starston Till, Harleston						
197	**** (86)	*	nd	nd	*	nd
'Clay', Sea Palling						
217	**** (57)	**	*	nd	*	nd
Lowestoft Till						
California Cliffs, Scratby						
189	**** (66)	**	*	*** (33)	*	nd
Corton						
196	*** (37)	**	*	*** (30)	*	**
Crag Clay						
Covehithe						
198	**** (67)	**	**	* (2)	*	nd
Blue Clay						
Easton Bavents						
201	*** (37)	**	*	nd	*	nd
202	**** (60)	*	*	nd	*	nd
ARC Quarry, Thorington						
204	**** (76)	**	*	* (2)	*	nd
205	*** (38)	**	*	nd	*	nd
? Holocene						
Waxham						
222	*** (41)	**	*	nd	*	nd

N.B. The proportion of minerals present are given in a 4 star ranking, relative to their peak intensity on an XRD trace. The ranking is as follows : **** = Dominant (> 50 wt %), *** = Major (20 - 50 wt %), ** = Minor (7 - 20 wt %) and * = Trace (<7 wt %)
The figures in brackets are weight percentages.

Table 4 Mineralogy of <2 μm fraction (clay content), East Anglia Till

Sample (CJM)	Smectite (wt %)	Illite (wt %)	Kaolinite (wt %)	Total (wt %)
Cromer Till				
Upper Hellesden, Norwich				
170	25	35	40	100
Trimingham				
172	26	37	37	100
173	25	36	39	100
175	26	40	35	100
180	46	31	23	100
West Runton				
176	34	35	31	100
177	31	37	32	100
179	39	31	31	100
Happisburgh				
181	21	39	40	100
182	26	39	36	100
183	31	35	34	100
California Cliffs, Scratby				
185	46	30	25	100
187	44	31	25	100
Welcome Quarry, Burgh Castle				
192	30	38	32	100
Corton				
194	34	36	30	100
Covehithe				
199	23	31	45	100
200	22	20	58	100
Sea Palling				
218	36	28	37	100
219	29	34	37	100
Transacre Estate				
220	46	26	28	100
221	52	23	25	100
Waxham				
223	44	26	31	100
Norwich Airport				
224	36	33	31	100
225	26	36	38	100
226	33	35	32	100
Ludham				
227	29	32	39	100
228	24	35	41	100

Table 4 Mineralogy of <2 μm fraction (clay content), East Anglia Till

Sample (CJM)	Smectite (wt %)	Illite (wt %)	Kaolinite (wt %)	Total (wt %)
? Cromer Till				
Starston Till, Harleston				
197	30	25	44	100
'Clay', Sea Palling				
217	32	33	35	100
Lowestoft Till				
California Cliffs, Scratby				
189 *	20	35	45	100
Corton				
196 *	5	40	55	100
Crag Clay				
Covehithe				
198	35	33	32	100
Blue Clay				
Easton Bavents				
201	38	26	36	100
202	45	23	31	100
ARC Quarry, Thorington				
204	46	28	26	100
205	26	29	45	100
? Holocene				
Waxham				
222	23	37	40	100

* Smectite present in the mixed-layer clay mineral illite-smectite

Table 5 Particle-size distribution, East Anglian Till

	Size fraction	Cromer Till										
		Hellesden	Trimingham				West Runton			Happisburgh		
	(CJM)	170	172	173	175	180	176	177	179	181	182	183
Gravel / cobbles	>2 mm	0.84	0.88	0.88	2.10	2.03	13.89	1.66	1.40	1.20	0.02	0.01
Coarse sand	2 mm - 600 µm	2.50	1.69	1.55	2.23	2.29	2.32	1.21	1.14	1.72	0.03	0.04
Medium coarse sand	600 - 425 µm	5.90	2.13	2.07	2.90	1.62	1.56	1.32	1.27	1.90	0.16	0.05
Medium fine sand	425 - 212 µm	12.51	10.11	9.86	12.95	6.87	5.59	8.61	6.95	9.64	0.84	0.42
Fine sand	212 - 63 µm	39.90	38.80	40.11	41.50	25.55	16.95	40.57	39.17	36.60	26.20	10.20
Coarse silt	63 - 10 µm	9.97	7.42	7.28	7.66	13.56	9.55	8.39	7.01	8.32	28.37	19.64
Fine silt	10 -2 µm	5.75	19.02	17.30	15.32	27.73	26.86	17.72	20.03	21.04	29.10	44.64
Clay	2 - 0.5 µm	5.75	12.99	14.11	10.73	16.02	21.49	13.06	14.52	12.72	10.18	16.96
	<0.5 µm	16.87	6.96	6.83	4.60	4.31	1.79	7.46	8.51	6.85	5.09	8.03
	Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

	Size fraction	Cromer Till		Burgh								
		California Cliffs		Castle	Corton	Covehithe		Sea Palling		Transacre Estate		Waxham
	(CJM)	185	187	192	194	199	200	218	219	220	221	223
Gravel / cobbles	>2 mm	0.07	0.03	0.59	4.03	0.15	5.53	0.02	6.50	2.13	6.27	1.70
Coarse sand	2 mm - 600 µm	0.95	0.18	2.80	3.28	0.48	3.56	0.42	0.63	3.20	3.65	3.20
Medium coarse sand	600 - 425 µm	1.26	0.23	3.68	3.73	0.10	3.76	0.52	0.72	5.99	5.49	3.97
Medium fine sand	425 - 212 µm	6.39	1.82	14.10	26.07	0.57	11.79	0.96	0.74	19.38	10.62	9.68
Fine sand	212 - 63 µm	27.90	22.52	33.50	37.23	47.88	24.07	2.65	1.47	25.06	32.91	30.33
Coarse silt	63 - 10 µm	18.40	24.07	9.07	5.90	20.33	15.90	24.82	33.28	7.08	11.09	10.22
Fine silt	10 -2 µm	23.47	21.06	13.15	5.13	8.13	13.85	32.45	31.48	19.91	9.03	8.69
Clay	2 - 0.5 µm	8.88	13.54	9.97	6.16	5.59	10.26	14.32	12.59	13.27	7.39	9.20
	<0.5 µm	12.69	16.55	13.15	8.47	16.77	11.28	23.86	12.59	3.98	13.55	23.01
	Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 5 Particle-size distribution, East Anglian Till

	Size fraction	Cromer Till					? Cromer Till		Lowestoft Till		Crag Clay
		Norwich Airport			Ludham		Starston	Sea Palling	Scratby	Corton	Covehithe
	(CJM)	**224**	**225**	**226**	**227**	**228**	**197**	**217**	**189**	**196**	**198**
Gravel / cobbles	**>2 mm**	1.16	0.69	0.91	1.20	0.84	12.43	0.81	7.75	4.19	0.61
Coarse sand	**2 mm - 600 µm**	2.86	2.85	2.80	3.33	3.21	6.05	0.62	1.95	1.95	0.45
Medium coarse sand	**600 - 425 µm**	4.29	4.51	5.02	5.04	5.63	5.26	0.24	3.57	0.67	0.10
Medium fine sand	**425 - 212 µm**	15.51	16.06	15.65	17.36	16.78	19.08	0.86	7.82	1.99	0.19
Fine sand	**212 - 63 µm**	39.81	39.50	37.81	29.06	31.33	15.38	8.39	22.81	5.05	10.75
Coarse silt	**63 - 10 µm**	9.46	9.83	12.48	10.56	5.91	8.36	66.81	9.54	13.79	27.25
Fine silt	**10 -2 µm**	6.55	6.19	6.81	8.36	8.44	7.94	11.58	24.12	29.29	21.98
Clay	**2 - 0.5 µm**	7.64	7.64	7.18	10.12	9.29	6.69	5.34	12.34	23.26	14.07
	<0.5 µm	12.73	12.74	11.34	14.97	18.57	18.81	5.34	10.10	19.82	24.61
	Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

	Size fraction	Blue Clay				? Holocene
		Easton Bavents		Thorington		Waxham
	(CJM)	**201**	**202**	**204**	**205**	**222**
Gravel / cobbles	**>2 mm**	0.00	0.06	0.01	0.02	1.20
Coarse sand	**2 mm - 600 µm**	0.02	0.05	0.01	0.05	0.82
Medium coarse sand	**600 - 425 µm**	0.07	0.14	0.05	0.07	1.35
Medium fine sand	**425 - 212 µm**	1.18	2.04	0.05	0.20	5.40
Fine sand	**212 - 63 µm**	4.76	5.21	2.28	1.49	12.79
Coarse silt	**63 - 10 µm**	22.55	14.80	46.85	16.69	22.75
Fine silt	**10 -2 µm**	39.47	32.38	23.43	38.29	16.47
Clay	**2 - 0.5 µm**	11.28	23.13	10.74	22.58	14.90
	<0.5 µm	20.67	22.20	16.59	20.62	24.32
	Total	100.00	100.00	100.00	100.00	100.00

Table 6. Summary of particle-size statistics, East Anglian Till

	Parameter	Cromer Till										
		Hellesden	Trimingham				West Runton			Happisburgh		
	(CJM)	**170**	**172**	**173**	**175**	**180**	**176**	**177**	**179**	**181**	**182**	**183**
> 2mm	**Gravel (wt %)**	0.84	0.88	0.88	2.10	2.03	13.90	1.66	1.40	1.20	0.00	0.01
63 µm - 2 mm	**Sand (wt %)**	60.82	52.73	53.59	59.59	36.34	26.42	51.71	48.53	49.86	27.20	10.71
2 µm - 63 µm	**Silt (wt %)**	15.72	26.44	24.58	22.99	41.29	36.41	26.12	27.04	29.36	57.50	64.28
< 2 µm	**Clay (wt %)**	22.62	19.95	20.94	15.32	20.34	23.28	20.52	23.03	19.58	15.30	25.00
	Total (wt %)	100.00	100.00	100.00	100.00	100.00	100.01	100.00	100.00	100.00	100.00	100.00
	Matrix (<2 mm)											
	Mean (phi)	3.76	3.50	3.55	3.19	3.93	3.59	3.56	3.71	3.53	4.19	5.16
	Mean (µm)	23.27	30.26	28.78	41.21	19.73	27.64	28.48	24.52	29.32	15.13	5.75
	Median (µm)	105.00	77.00	78.00	100.00	20.00	67.00	75.00	67.00	70.00	15.00	5.00
	Standard deviation (phi)	2.88	2.28	2.31	2.17	2.23	2.15	2.29	2.33	2.29	1.88	1.81
	Skewness	0.76	0.55	0.56	0.58	0.06	0.53	0.56	0.55	0.52	0.07	-0.12

	Parameter	Cromer Till		Burgh								
		California Cliffs		Castle	Corton	Covehithe		Sea Palling		Transacre Estate		Waxham
	(CJM)	**185**	**187**	**192**	**194**	**199**	**200**	**218**	**219**	**220**	**221**	**223**
> 2mm	**Gravel (wt %)**	0.07	0.03	0.59	4.03	0.15	5.50	0.00	6.50	2.10	6.30	1.70
63 µm - 2 mm	**Sand (wt %)**	36.50	24.75	54.07	70.31	49.03	43.20	4.50	3.60	53.60	52.70	47.20
2 µm - 63 µm	**Silt (wt %)**	41.87	45.13	22.21	11.03	28.46	29.80	57.30	64.80	27.00	20.10	18.90
< 2 µm	**Clay (wt %)**	21.57	30.09	23.12	14.62	22.36	21.50	38.20	25.20	17.30	20.90	32.20
	Total (wt %)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	Matrix (<2 mm)											
	Mean (phi)	4.26	4.08	3.60	2.70	4.16	3.57	5.82	4.56	3.15	3.21	4.13
	Mean (µm)	14.15	16.85	27.25	67.50	15.58	28.06	2.96	10.47	42.80	40.23	16.06
	Median (µm)	18.00	95.00	85.00	170.00	63.00	85.00	3.70	9.00	115.00	140.00	74.00
	Standard deviation (phi)	2.47	2.40	2.62	2.15	2.77	2.37	2.21	2.42	2.22	2.53	3.16
	Skewness	0.20	0.89	0.60	0.72	0.72	0.63	0.12	-0.03	0.61	0.72	0.63

Table 6. Summary of particle-size statistics, East Anglian Till

	Parameter	Cromer Till					? Cromer Till		Lowestoft Till		Crag Clay
		Norwich Airport			Ludham		Starston	Sea Palling	Scratby	Corton	Covehithe
	(CJM)	**224**	**225**	**226**	**227**	**228**	**197**	**217**	**189**	**196**	**198**
> 2mm	**Gravel (wt %)**	1.20	0.70	0.90	1.20	0.80	12.43	0.80	7.75	4.19	0.61
63 μm - 2 mm	**Sand (wt %)**	62.50	62.90	61.30	54.80	56.90	45.77	10.10	36.16	9.65	11.49
2 μm - 63 μm	**Silt (wt %)**	16.00	16.00	19.30	18.90	14.40	16.30	78.40	33.66	43.08	49.23
< 2 μm	**Clay (wt %)**	20.40	20.40	18.50	25.10	27.90	25.50	10.70	22.44	43.08	38.68
	Total (wt %)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	Matrix (<2 mm)										
	Mean (phi)	3.38	3.38	3.28	3.57	3.71	3.22	4.04	3.65	5.06	5.65
	Mean (μm)	33.89	34.09	37.52	28.23	24.58	40.08	17.64	25.92	6.34	3.52
	Median (μm)	110.00	110.00	110.00	100.00	110.00	230.00	22.00	67.00	3.70	3.80
	Standard deviation (phi)	2.56	2.57	2.46	2.66	2.82	2.88	1.55	2.34	2.59	2.52
	Skewness	0.66	0.66	0.64	0.64	0.68	0.87	0.26	0.54	-0.25	0.03

	Parameter	Blue Clay				? Holocene
		Easton Bavents		Thorington		Waxham
	(CJM)	**201**	**202**	**204**	**205**	**222**
> 2mm	**Gravel (wt %)**	0.00	0.06	0.01	0.00	1.20
63 μm - 2 mm	**Sand (wt %)**	6.00	7.44	2.38	1.80	20.40
2 μm - 63 μm	**Silt (wt %)**	62.00	47.18	70.28	55.00	39.20
< 2 μm	**Clay (wt %)**	31.90	45.33	27.33	43.20	39.20
	Total (wt %)	100.00	100.00	100.00	100.00	100.00
	Matrix (<2 mm)					
	Mean (phi)	5.72	5.89	5.31	6.07	4.31
	Mean (μm)	3.28	2.76	4.95	2.31	13.42
	Median (μm)	4.20	2.60	9.60	2.70	70.00
	Standard deviation (phi)	2.16	2.04	1.93	1.77	2.86
	Skewness	0.15	-0.11	0.47	0.07	0.70

Table 7. Summary of mineralogical and particle-size data for Cromer Till samples, East Anglia

Mineralogy

>425 µm fractions (clasts)	Flint	Chalk	Quartz	Sandstone	Other
> 2 mm					
Range (%)	5 - 90	0 - 95	0 - 50	0 - 100	Shell 0 - 30; Pyrite 0 - 5; Limestone 0 - 5 ; Siltstone 0 - 2; Porphyry 0 - 1
Average (%)	42.4	10.6	14.3	28.8	Shell 3.2; Pyrite 0.2; Limestone 0.2; Siltstone <0.1; Rhomb Porphyry <0.1
2 mm - 600 µm					
Range (%)	0 - 30	0 - 30	10 - 80	2 - 95	Shell 0 - 20; Coal 0 -5; Pyrite 0 - 2; Siltstone 0 - 1
Average (%)	8.7	5.6	58	25	Shell 2.0; Coal 0.9; Pyrite 0.1; Siltstone <0.1
600 - 425 µm					
Range (%)	0 - 10	0 - 10	15 - 90	0 - 80	Pyrite 0 - 2; Coal 0 - 4; Feldspar 0 - 5
Average (%)	2	1.5	81.6	13.5	Pyrite 0.1; Coal 0.3; Feldspar 0.2

<425 µm fractions (matrix)	Quartz	Feldspar	Mica	Calcite	Kaolinite	Pyrite
Range (wt % or intensity)	37 - 91	** - ***	*	nd - 33	nd - *	nd
Average (wt % or intensity)	71.6	**	*	8.9	*	nd

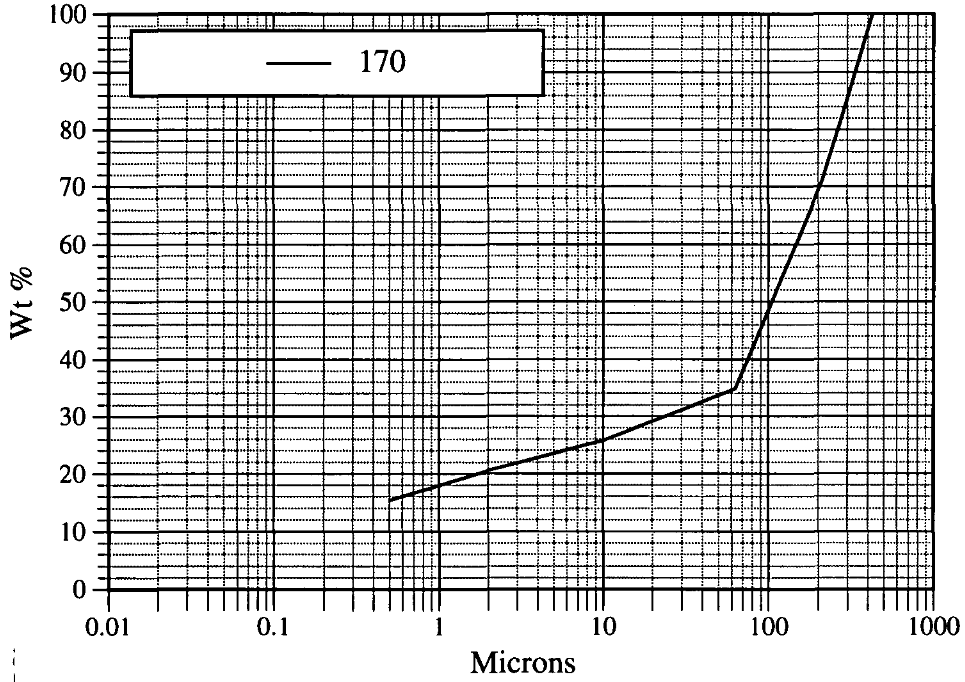
<2 µm fractions (clay)	Smectite	Illite	Kaolinite
Range (wt %)	21 - 52	20 - 40	23 - 58
Average (wt %)	33	33	34

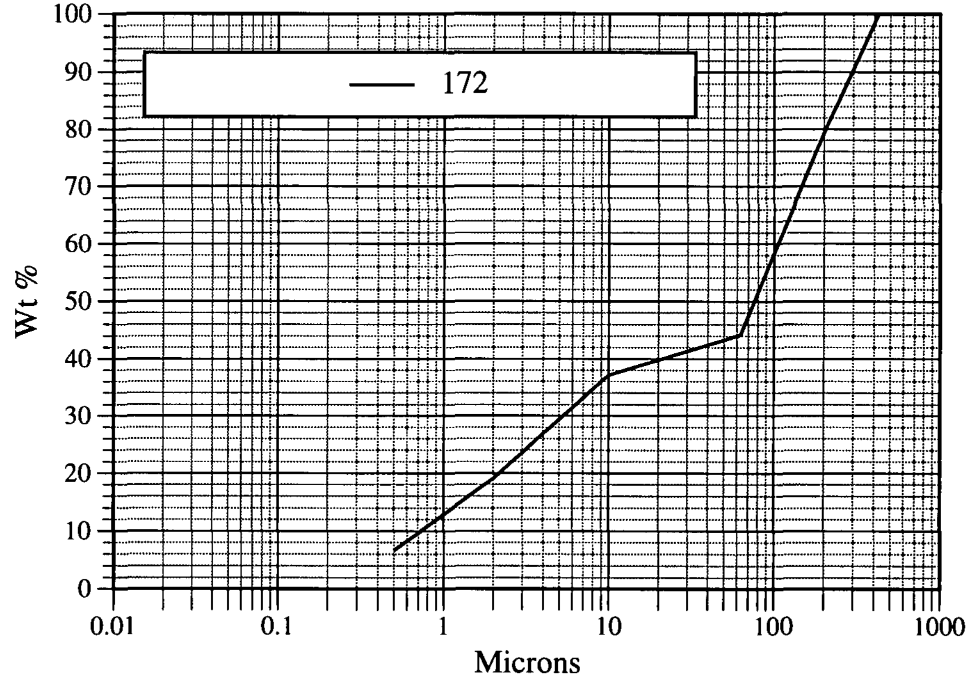
N.B. Figures for >425 µm are volume percentages. Intensities for <425µm are as follows: *** = 20-50%, ** = 7-20% and * = <7%. nd = not detected

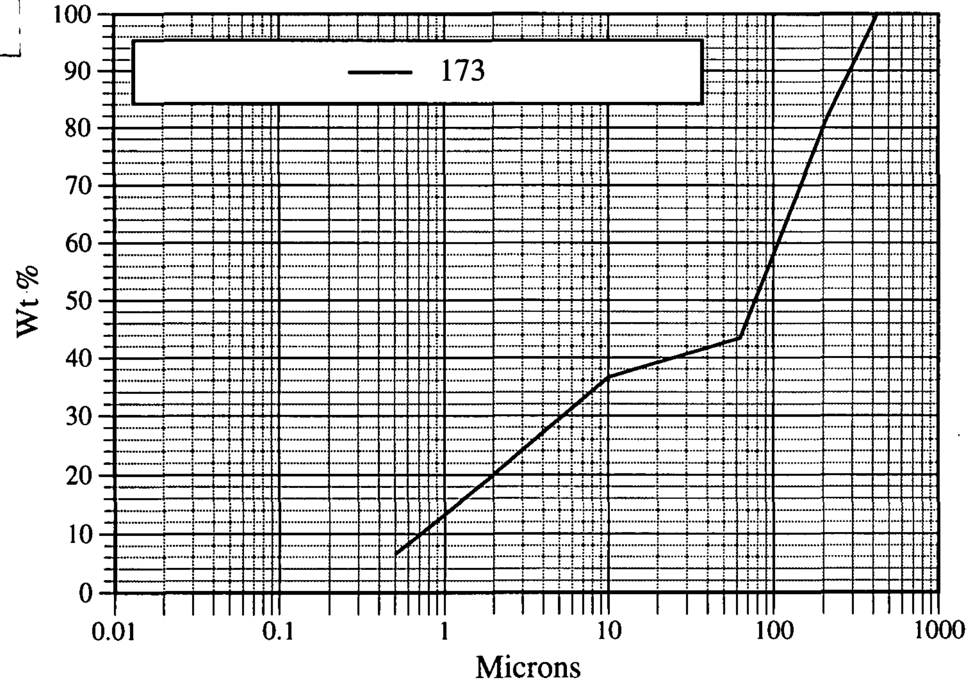
Particle-size distribution and statistics

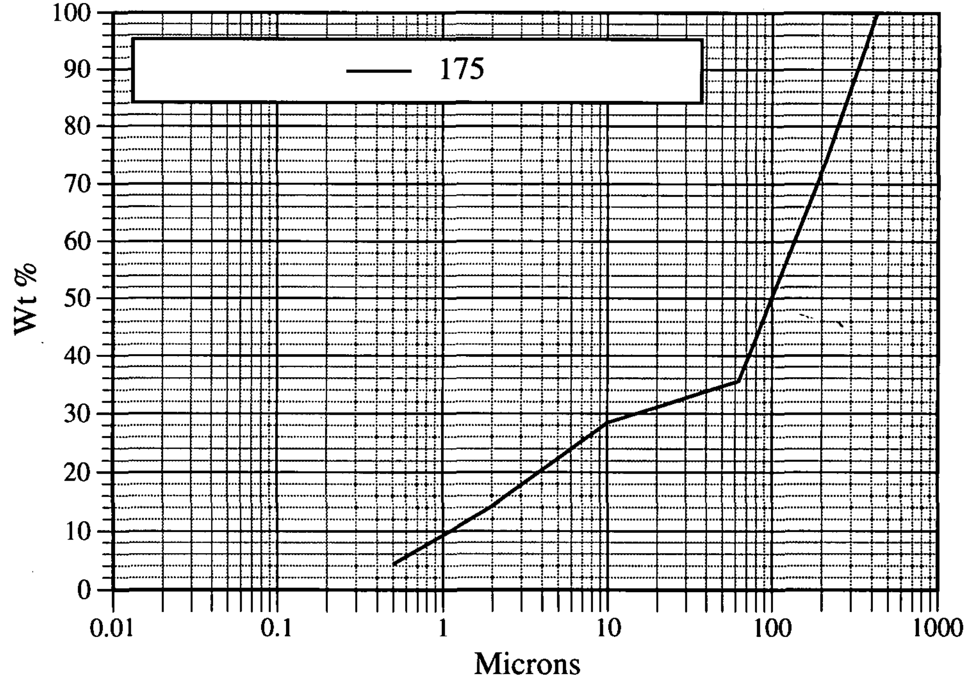
	Size fraction	Range	Average			Range	Average
Gravel / cobbles	**>2 mm**	0.01 - 13.89	2.10	**> 2mm**	**Gravel (wt %)**	0.00 - 13.9	2.10
Coarse sand	**2 mm - 600 µm**	0.04 - 6.05	2.00	**2 mm - 63 µm**	**Sand (wt %)**	3.60 - 70.31	45.01
Medium coarse sand	**600 - 425 µm**	0.05 - 5.9	2.80	**63 - 2 µm**	**Silt (wt %)**	11.03 - 64.80	30.48
Medium fine sand	**425 - 212 µm**	0.19 - 26.07	9.90	**< 2 µm**	**Clay (wt %)**	14.62 - 38.2	22.42
Fine sand	**212 - 63 µm**	5.05 - 47.88	30.30		**Total (wt %)**	100.00	100.00
Coarse silt	**63 - 10 µm**	5.9 - 27.25	13.20		**Statisitics for <2 mm fractions**		
Fine silt	**10 - 2 µm**	5.13 - 44.64	17.30		**Mean (µm)**	5.75 - 67.5	26.46
Clay	**2 - 0.5 µm**	5.59 - 23.26	11.20		**Median (µm)**	3.70 - 170.0	76.91
	<0.5 µm	1.79 - 24.61	11.20		**Standard deviation (phi)**	1.81 - 3.16	2.41
	Total	100.00	100.00		**Skewness**	-0.12 - 0.89	0.51

Appendix A Cumulative frequency particle-size distribution graphs for till samples from East Anglia

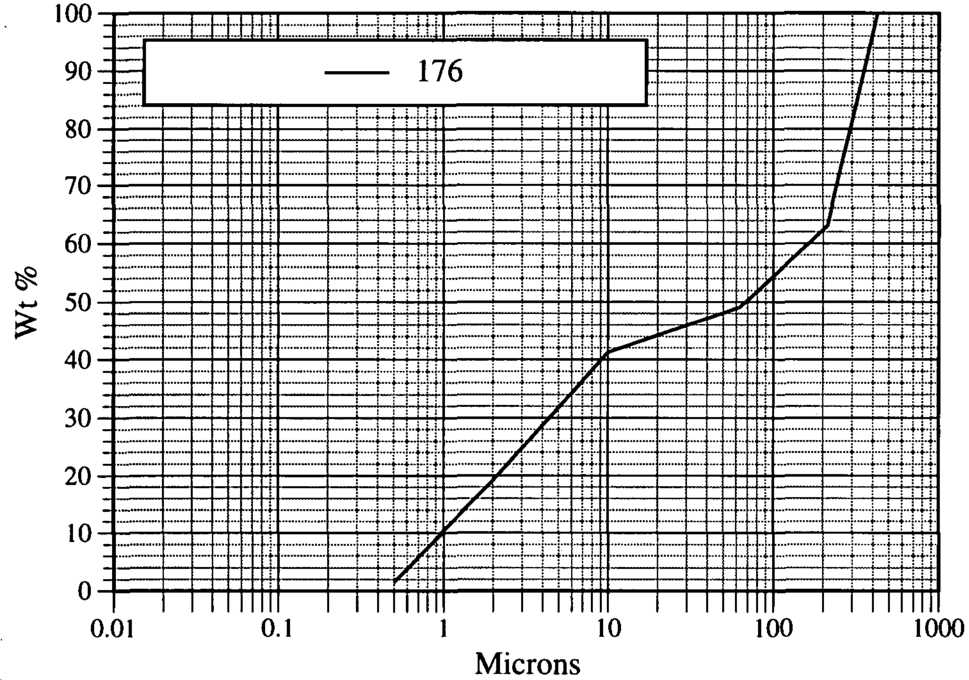


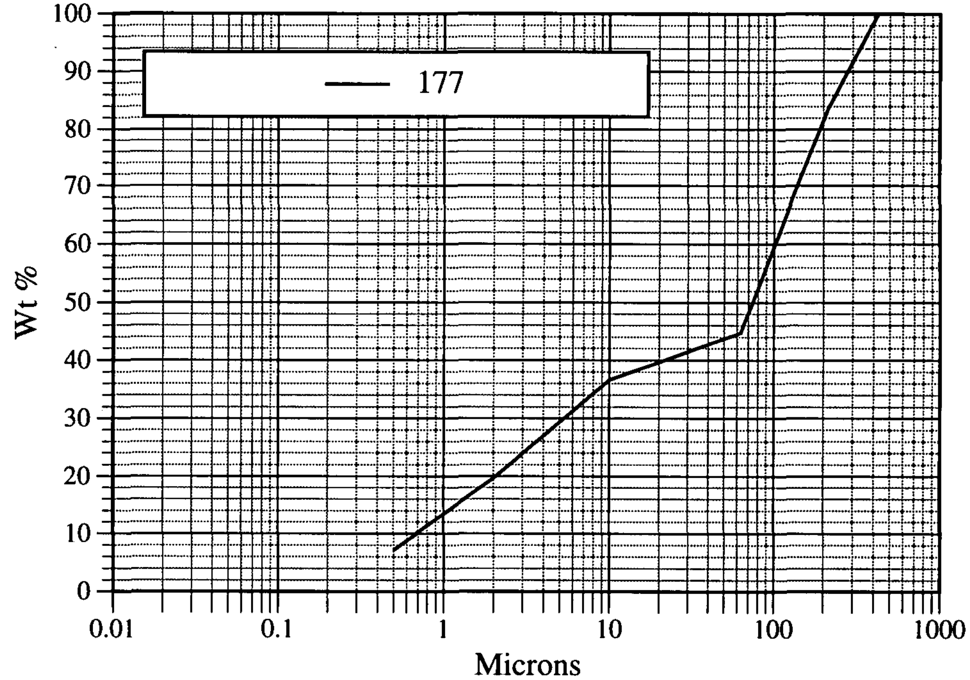


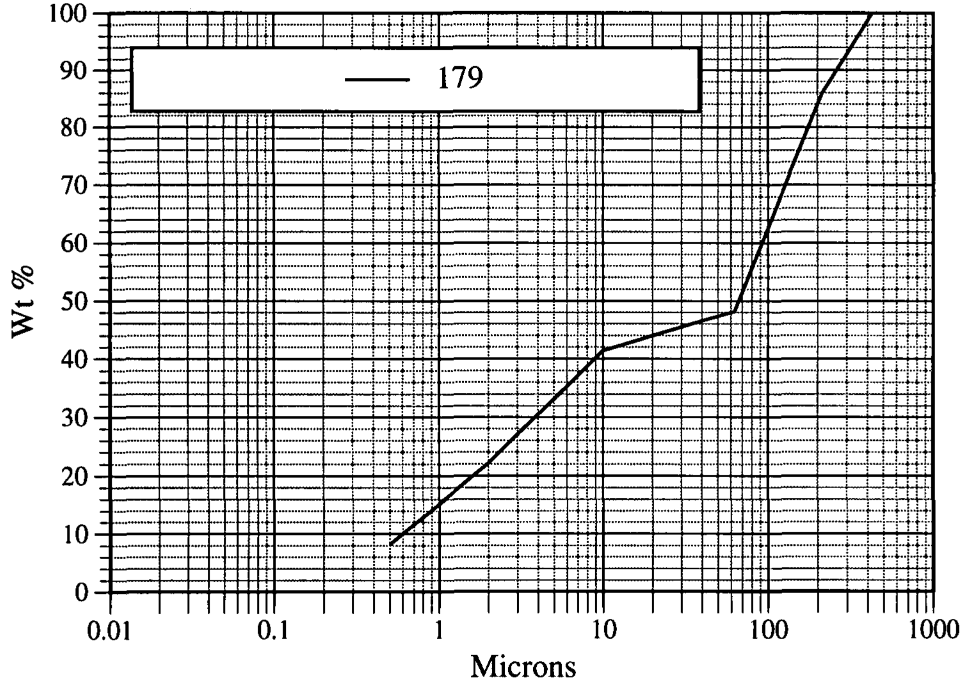


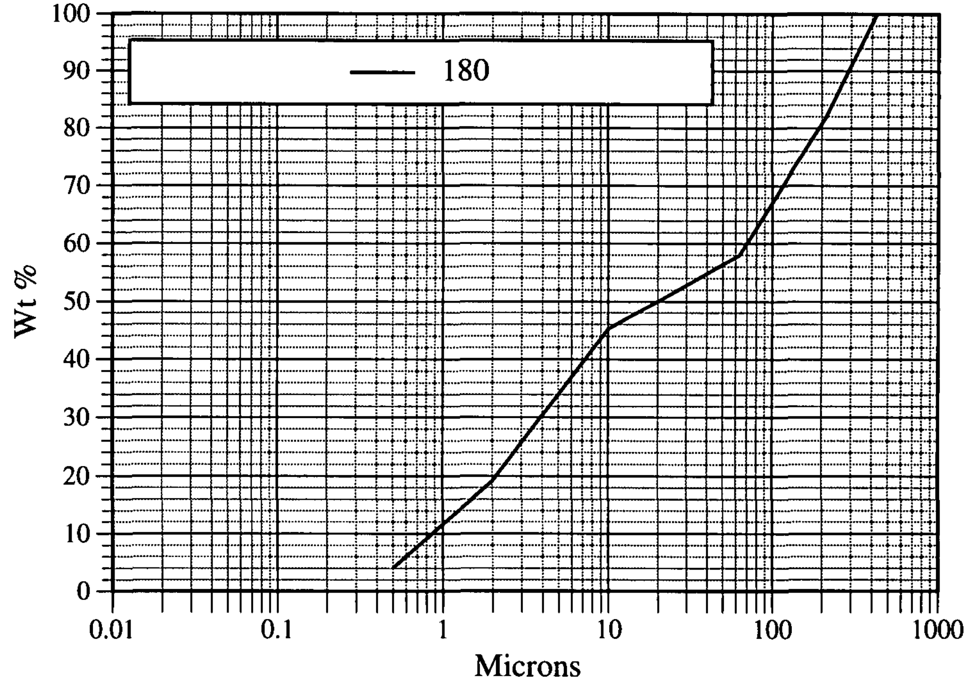


Appendix A Cumulative frequency particle-size distribution graphs for till samples from East Anglia

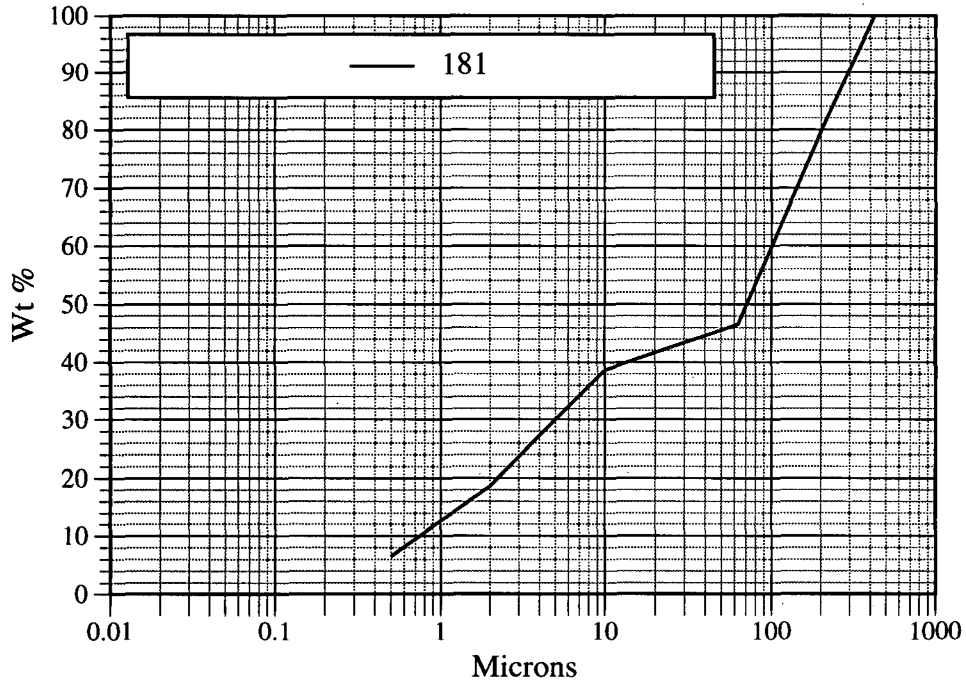


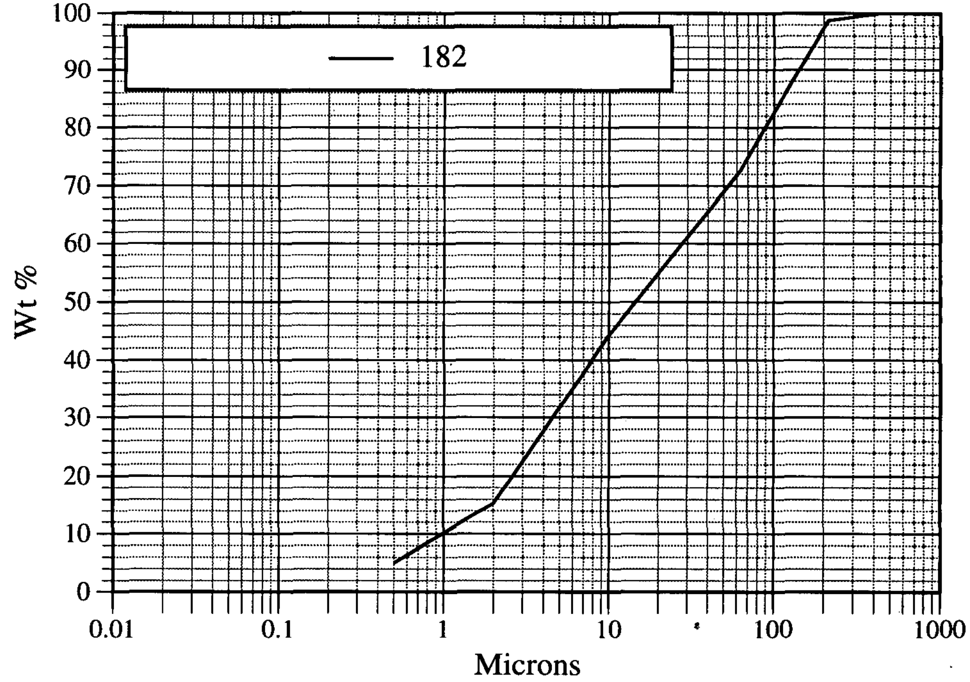


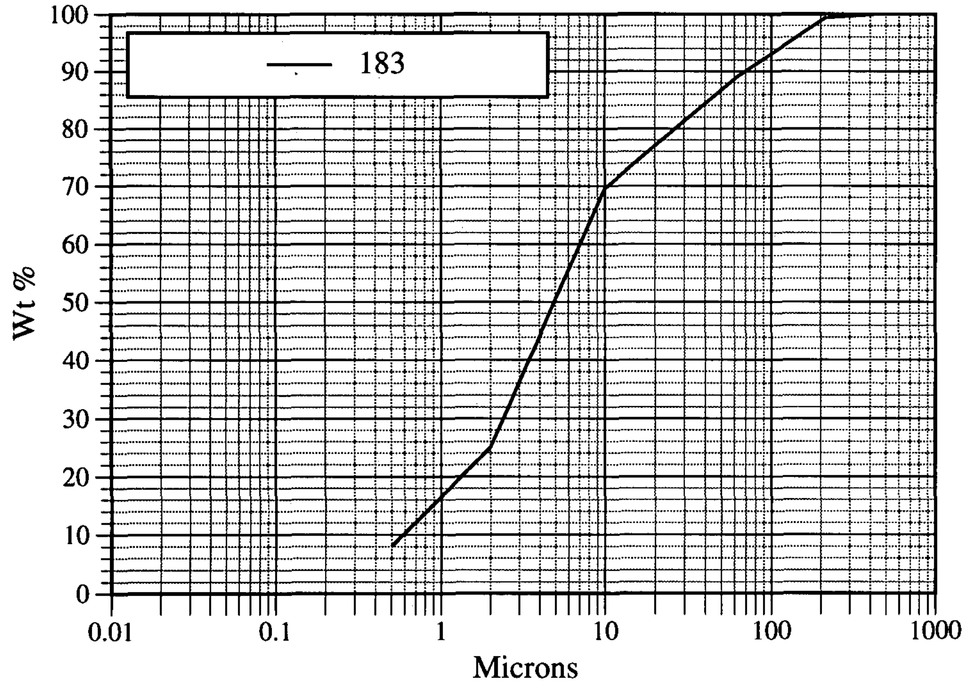


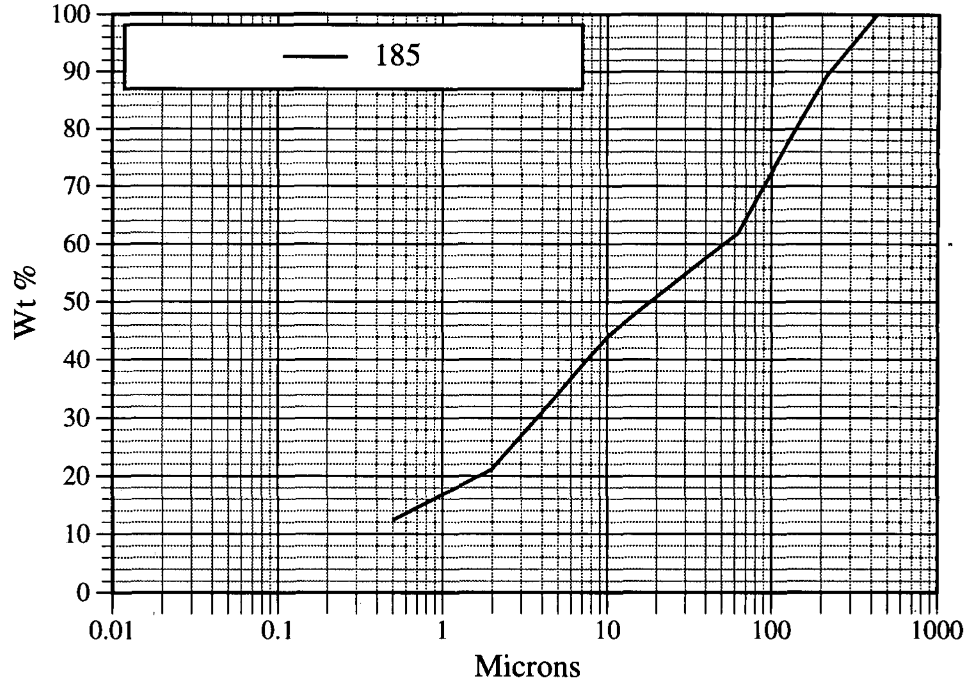


Appendix A Cumulative frequency particle-size distribution graphs for till samples from East Anglia

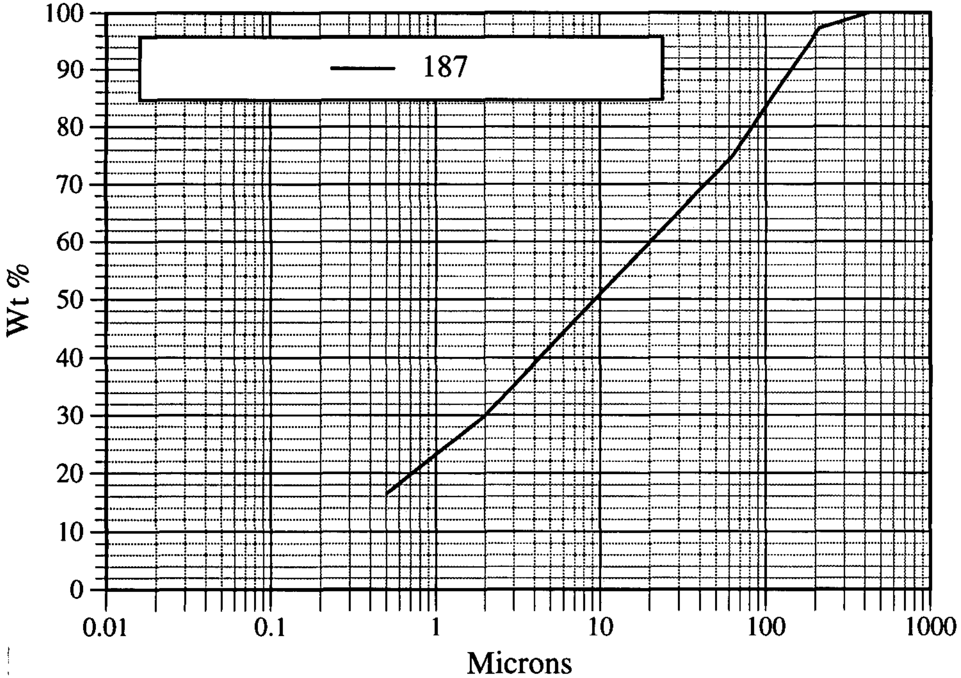


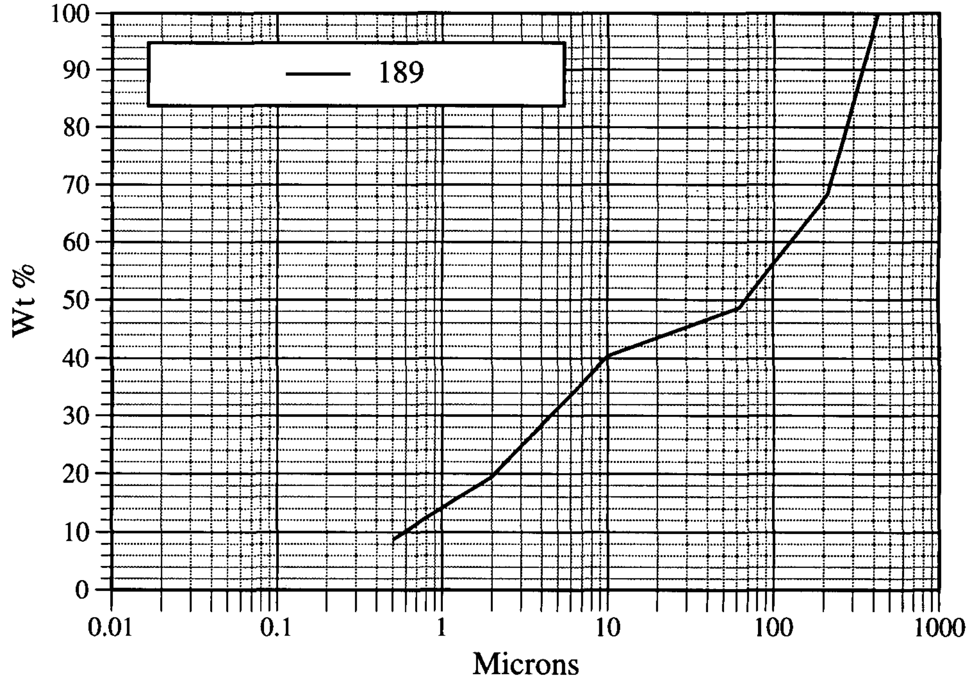


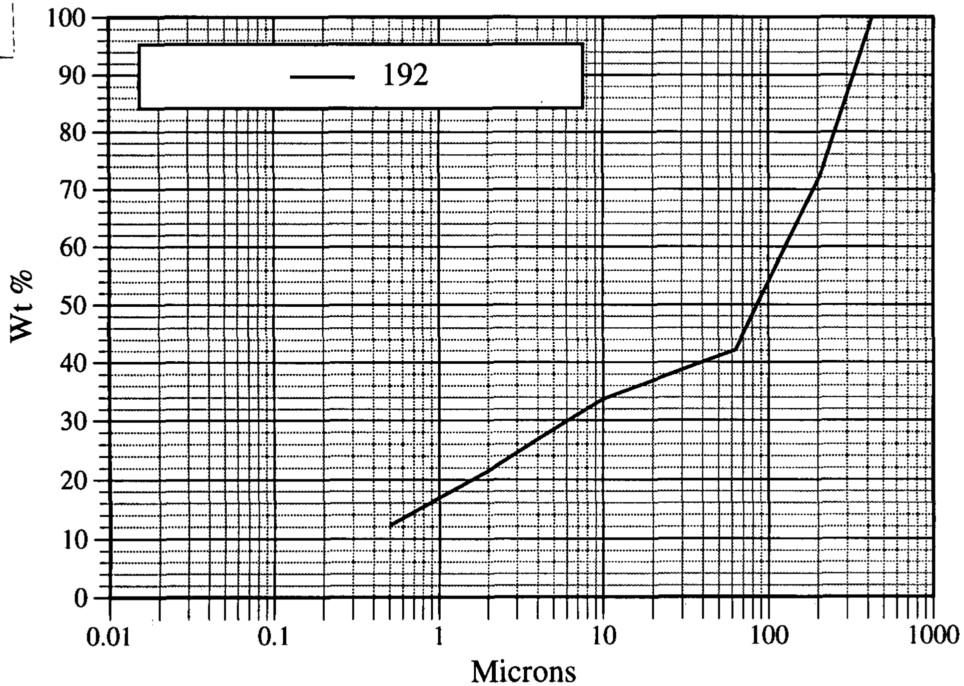


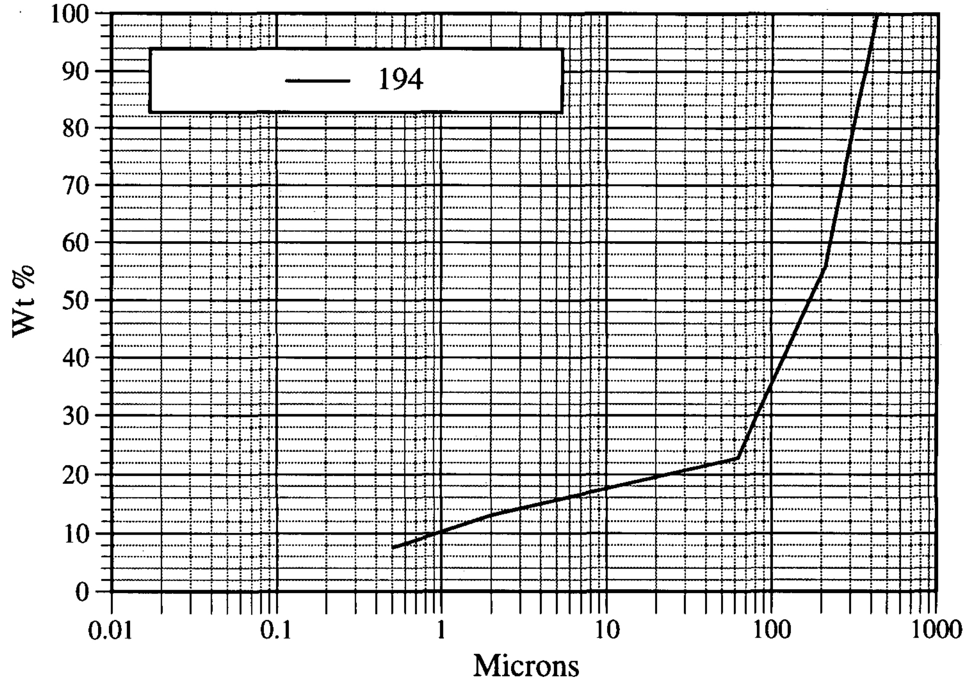


Appendix A Cumulative frequency particle-size distribution graphs for till samples from East Anglia

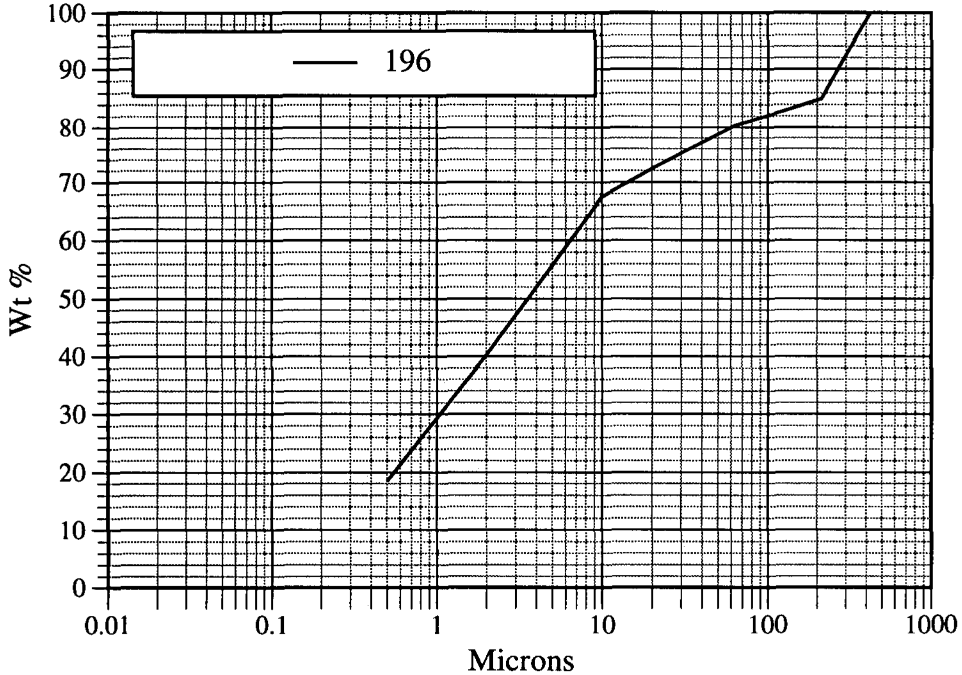


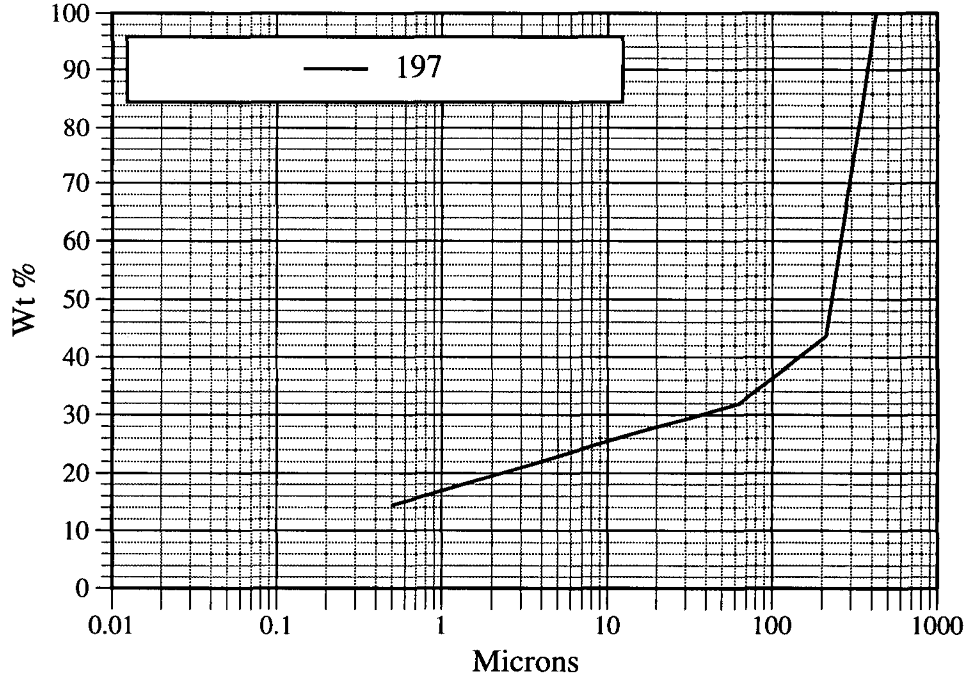


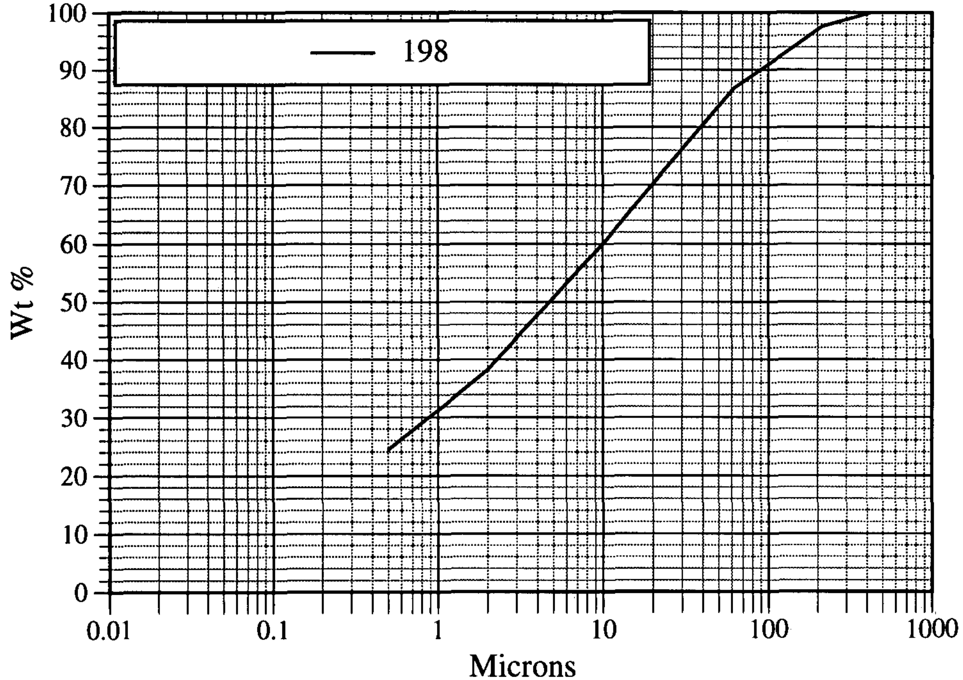


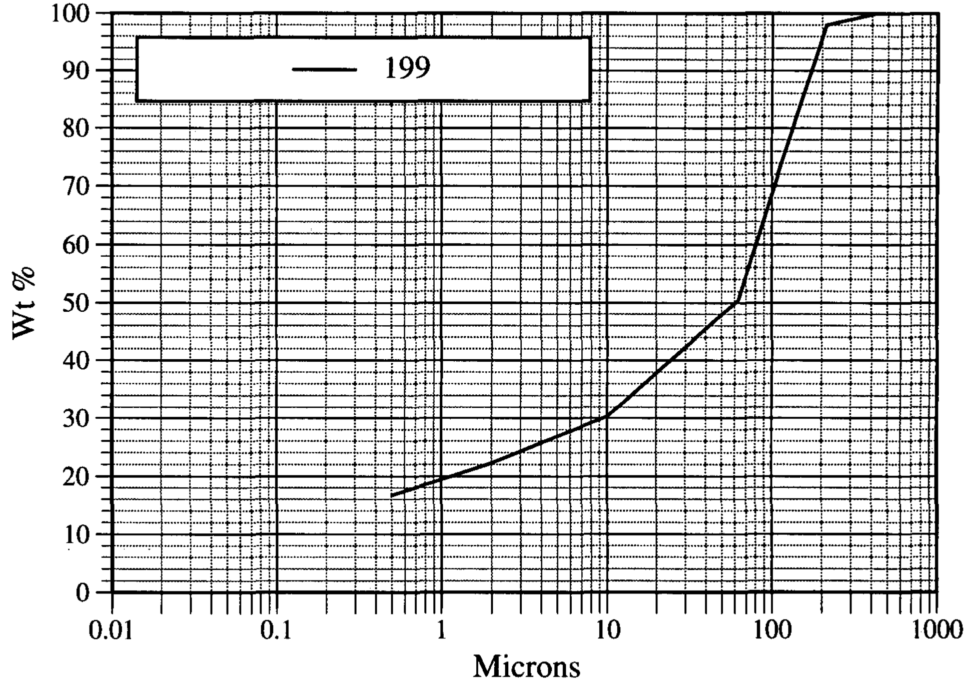


Appendix A Cumulative frequency particle-size distribution graphs for till samples from East Anglia

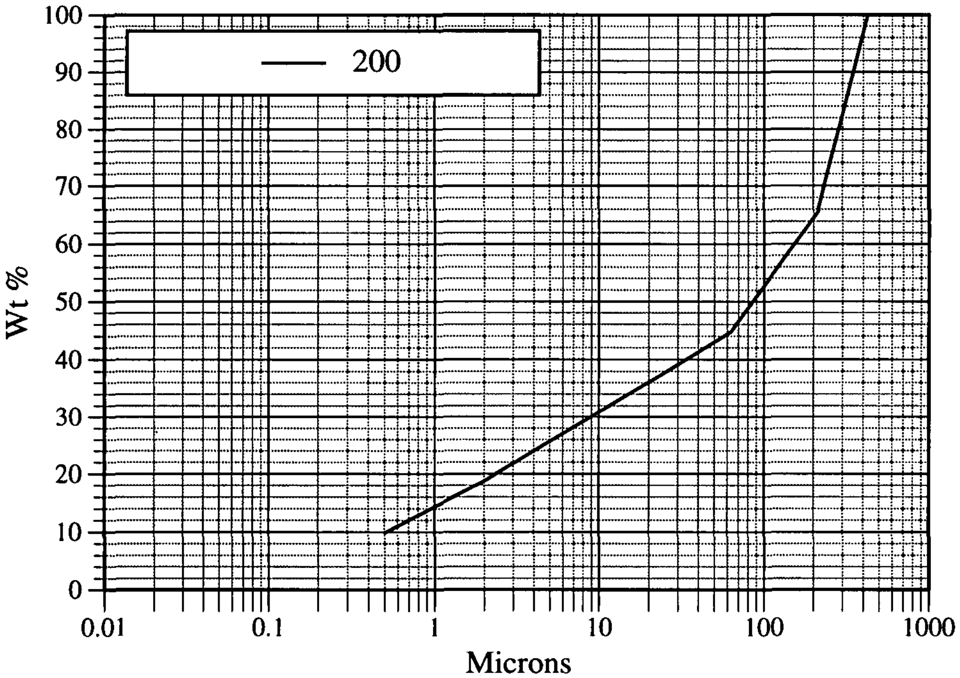


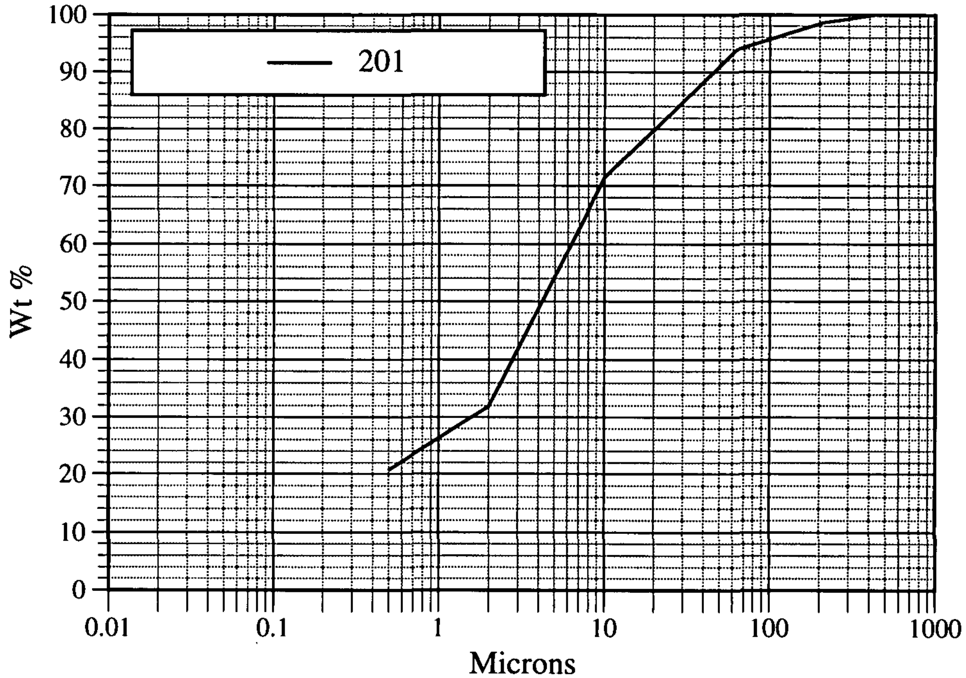


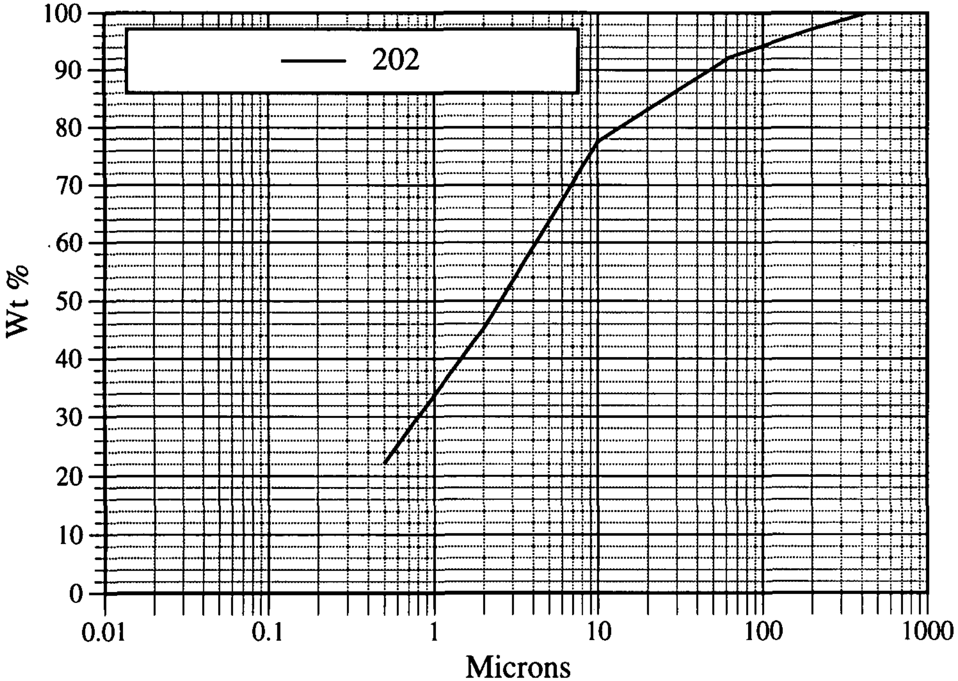


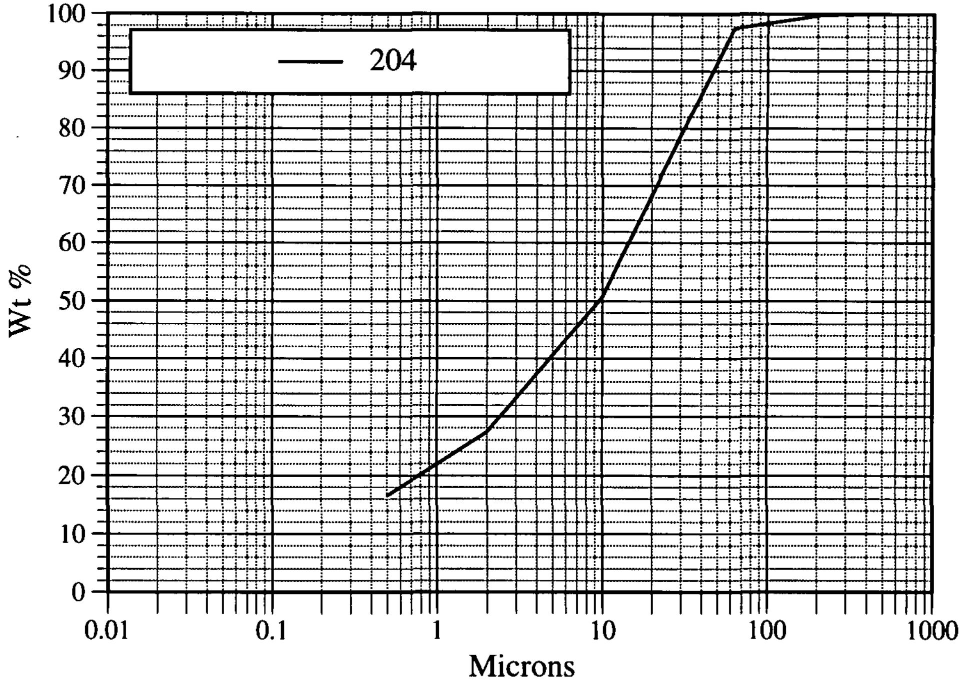


Appendix A Cumulative frequency particle-size distribution graphs for till samples from East Anglia

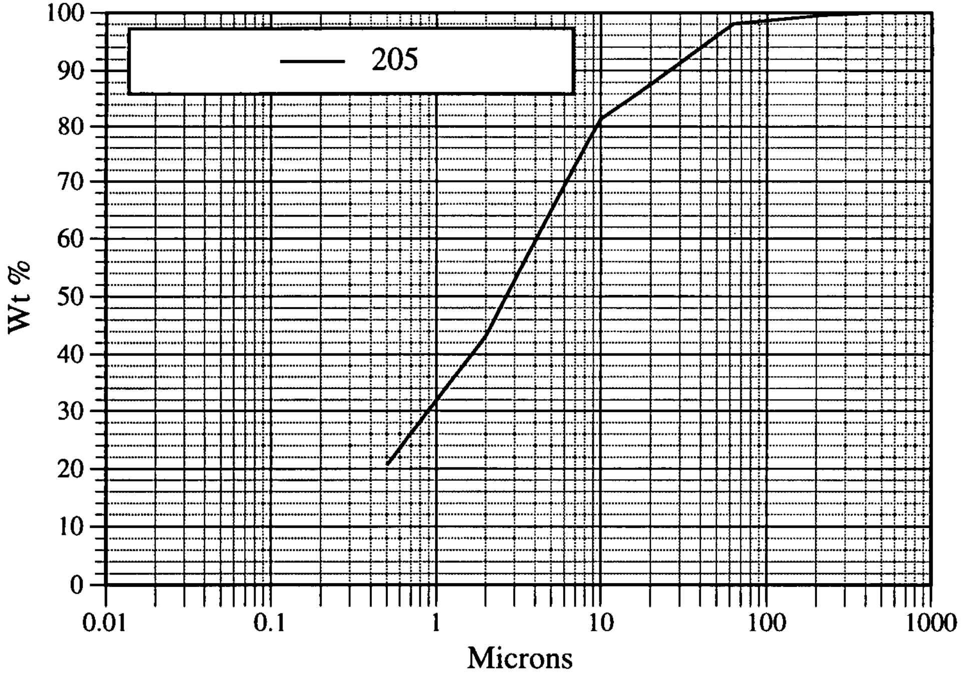


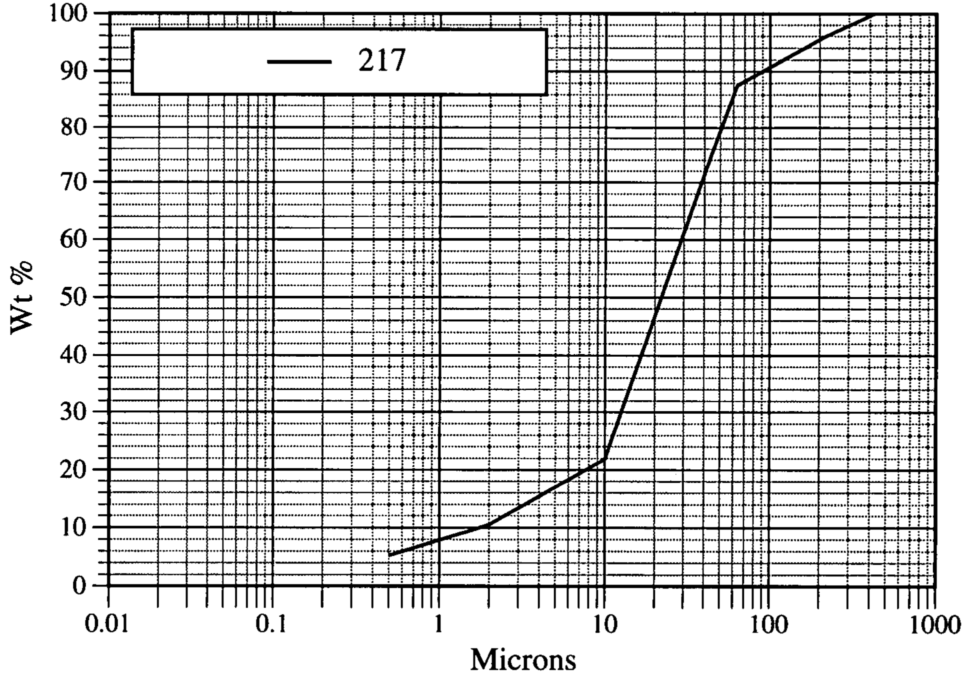


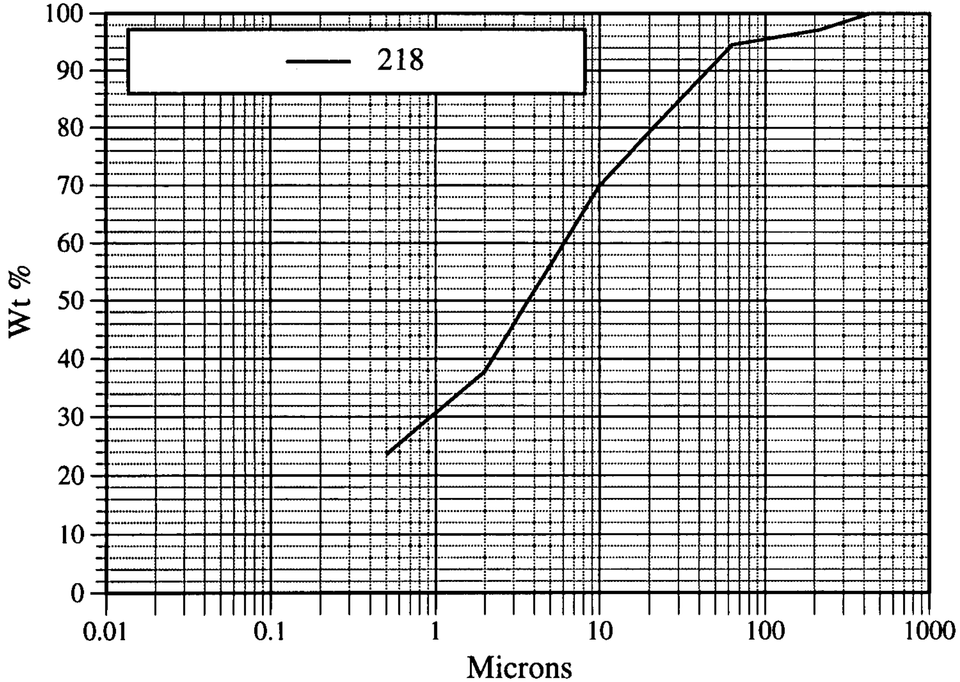


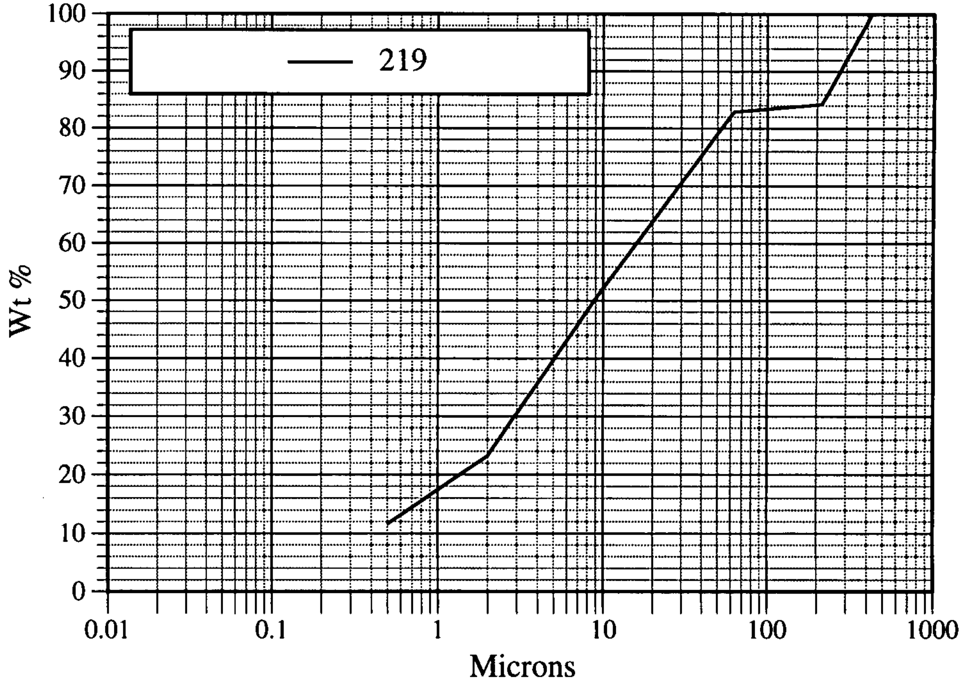


Appendix A Cumulative frequency particle-size distribution graph for till samples from East Anglia

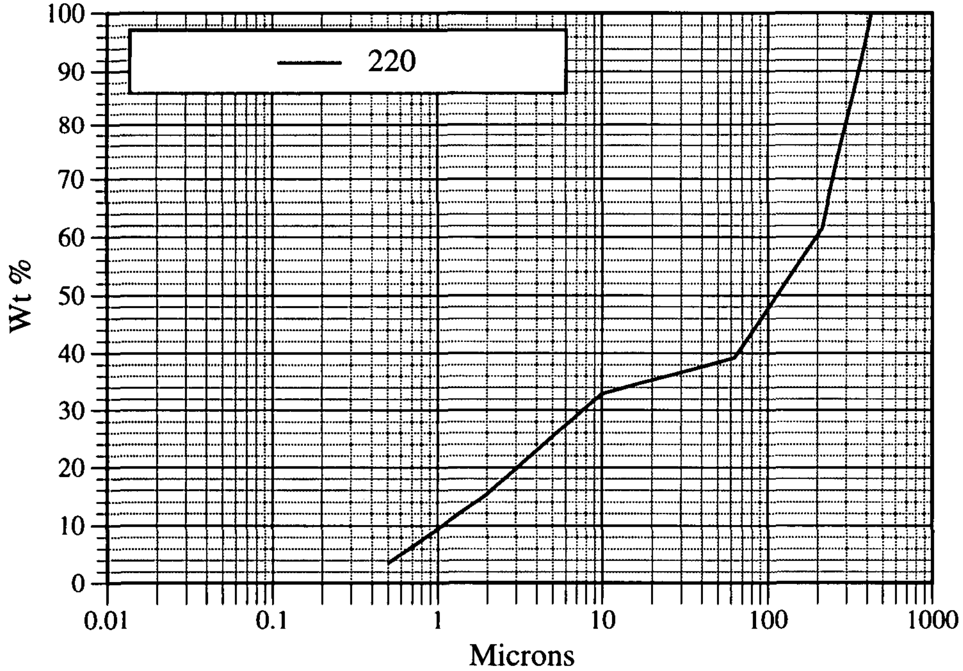


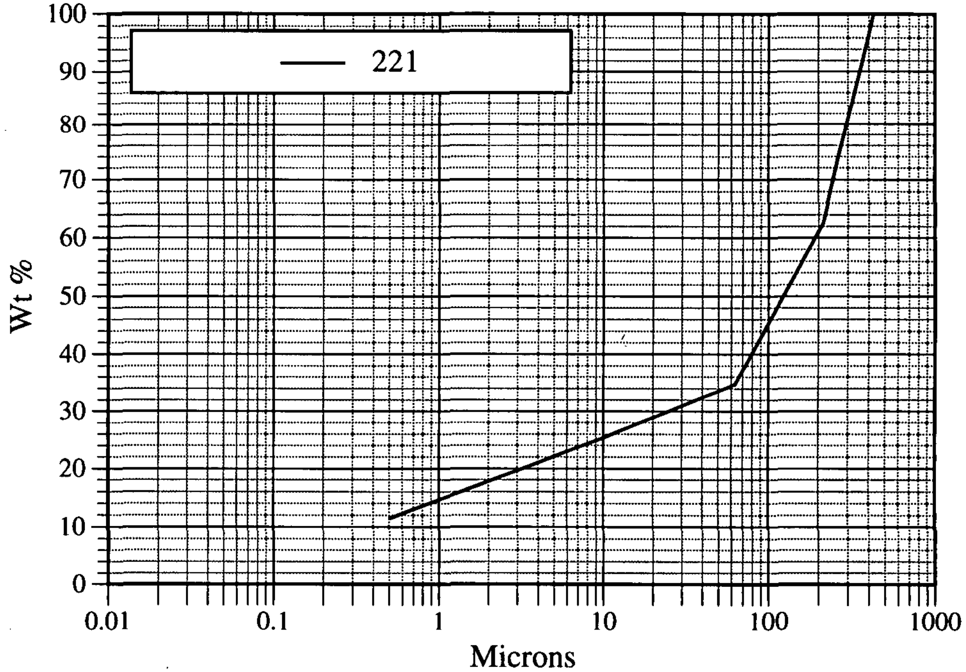


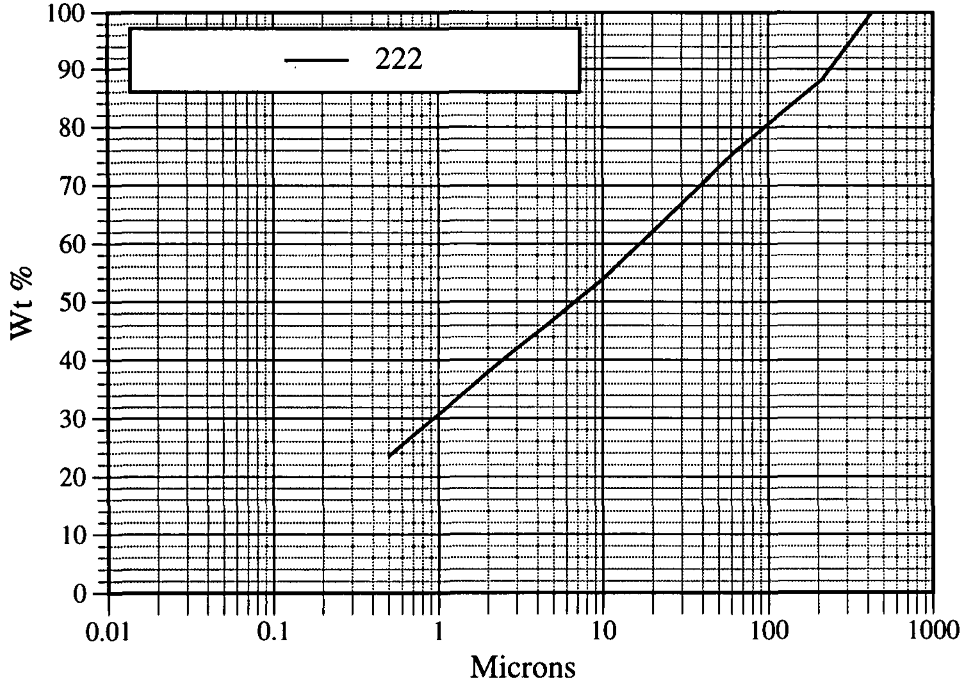


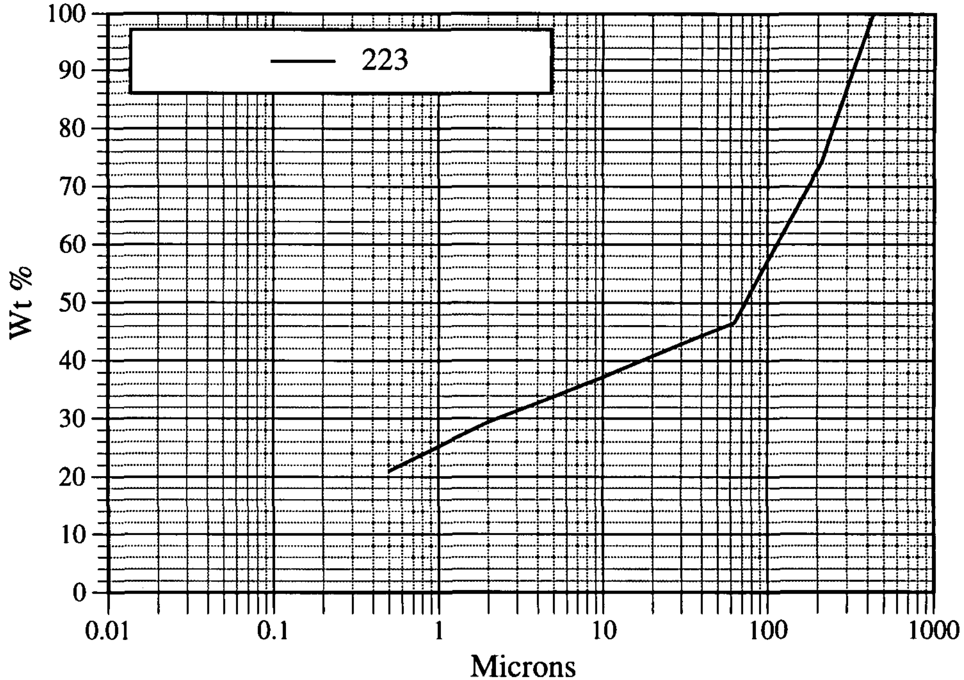


Appendix A Cumulative frequency particle-size distribution graphs for till samples from East Anglia

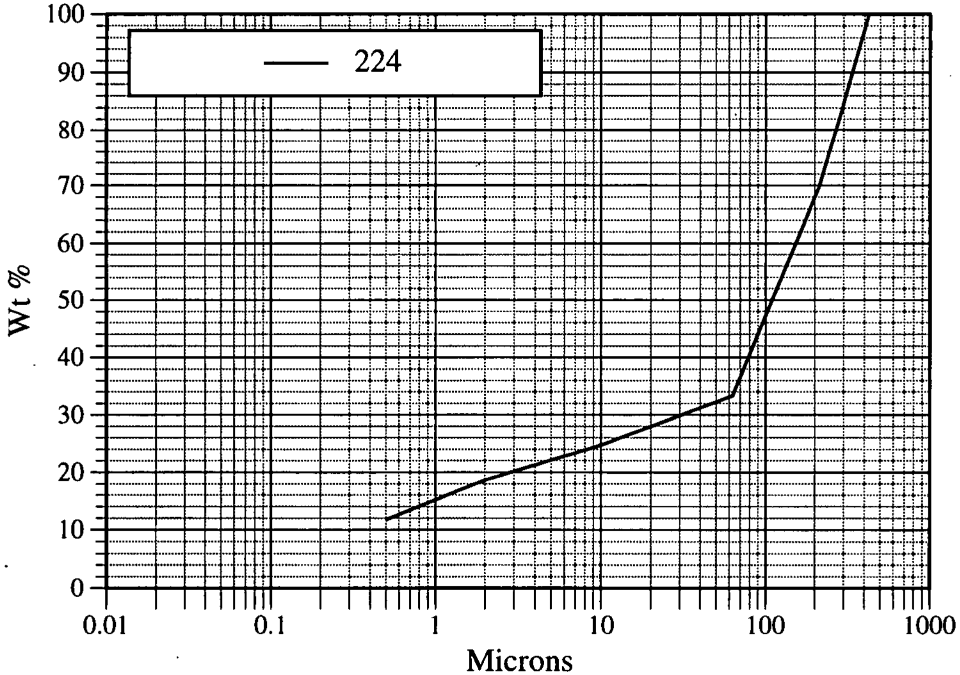


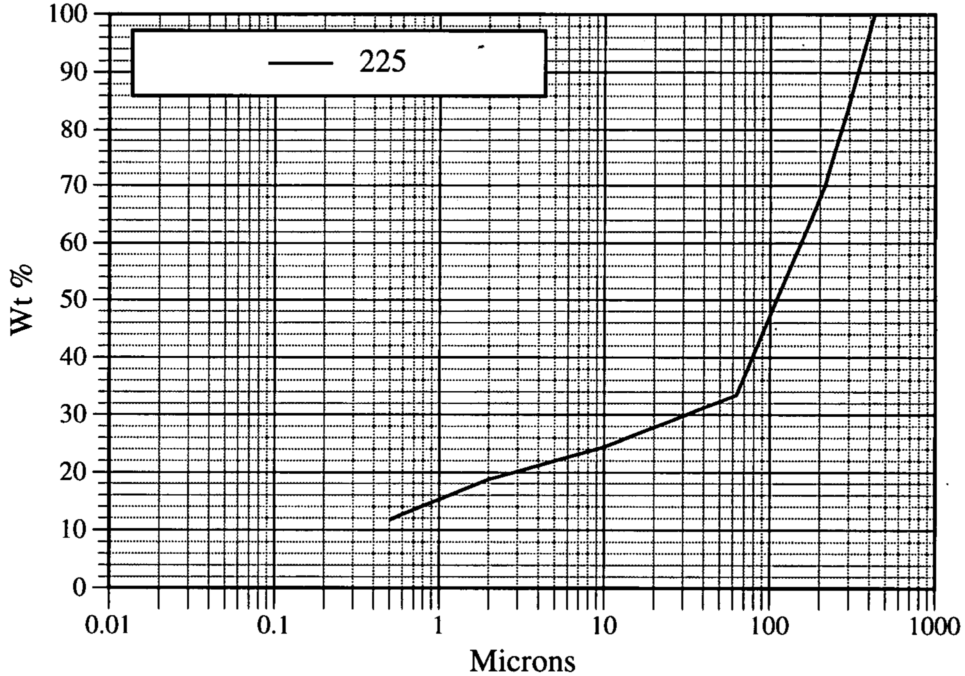


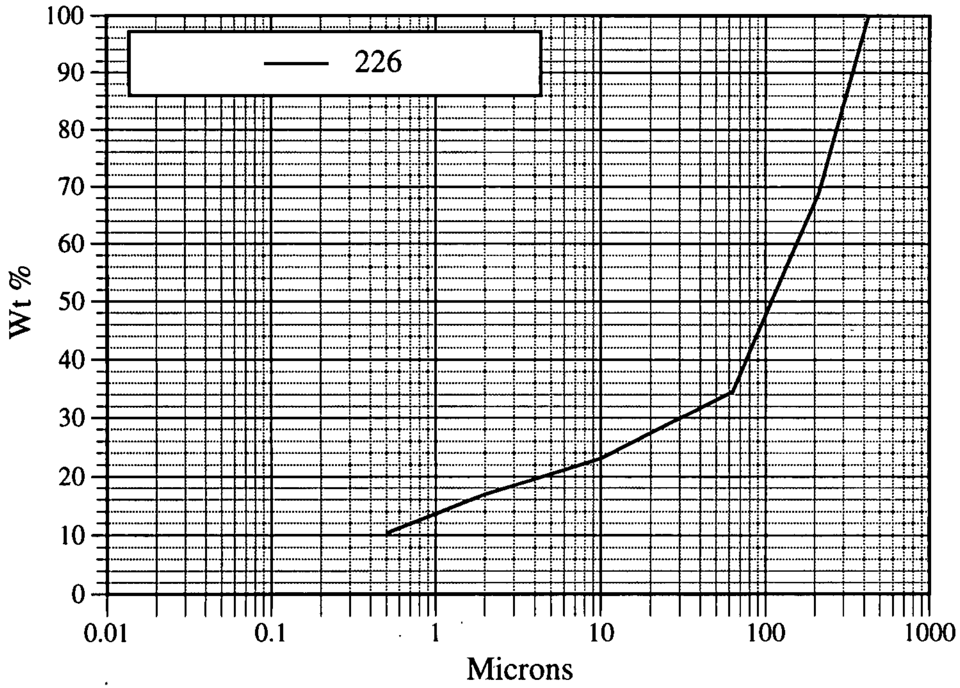




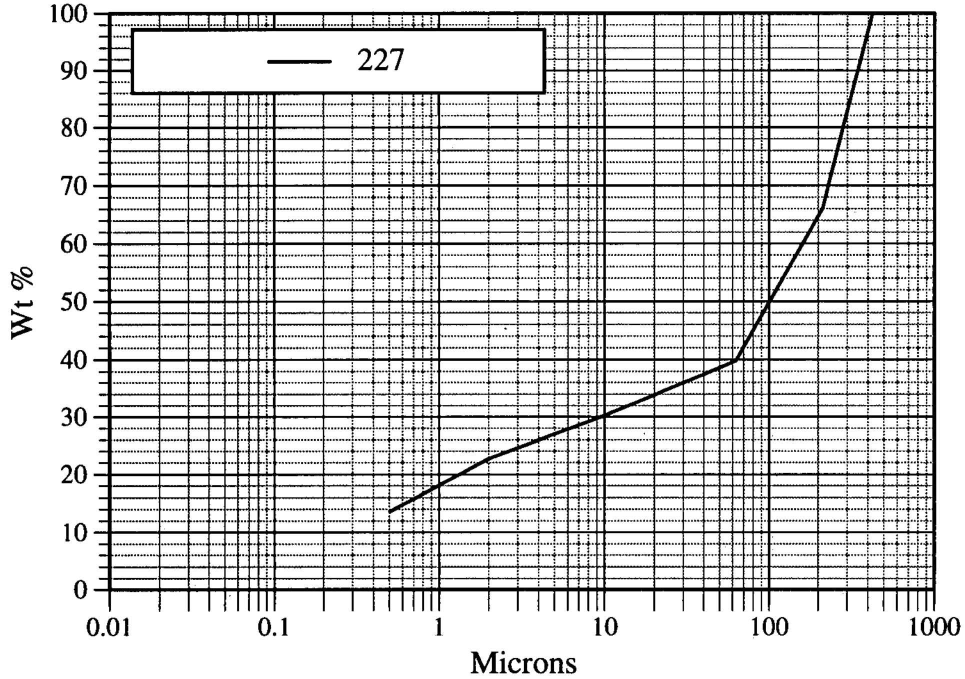
Appendix A Cumulative frequency particle-size distribution graphs for till samples from East Anglia

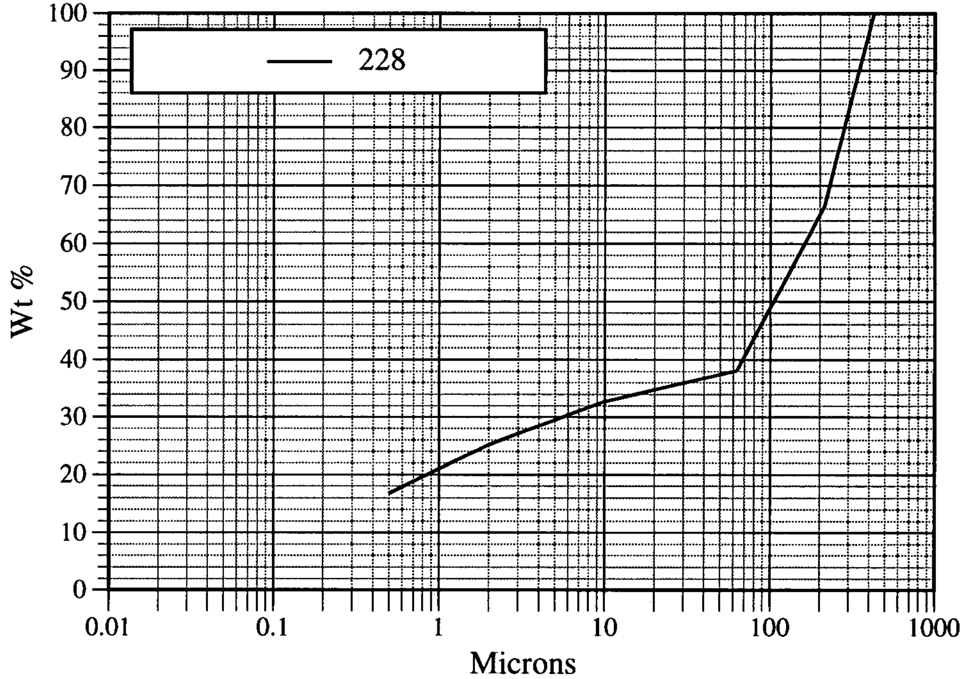




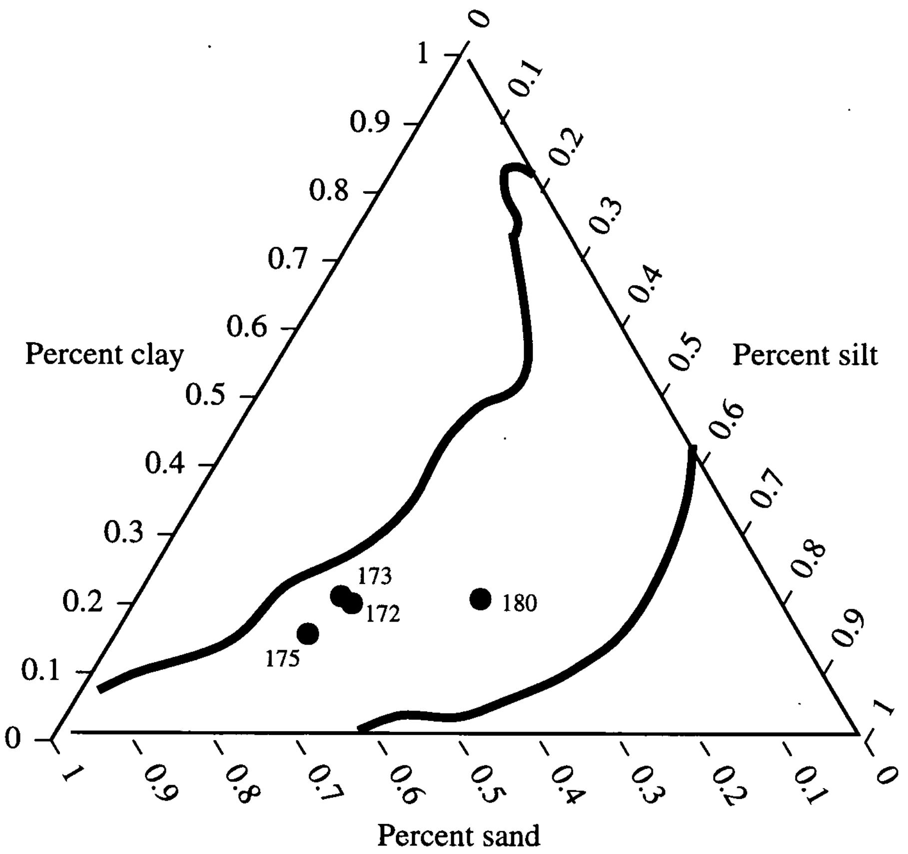


Appendix A Cumulative frequency particle-size distribution graphs for till samples from East Anglia

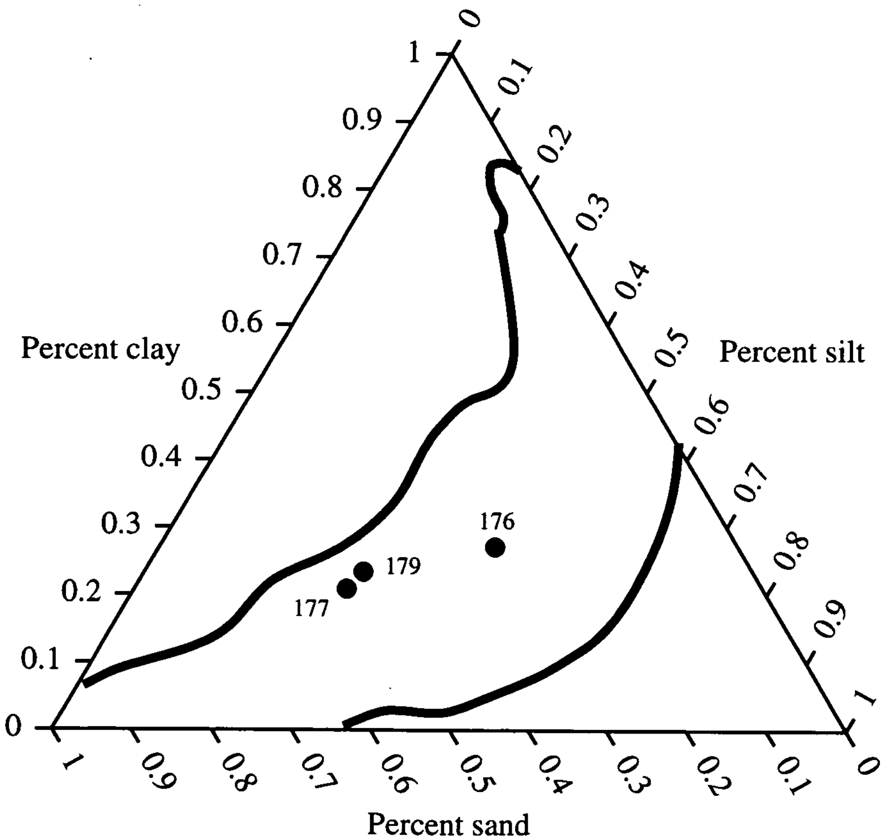




Appendix B Ternary particle-size distribution plots for till samples from East Anglia

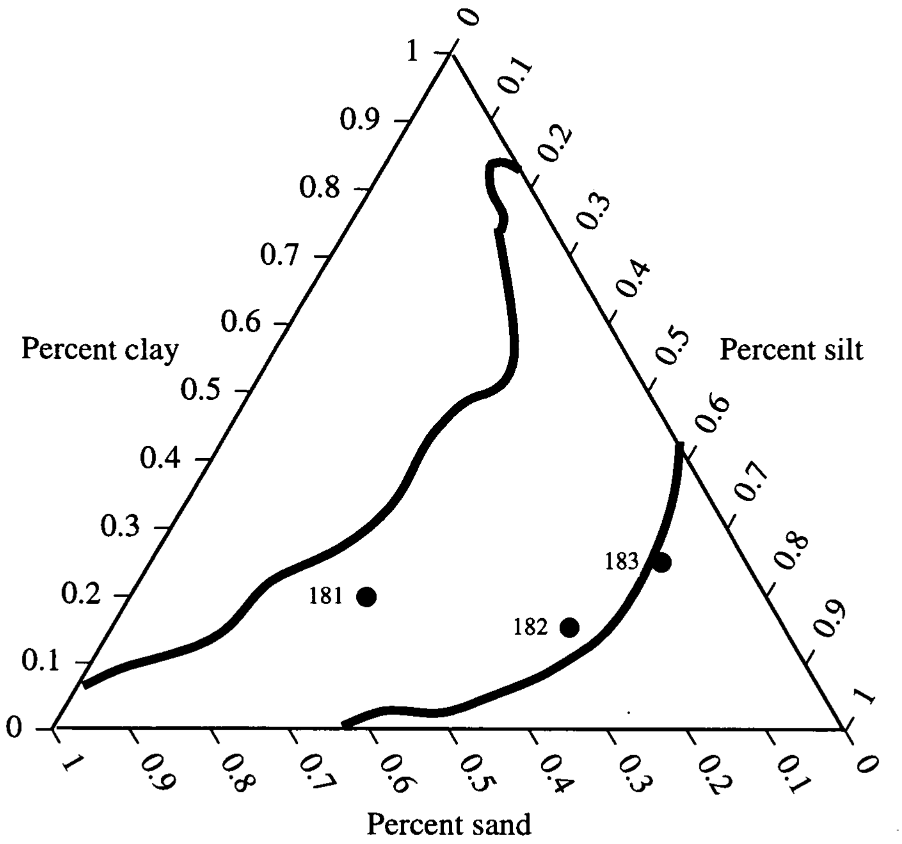


Cromer Till, Trimingham

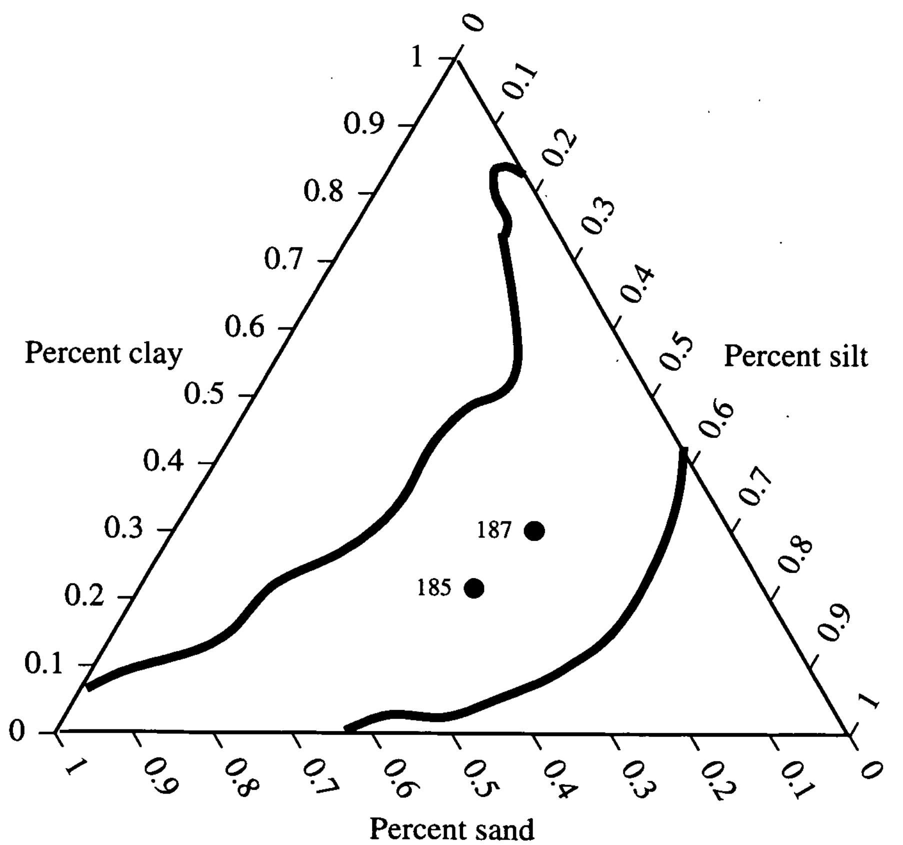


Cromer Till, West Runton

Appendix B Ternary particle-size distribution plots for till samples from East Anglia

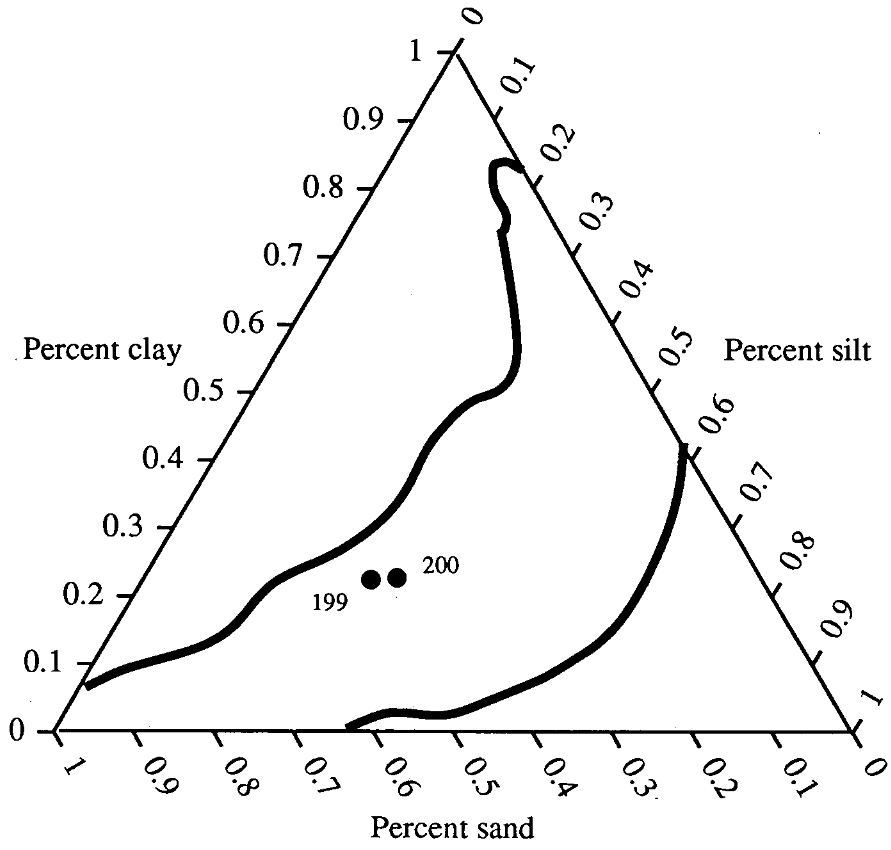


Cromer Till, Happisburgh

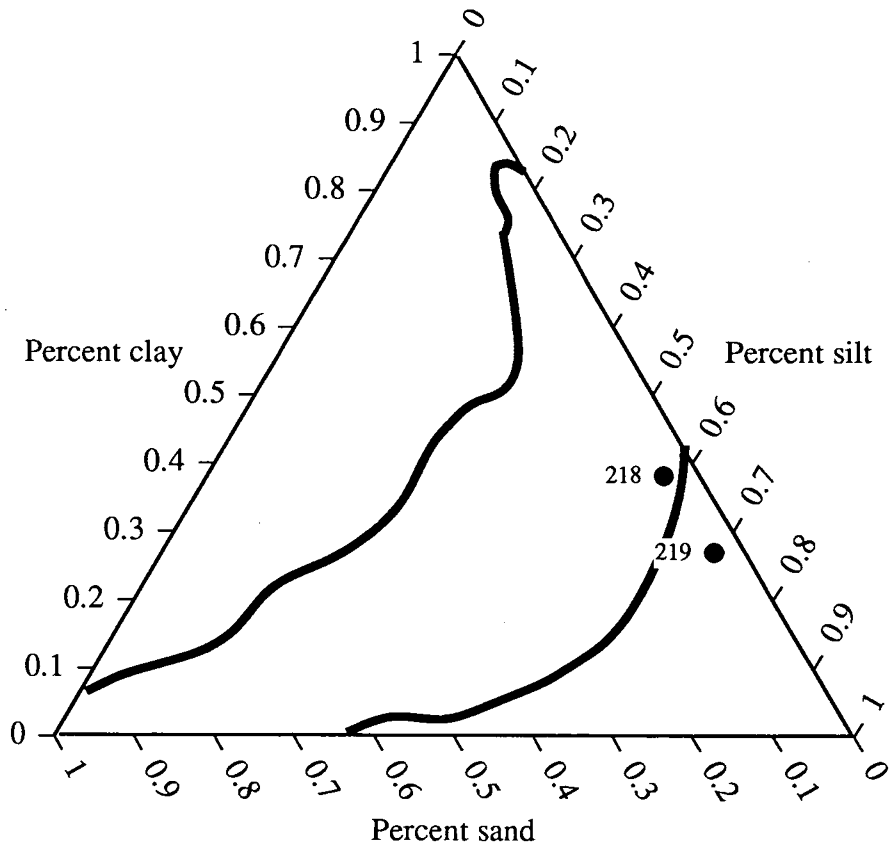


Cromer Till, California Cliffs

Appendix B Ternary particle-size distribution plots for till samples from East Anglia

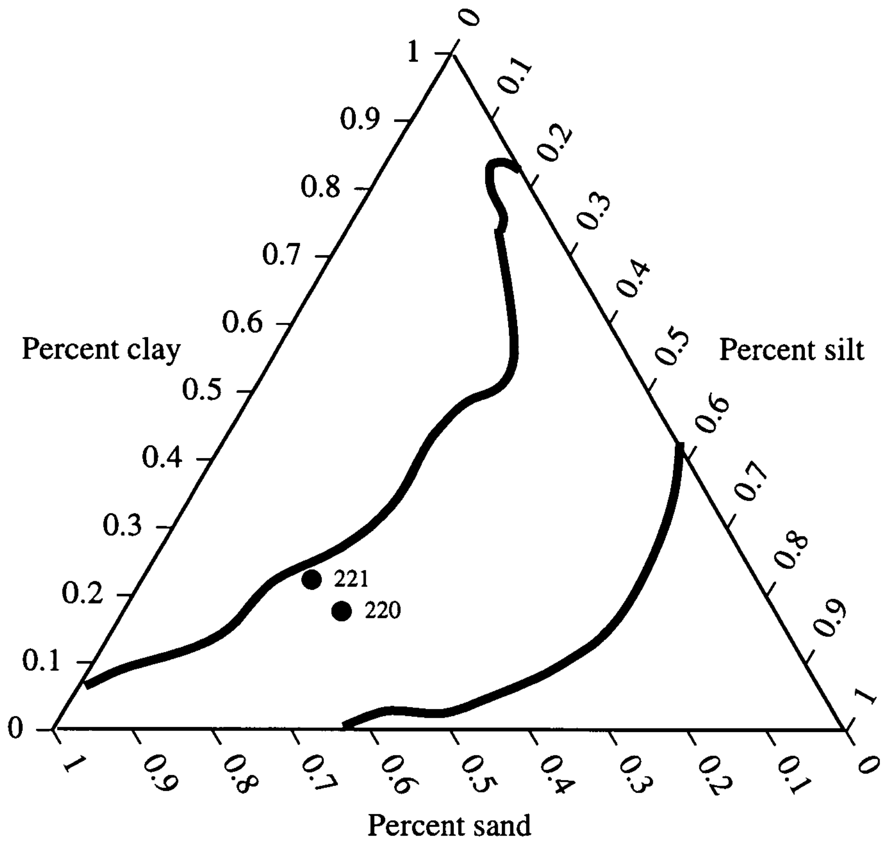


Cromer Till, Covehithe

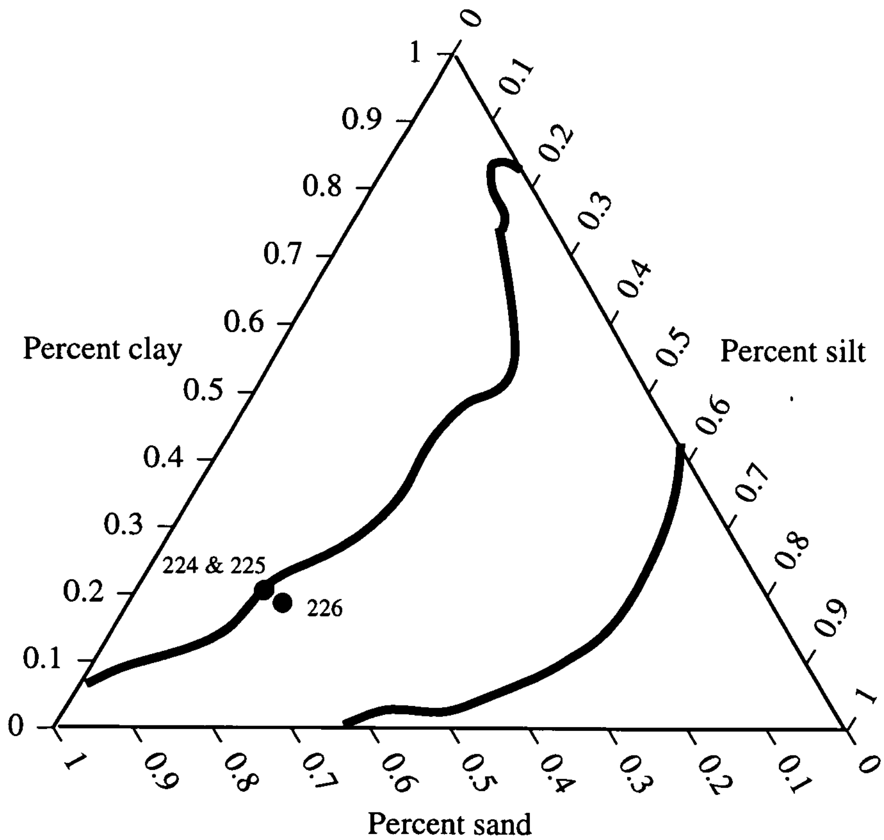


Cromer Till, Sea Palling

Appendix B Ternary particle-size distribution plots for till samples from East Anglia

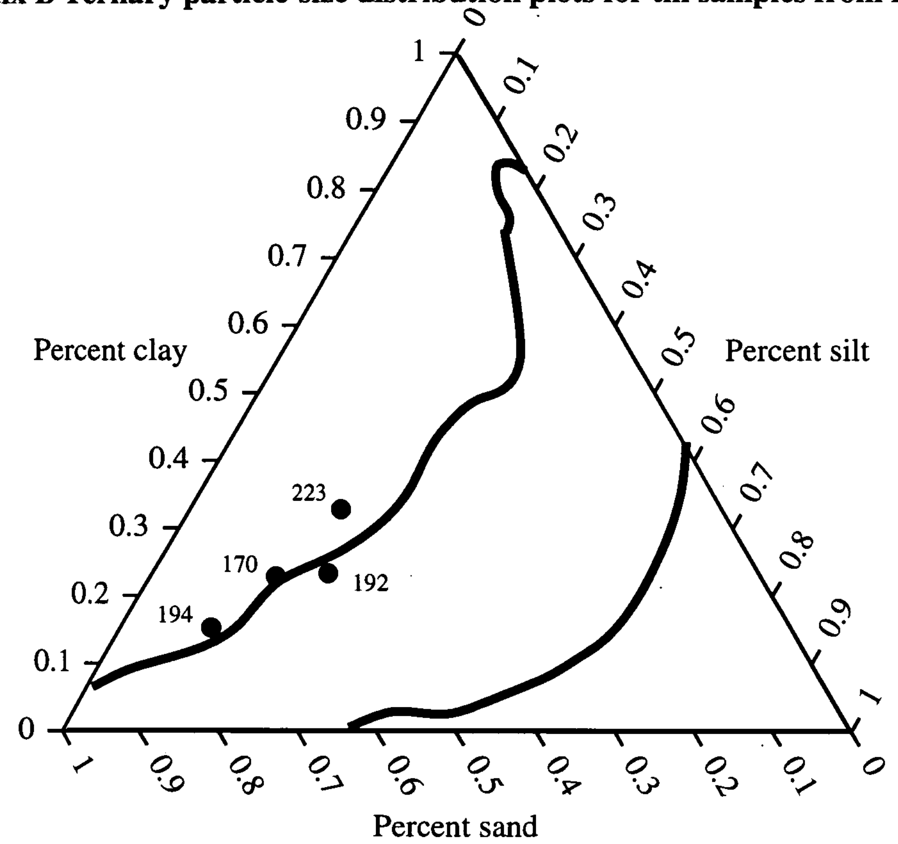


Cromer Till, Transacre Estate

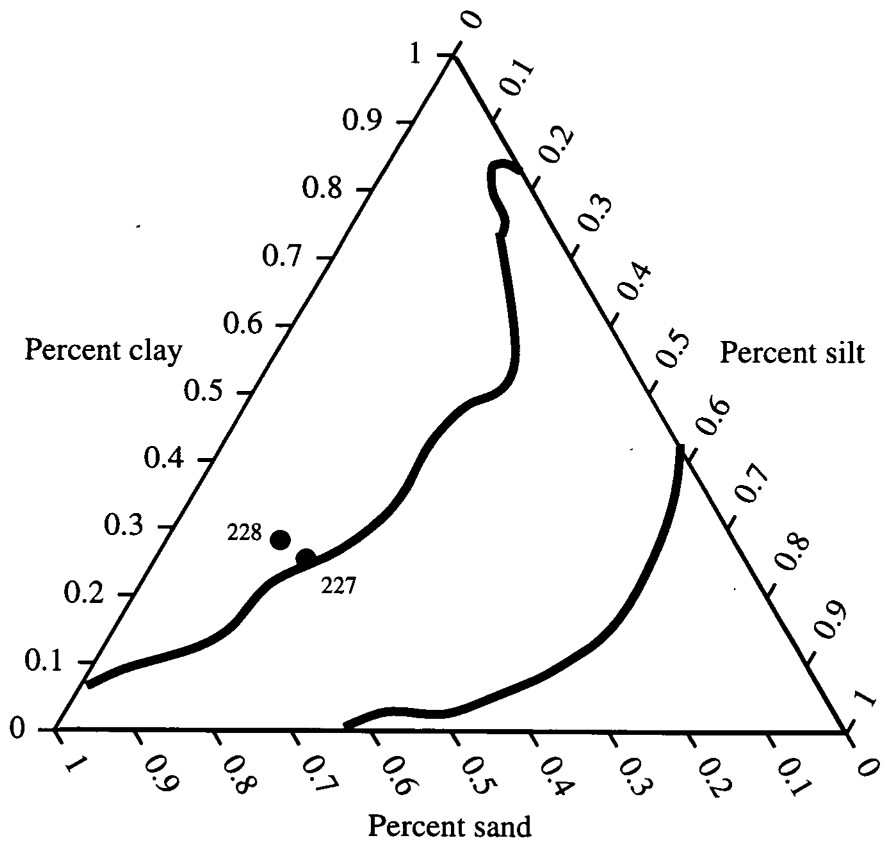


Cromer Till, Norwich Airport

Appendix B Ternary particle-size distribution plots for till samples from East Anglia

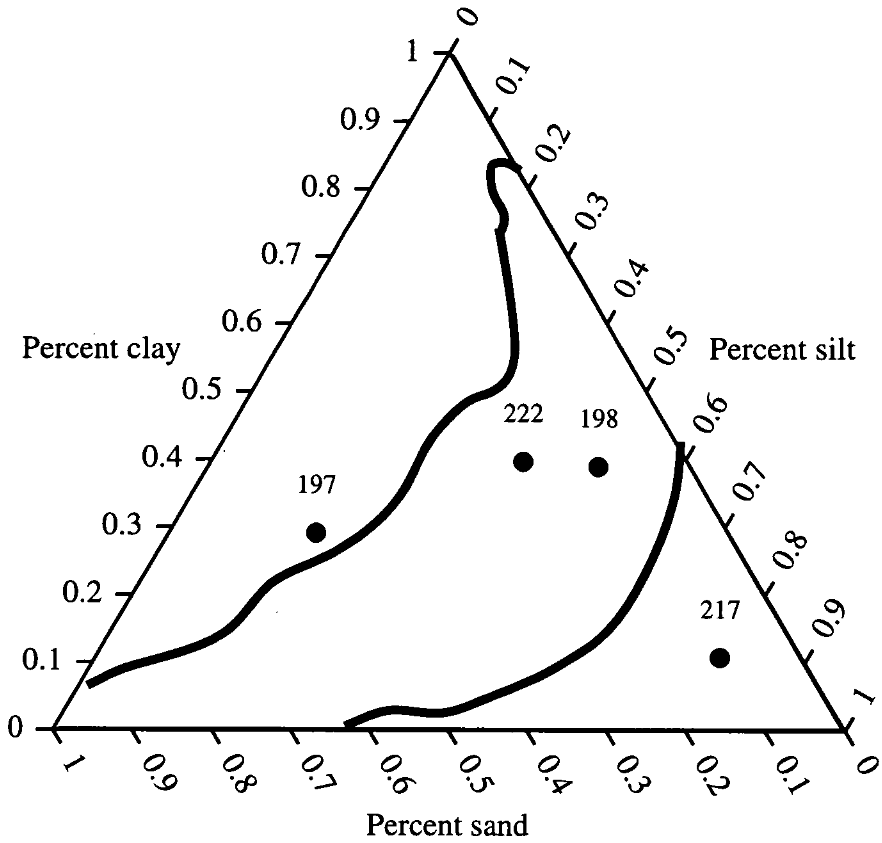


Miscellaneous Cromer Till, Hellesden (170), Burgh Castle (192), Corton (194) and Waxham (223)



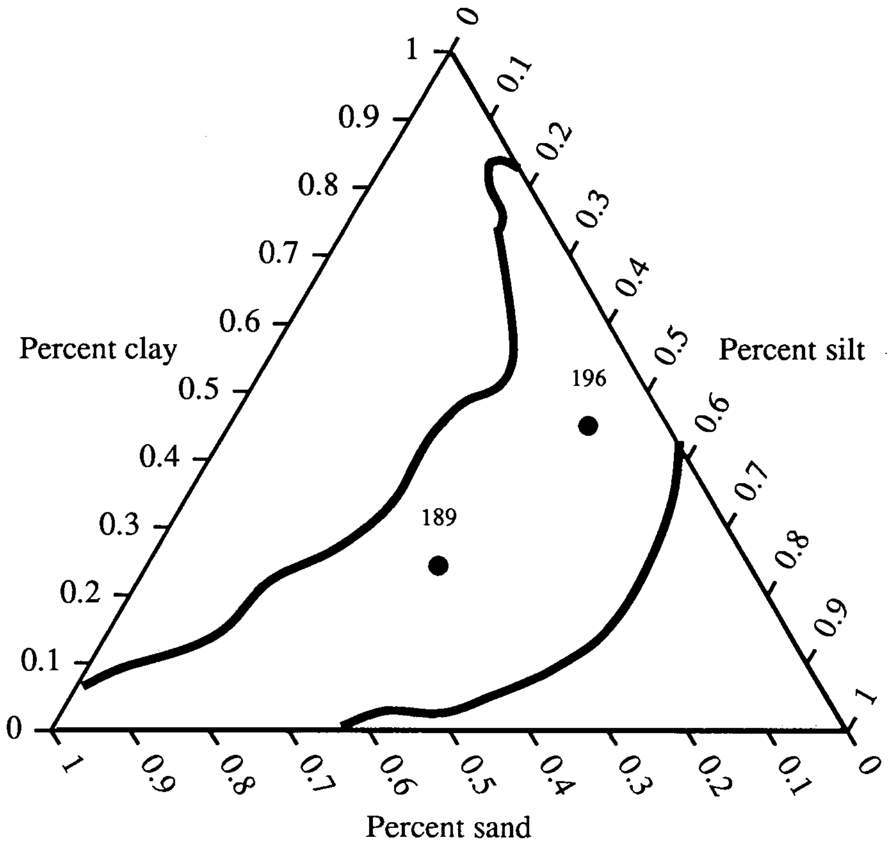
Cromer Till, Ludham

Appendix B Ternary particle-size distribution plots for till samples from East Anglia

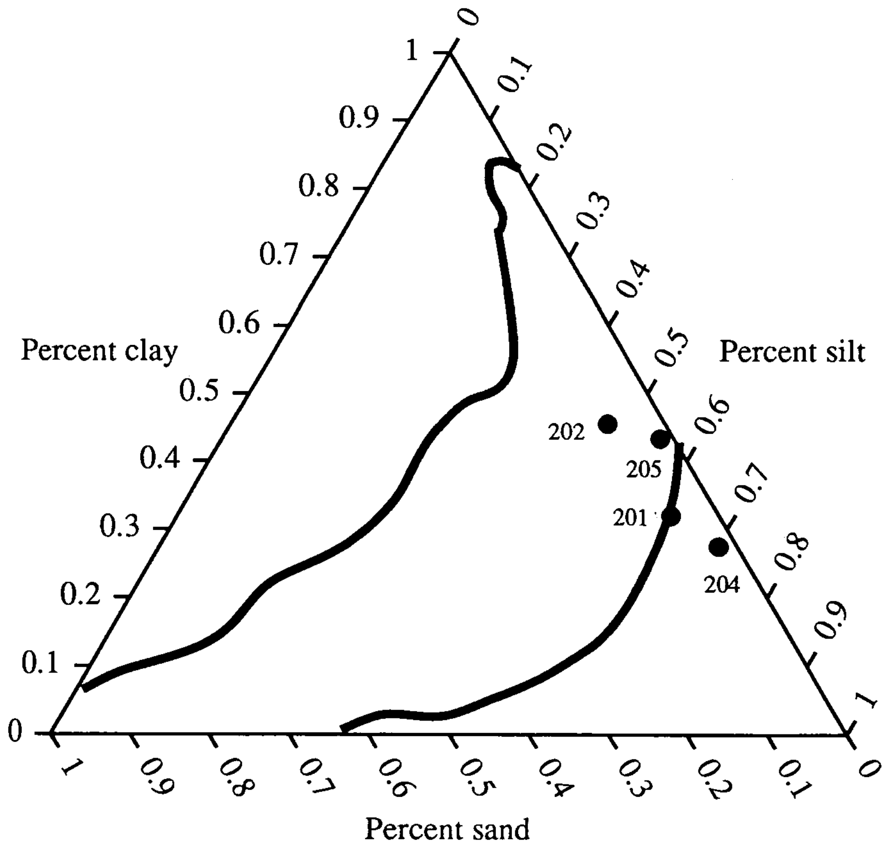


Starston Till (197), Crag Clay (198), 'Clay' from Sea Palling (217) and Holocene from Waxham (222)

Appendix B Ternary particle-size distribution plots for till samples from East Anglia



Lowestoft Till, California Cliffs (189) and Corton (196)



Blue Clay, Easton Bavents (201 & 202) & Thorington (204 & 205)