APPENDICES

APPENDIX 1 Procedure for taking macrofabric measurements.

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Appendix 1: Procedure for macrofabric measurements

1. Rectangular sections of till, each measuring approximately 1 m long x 20 cm deep x 20 cm wide are chosen at 1 m vertical intervals.
2. The outer 4 cm of the top and front surfaces are carefully removed by trowelling so as to avoid the outer zone disturbed by the spade. Working across the surface of the area the till matrix is carefully removed with a flat bladed knife until a clast is encountered.
3. Clasts within the clay matrix are carefully exposed using a flat bladed knife. By gradually scraping away the matrix until the clast is freed, a mould of the clast's position remains in undisturbed clay. Once the clast is carefully removed it is then assessed to see if it meets the criteria shown in the following table.

Minimum length	20 mm	Smaller clasts may not become oriented
Maximum a : b ratio	3 : 1	Ice action causes "swivelling" on longer cylindrical clasts
Minimum a : b ratio	1.2 : 1	The effect of moving ice on spherical clasts is unclear.
Maximum proximity of larger clast	20 mm	Large clasts laid down in close proximity may disturb earlier clasts.

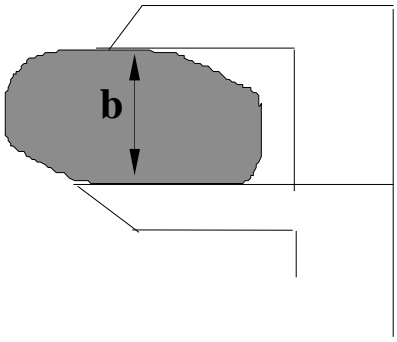
If these criteria are met, measurements are taken and recorded following the procedure given below:

Clast Measurement

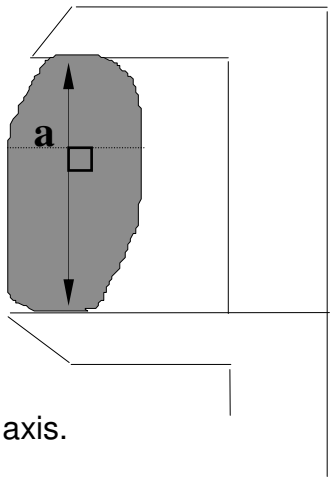
1. The maximum plane of projection (MPP) is located - being the plane of greatest surface area.
2. The shortest axis of the MPP ('b' - axis), is then located and measured with calipers.

3. The ‘a’ - axis is then located, being the axis of the MPP at right angles to the'b' – axis and passing through the centre of the clast. The 'a'-axis is measured with calipers and marked in pencil on the clast if possible

Location of 'a' and 'b' axis



Measuring the 'b' axis



Measuring the 'a' axis.

The clast is then carefully replaced in the mould and a non-magnetic aluminium needle lodged in the till matrix whilst aligned parallel with the 'a' - axis. Using a clinometer the dip of the needle (hence of the'a' -axis) from horizontal is then measured. A hinged lid Silva compass is then used to measure the downdip orientation from grid north.

APPENDIX 2

PILOT STUDY ON LASER DIFFRACTION METHOD OF PARTICLE SIZE ANALYSIS FOR THE CORRELATION AND DIFFERENTIATION OF TILLS

INTRODUCTION

The use of particle size analysis in the study of Quaternary deposits is well established. Not only are particle size distribution curves important in describing sedimentary units, but, in conjunction with other data, they are extremely useful when attempting differentiation and correlation of tills. The effectiveness of this method is illustrated by several studies over the last 30 years, some examples of which are shown in Table 1.

In each of the studies shown, size distributions were obtained using conventional sieving for coarser particles (usually above 63μm) and sedimentation methods for finer fractions. These techniques have been used since the inception of particle size analysis, and despite many advances in sizing technology they remain robust and reliable. However, many alternatives are now available, some of which involve the assessment of particle size based on measurements of various properties including those produced by x-ray attenuation, electrical resistance, and various optical properties. In particular, there have been major recent advances in instruments capable of assessing particle size distributions from the light scattering properties of suspended particles. The combination of laser technology and powerful software can produce extremely detailed size distribution data with high level of reproducibility and precision.

The purpose of this work is to evaluate the use of particle size distributions obtained from a laser diffraction instrument in the differentiation and correlation of till deposits.

LASER DIFFRACTION SIZE ANALYSIS

The laser diffraction method is based on the principle that particles diffract light at an angle inversely proportional to their size. By measuring diffraction angles, the size distribution of particles responsible for a particular diffraction pattern can be calculated. Although the equipment is expensive, laser diffraction offers distinct advantages over conventional methods:

- Analysis takes only a few minutes for each sample so many samples can be processed in a short time.

Table 1 Examples of Particle Size Studies

Reference	Details	Conclusion
Rose (1974)	Two Hertfordshire Tills: Particle size used alongside lithological and fabric data. Size distribution assessed using sieving and pipette data	One till was interpreted as lodgement, the other was identified as a slumped till. That running water had modified the latter was indicated by the relative lack of clay size particles.
Perrin, Rose Davies, (1979)	East Anglian Tills: Particle size used alongside heavy mineral analyses • 2.0 mm -20µm sieved • < 20µm analysed by gravity settling/pipette	Results led to the following division of East Anglian tills: A) North sea drift group with relatively high sand content (Cromer Tills, Norwich Brickearth and part of Marly Drift) B) Lowestoft Till Group with relatively smaller sand fraction
Allen, Cheshire & Whiteman, (1991) & Cheshire (1986)	Tills of Hertfordshire & Essex Particle size distribution down to 45µm sieved – used in conjunction with carbonate analyses and small clast lithology.	Differentiation of three lodgement tills in Hertfordshire together with meltout and lodgement tills in Essex.

- Depending on the nature of the sediment in question, sample preparation is often very simple - clean sand for instance can be introduced directly into the sample handling unit with no prior treatment.

- Although particle re-aggregation can be a problem in certain cases, live monitoring of the sample passing through the cell enables rapid remedial action to be taken. In this respect the Mastersizer S offers the provision of ultrasonic treatment within the dispersion tank.

- Very small samples are required, amounts varying from approximately 0.1 – 0.2g for fine silts to approximately 1 – 2g for sand (Loizeau *et al.,* 1994).

- Measurement of a wide range of particle sizes from 0.05µm up to 3.5 mm can be obtained with the same equipment, (albeit with different lenses) (Malvern Instruments, 1997). This increases the reliability of measurement and facilitates comparison of data.

MALVERN MASTERSIZER S

The instrument used in these analyses was the long bench Mastersizer S manufactured by Malvern Instruments Ltd. A detailed description of this equipment can be found in the Mastersizer Handbook (Malvern Instruments, 1997). Briefly however, the equipment incorporates a He-Ne laser source, sample chamber, Fourier (or reverse Fourier) focusing lens and detector array, operated by a microcomputer. The samples to be analysed are suspended in a liquid dispersant and introduced to a sample handling unit attached to the instrument. From here the suspension is pumped through the sample chamber. The laser is focused onto the chamber and the diffracted light collected by a series of detectors. The scattering pattern is then processed by the microcomputer. An optical model based on a

choice of Fraunhofer or Mie diffraction theory is then employed to predict the sizes of particles responsible for the scattering pattern. This distribution is presented in the form of a volume percentage in each size class. For the current work the 300RF lens was used, which the manufacturers claim is capable of measuring particles between 0.05µm and 880µm. The presentation used was one utilising the Mie Theory in which an average sample refractive index of 1.53 is assumed.

ANALYSIS OF TILL SAMPLES

This study represents an attempt to replicate the results of a textural analysis of tills in Hertfordshire and west Essex (Cheshire, 1986; Allen *et al*., 1991).

Cheshire (1986)

In a detailed study of these tills, particle size data formed part of a multivariate analysis of 286 till samples. The use of 21 petrographic variables enabled Lowestoft Till deposits of this area to be divided into four distinct units, each of which probably represents a separate re-advance of ice following repeated retreats within a single glaciation. These till units are the Ware Member (oldest) followed by the Stortford, Ugley and Wadesmill (youngest) Members (Lewis, 1999). Particle size distributions of fractions larger than 45µm were obtained by sieving.

Sample Selection

The tills selected are from three units from Westmill Quarry in Hertfordshire (TL 344148). The latter location is the type site for the Wadesmill Member (formerly Westmill Till) and Ware Member (formerly Ware Till). The Ugley Member is not represented at this particular site. The samples were collected under the supervision of Cheshire and previous work has shown them to be representative of the Wadesmill, Ware and Stortford Members of the Lowestoft Advance (Cheshire, pers comm.).

PREPARATION

Two samples were randomly selected from each of the till units, the material previously having been air–dried.

Sand fraction

These samples, (WADE(i), WARE(i) and STORT(i)) were chosen to replicate as closely as possible the sieving analyses performed by Cheshire.

The size range covered by the 300RF lens used is 0.05µm to 880µm, whereas the upper limit of sand sized particles is 2.0mm (Wentworth,1922). Therefore analysis of the sand fraction does not show the complete range of coarse and very coarse sand particles. The purpose of this exercise was to provide some overlap with the matrix samples and to compare the medium/fine/very fine sand content with that obtained by sieve analysis.

Approximately 500g of till was randomly selected, removing any stones larger than 5mm. The sample was then deflocculated in 8g /l of sodium hexametaphosphate overnight. Rinsing took place under running water through a nest of Endecott sieves, ranging from 1mm to 63µm. All particles remaining on the 1mm sieve and smaller than 63µm were discarded, the < 63µm finer fraction being subjected to separate analysis (see below). Following rinsing, the sample was immersed in 1molar hydrochloric acid for approximately 48 hours to remove carbonates. The reason for this treatment is that many of the clasts composed of soft chalk break down upon handling thereby altering the true particle size distribution. When there was no further evidence of effervescence, the samples were thoroughly rinsed before being submitted to the analyser

These samples therefore, provide data on the range of particles lying between 63µm and 880µm. This corresponds to part of the coarse sand together with the medium, fine and very fine sand fractions.

Matrix Samples

A second set of samples (WADE(ii), WARE(ii) and STORT(ii)) were selected from the till matrix, avoiding as many clasts as possible. It should be noted that measuring these finer particles requires much less sample material; hence it was relatively easy to select a portion of the matrix containing mainly clay and silt size particles.

Prior to weighing, the sediment was crushed lightly following the methods of Perrin *et al.,* (1979), and then carefully brushed through a 1mm sieve. From the sieved sediment a sample of approximately 100g was randomly selected. This was then submersed in 1 molar hydrochloric acid as for previous samples. Rinsing was achieved by addition of de-

ionised water. After vigorous stirring, the sample was allowed to settle for 24 hrs before decanting the clear liquid above. This procedure was repeated at least 3 times, until the acidity of the liquid was reduced to an approximate value of pH 5.5 . When as much of the liquid as possible had been poured way, the sample was left for 3 days to evaporate until sufficient liquid remained to allow thorough mixing but not to allow 'settling out'. Although the latter was difficult to achieve it was felt that by using wetted particles, thorough mixing of sample could be achieved, whereas if allowed to dry completely, size segregation and aggregation of clay particles would occur.

These samples therefore, provide information on the range of particles from 0.05µm to 880µm.

Procedure

Although the use of such small samples reduces the chances of obtaining a single representative sample, speed of analysis means that many more samples can be processed very quickly. For this reason, 25 subsamples from each of the till samples were subjected to analysis.

For the matrix samples it was necessary to add a deflocculant to the sample during analysis. The sample tank was therefore filled with sodium hexametaphosphate at a rate of 4g/l. A single drop of a surfactant (Nonidet P40) was also added to prevent surface flotation. After sufficient sediment had been added to provide a suitable level of obscuration, five runs were performed and average calculated. Thus 25 sets of data were made available for each sample.

DATA TREATMENT

The results were analysed using the "Gradistat" programme designed by Blott & Pye (2001) for the analysis of unconsolidated sediments. The programme enables rapid calculation of statistical parameters modified from the graphical method of Folk & Ward (1957).

Results obtained from the 63 - 880 µm fraction samples included data on particles smaller than 63 µm. As mentioned above, sample passing through the finest sieve was discarded, so any data on sizes below this range must result either from particles breaking down

during analysis or from inadequate washing. Therefore any <63 µm data were removed from the dataset before analysis.

The data from the 25 subsamples were fed into Gradistat and summary statistics calculated for each. The tables and figures below show averages and ranges for each till. Descriptions of particle size used in Tables 2 and 3 are those given in Blott & Pye (2001) – the sand/silt boundary lying at 63 µm and silt/clay boundary at 2µm.

RESULTS

Sand Fraction

A summary of the results from these samples giving average figures for each till member at Westmill is shown in Table 2. As pointed out, these data are limited to the sand fraction between 63 µm and 1 mm. Thus the frequency curves for the particle size distribution of sand fractions shown in Figure 1 represent only part of the overall particle size distributions of these sediments.

The frequency curves shown in Figure 1 represent mean values for each till. The principle modes of Ware and Stortford Members are very close, although those of the Wadesmill are of a slightly smaller particle size (Table 2). Mean particle sizes for each of the 25 sets of data overlap considerably, as shown in Figure 2.

The results here show therefore, that there is very little difference in the particle size distributions of the sand fraction of these three tills.

Matrix

A summary of the results from the finer fractions is shown in Table 3. Here the data are confined to the particle size distribution curve below 880 µm, but as the sediment was selected from the matrix and passed through a 1mm sieve, - most of the particle sizes are concentrated (by volume) in the < 500µm fraction. The distribution means are very close and the three units possess principle modes between 7.2 and 8.4 µm.

However, if total sand content is plotted against the silt/clay ratio (Fig. 3), it is clear that there are distinct differences in the particle size distribution of these three till members. This figure clearly shows the higher sand content of the Stortford Member and the wide scatter of the Wadesmill samples (see Discussion).

SAMPLE :	STORT(i)	WARE (i)	WADES(i)
MEAN PARTICLE SIZE (μm)	211.7 (10.6)	208.7 (9.1)	204.6 (9.0)
MODE 1(μm)	237.0 (19.0)	236.5 (11.3)	187.3 (21.5)
SAND CONTENT (% vol)			
COARSE (1.0 – 0.5 mm)	8.6	6.8	7.5
MEDIUM (0.5 – 0.25 mm)	32.0	32.4	28.2
FINE (0.25 – 0.125 mm)	38.0	40.2	43.6
V FINE (125 – 62.5 μm)	19.1	18.6	19.4
TOTAL SAND :	**97.7**	**98.0**	**98.7**
CLASTS < 63μm ((% vol)	2.3	2.0	1.3

Table 2 Laser Analyses : Statistical Summary Of Sand Fraction

(Std dev shown in brackets) n = 25

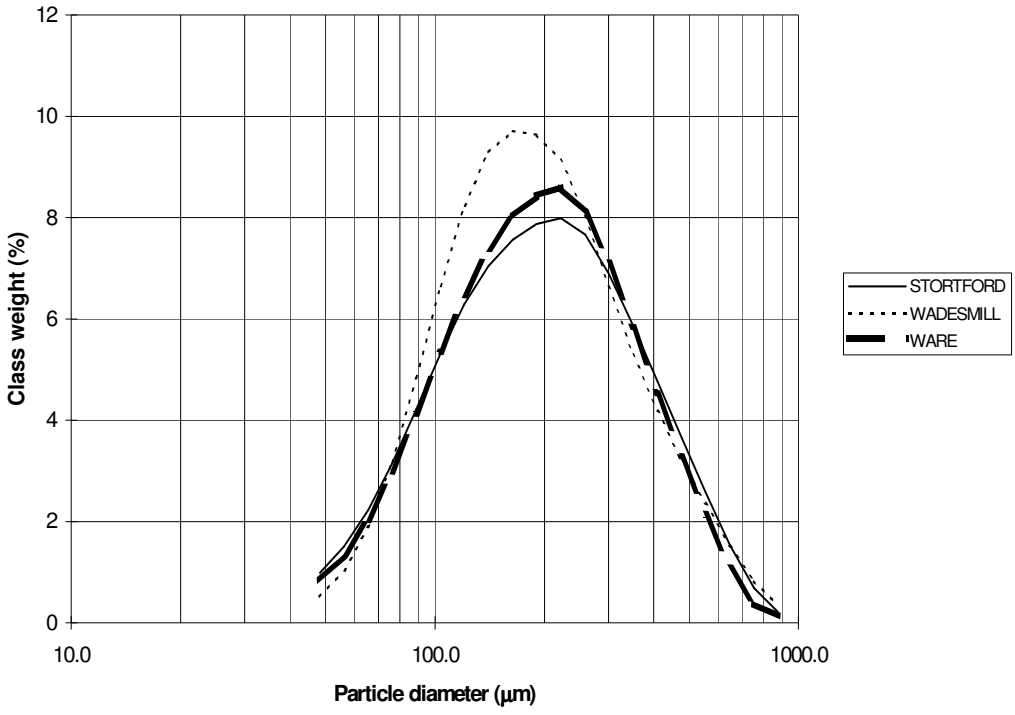


Figure 1

Laser Diffraction Results – Sand Fraction

Curves indicate mean values for each till (n=25)

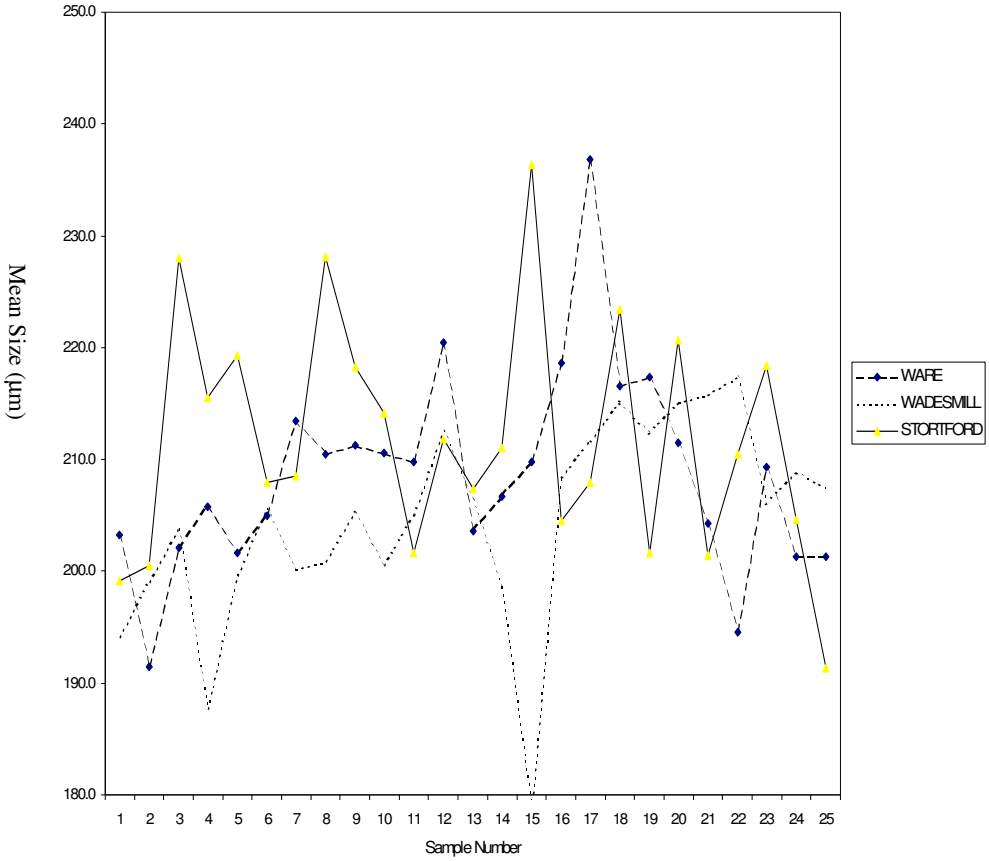


Figure 2
Laser Diffraction
Variances in mean particle Size of Sand Fraction

SAMPLE :	STORT(ii)	WARE (ii)	WADES(ii)
MEAN PARTICLE SIZE (µm)	7.0 (0.5)	7.4 (0.2)	7.0 (1.4)
MODE 1(µm)	8.4 (0.0)	7.2(0.4)	7.8 (1.3)
MODE 2 (µm)	0.4 (0.0)	8.2 (31.5)	0.4 (0.0)
SAND CONTENT (% vol)			
COARSE (1.0 mm – 500 µm)	0.0	0.1	0.1
MEDIUM (500 – 250 µm)	2.1	0.4	0.2
FINE (250 – 125 µm)	4.9	1.0	0.7
V. FINE SAND (125 – 63 µm)	5.7	3.9	2.1
TOTAL SAND	**12.7**	**5.4**	**3.1**
SILT CONTENT (% vol)			
V COARSE (63 – 31 µm)	10.0	9.3	7.5
COARSE 31 – 16 µm)	12.4	13.0	13.8
MEDIUM (16 – 8 µm)	15.1	16.8	22.1
FINE (8 -4 µm)	14.6	17.3	22.5
VERY FINE (4- 2 µm)	10.9	13.8	14.0
TOTAL SILT	**63.0**	**70.2**	**79.9**
CLAY (% vol)	**24.3**	**24.5**	**17.2**

Table 3 Laser Analyses: Statistical Summary Of Matrix Samples

(Std dev shown in brackets)

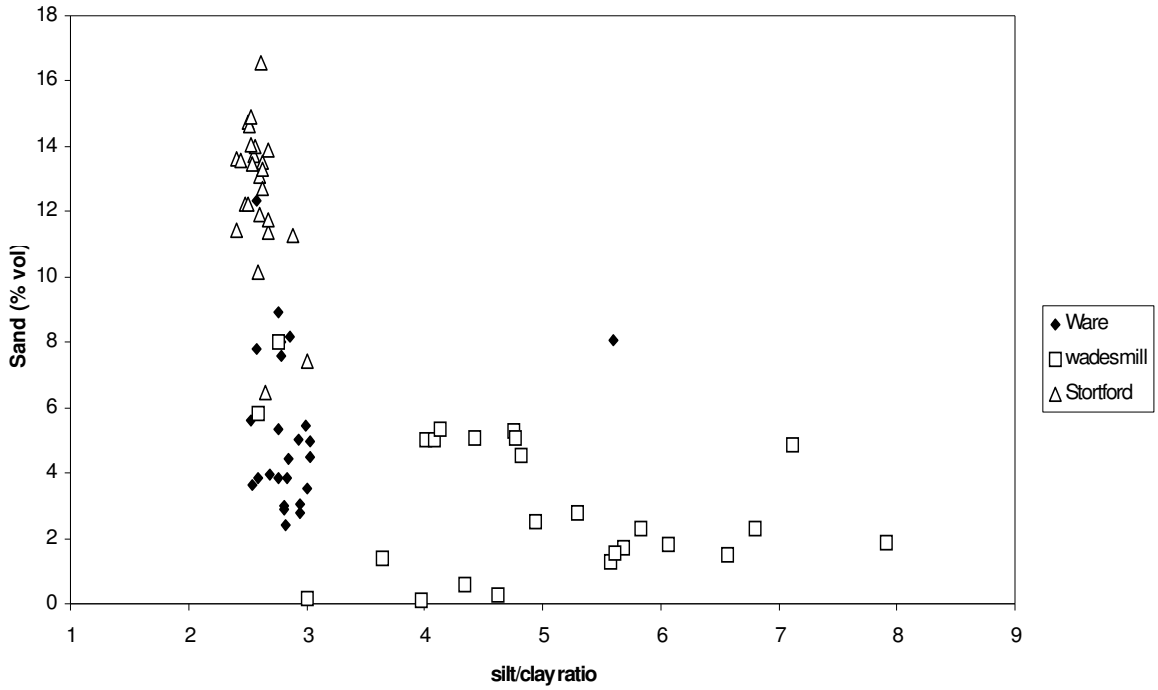


FIGURE 3
Laser Analyses of Matrix (2 – 1000 um)

Comparison of Sand and Matrix samples

Due to size overlap, the sand fraction is also present in the laser-analysed matrix samples. Results of both laser and sieve analysis show volumes of sand steadily increase through the coarse, medium and fine fractions. The sieved sample then shows a decrease in the very fine sand fraction (samples STORT(i), WARE(i) and WADE(i)). It is felt that this may be due to preparatory sieving at 63µm (the boundary between very fine sand and coarse silt) of the samples for analysis of fractions > 63um. Elongate particles of 63µm or more are able to pass through the sieve if they are presented lengthwise – hence part of this sample can be lost. The matrix samples were not subjected to sieving below 1mm.

COMPARISON WITH SIEVE ANALYSIS

In order to compare the laser method with the more traditional approach of sieving used by previous workers, a further set of samples were sieved. Table 4 summarises results obtained from sieve analyses of the Westmill Quarry samples. Following the preparation procedure described above for the laser-analysed sand fraction, particles above 63µm were sieved at half phi intervals. It must be noted that data in this table are presented in percentage by weight, whereas that in Tables 2 & 3 are presented in percent by volume.

The data in Tables (2) and (4) are presented graphically in Figures 5 and 6 respectively. Although the Stortford and Ware Members appear to follow a similar pattern of particle size distribution in the sand fraction in both laser analysis and sieved samples, there appears to be some variation in results produced by Wadesmill sample, with larger amounts in the very fine fraction, and less in the other fractions, for the sieved results.

A variety of factors could be responsible for these anomalies:

1. Differences in preparation of samples for laser and sieving analyses – although the methods of preparation are the same it is always possible that inefficient disaggregation or acid treatment may be responsible for erroneous results.

2. Results from sieving analyses are expressed in percent by weight, whereas those produced by laser particle sizing are presented by volume. This will present differences that may vary according to minerals present in each fraction.

3. It was noted that there were organic particles (presumably modern roots) present in the Wadesmill sample. These were removed as far as possible by immersing sample in water and skimming particles from the surface. However, it is possible that a small amount of organic matter may have been present during analysis. Although this would make very little difference to the sieved sample, laser analysis could not differentiate between these organic and sediment particles.

4. The variation in very fine sand content could be due to inefficient sieving of very fine fraction – perhaps by not allowing insufficient shaking time. However, differences in the coarse/medium to fine ratios are more difficult to explain in this way.

5. It is of course, possible that this may be due to random differences between samples (only one set of sieved data was available for these tills).

Matrix Fraction

This fraction cannot be analysed by sieving. BS 1377-2 (British Standards Institution, 1990) recommends the investigation of particles smaller than 63µm by sedimentation methods.

SAMPLE	STORTFORD	WARE	WADESMILL
MEAN PARTICLE SIZE (µm)	169.8 (0.6)	167.6 (1.4)	131.0 (0.7)
MODE 1 (µm)	215.0	215.0	76.5
MODE 2 (µm)	76.5	76.5	152.5
SAND CONTENT (% Wt)			
COARSE (1.0 mm – 500 µm)	5.6	4.7	3.4
MEDIUM (500 – 250 µm)	22.7	22.0	12.1
FINE (250 – 125 µm)	40.5	41.8	34.8
V. FINE (125 – 63 µm)	27.8	28.2	43.5

Table 4 Statistical Summary Of Sieve Data

(Std dev shown in brackets)

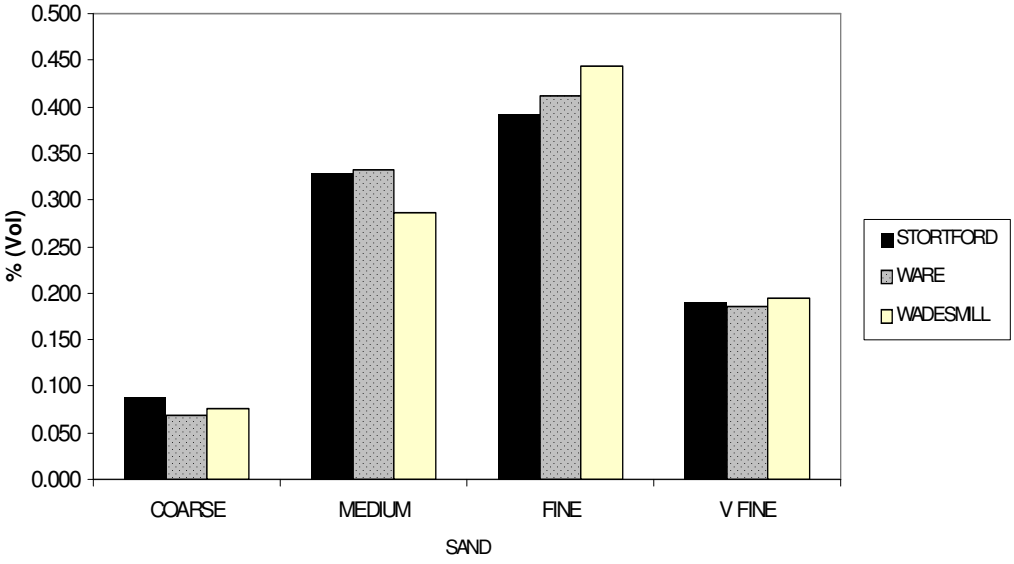


FIGURE 5
LASER ANALYSED SAND FRACTION

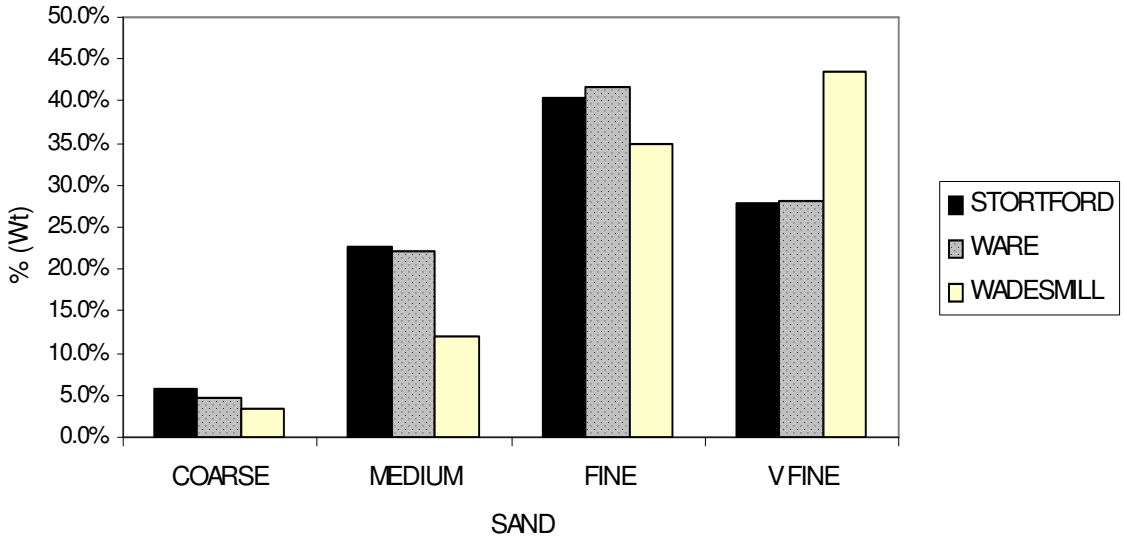


FIGURE 6
SIEVED SAND FRACTION

CHESHIRE'S RESULTS

The four units recognised by Cheshire in Hertfordshire and west Essex are the Wadesmill, Stortford, Ugley and Ware Members. The Ugley Member was found to have similar particle size characteristics to the Wadesmill Member, but data from the Wadesmill and Ware units were found to have distinct particle size distributions. A summary of the results of particle size analyses of the Wadesmill, Stortford and Ware Members is shown below (Cheshire, 1986; Allen *et al*., 1991).

- WARE TILL (WARE MEMBER)

Size distributions of this till were found to have a well-defined mode between 125µm to 250µm (+2 to +3 phi). The sand content of this till was found to be higher than found in the Stortford and Wadesmill members.

- STORTFORD TILL (STORTFORD MEMBER)

This till, which lies directly above the Ware Member at Westmill, was described by Cheshire at its stratotype borehole near Bishop's Stortford. (TL 479195). Here, it was separated from the Ware Member by chalky gravel. It was found that the sand content decreased on passing upwards through the profile, at the same time decreasing in particle

size. The Stortford Member was found to have less medium and coarse sand (between 250µm to 1.00mm, or +2 to 0 phi) than the Ware Member.

- WESTMILL TILL (WADESMILL MEMBER)

The Wadesmill member shows well-defined modes at 125µm – 180µm (+3 to + 2.5phi) and 63 – 90µm (+4 to +3.5 phi) noted by Cheshire to be larger than those found in the Stortford Member. It was also noted to have less medium sand (500 – 250µm or +1 to +2 phi) when compared to the Ware Member.

DISCUSSION

Ware & Stortford Members

From Tables 2 and 4 it can be seen that the principle modes shown by both sieving and laser analysis of the Ware Member agree with that of Cheshire, i.e. lying between 125 – 250µm. However, only the sieving analysis produces a secondary mode at 76.5µm.
In general the laser analyses do not agree with Cheshire's findings of a higher sand content for this till. The overall sand content shown in Table 3 shows the Stortford Member possesses more than twice that of the Ware Member. Analysis of the sand fraction alone (Table 2) shows only small differences in the proportions of medium and very fine fractions of the Ware and Stortford Members, but the Stortford and Wadesmill samples have higher proportions of coarse and very fine sand, respectively (Figure 5).

However, results from the laser analyses are not supported by sieving the same samples. Sand contents shown below (Table 5) are calculated from the full range of sizes measured by sieving, i.e. from 11.43 mm to 45µm. These data are in agreement with Cheshire, i.e. that the Ware Member contains the highest overall proportion of sand, although the difference is small.

These differences between the results using the two methods are difficult to explain, but it would seem likely that they are related to the measuring techniques. It is unlikely (although not impossible) that two samples taken from the same bulk sample would show such striking differences in sand content.

	STORTFORD	WARE	WADESMILL
Sand (1000 – 63 µm) (%Wt)	90.2	92.5	84.7

Table 5: Sieved Data from Westmill Quarry Samples
Sand content as proportion (% Wt) of total sieved fraction (see above).

Despite the disagreement between laser and sieving analyses of the same samples, neither set of data points to the conclusion that the Ware Member contains a consistently higher proportion of sand. There may be several reasons for this discrepancy. Cheshire's analysis of the Stortford Member was based on a sample at the stratotype site near Bishop's Stortford, and there may be lateral variations in the composition of this till. Cheshire noted vertical changes in the sand content of this till, which also might explain such variations.

Examination of the sand fraction data shows the Ware and Stortford Members have very similar particle size characteristics. Discrimination of the two units could not be achieved on the basis of laser or sieved analyses of these data.

However, greater differences are found in the matrix data (2 – 1000 um). Although showing some overlap, it is clear that these two till members plot in distinct areas of Figure 3. This is due to the effects of the higher sand content determined by the laser analysis.

Wadesmill Member

The presence of two modes reported by Cheshire are supported by the sieved data and one of the modes was also found in the laser study. All analyses consistently show that the Wadesmill Member has considerably less medium sand than the Ware Member.

The wide spread of data for this till member shown in Figure 3 is of some concern. Some problems were encountered with modern organic particles in this sample. Although every effort was made to remove these by repeated flotation, it is possible that small particles remained during analysis. Being of extremely low density, these would not greatly affect a sieve analysis but would be interpreted by the Mastersizer as additional particles. Both the shape and density of these particles would affect the resulting particle size distribution.

Differentiation and Correlation

Laser diffraction and sieving methods measure different properties of constituent particles and, as noted by Konert & Vandenberghe (1997), the different methods can produce very different results. This study has shown substantial variation in size distributions obtained by these two methods, the reasons for which may be complex. It is therefore inadvisable to attempt correlation of till units on the basis of a comparison of data obtained by different techniques.

Although the two methods disagree in the determination of sand content, this should not affect the usefulness of either method of differentiation or correlation. Repeated analyses of the same till unit provides a reasonably consistent particle size distribution, and a plot such as that in Figure 3 should enable discrimination of units.

CONCLUSIONS

The till samples examined in this study have shown that there is little to be gained by performing laser particle size analysis of the sand content of these particular tills. Although simpler and quicker than sieving, the resulting characteristics of the three tills determined by laser diffraction do not exhibit sufficient differences to enable discrimination of these three units. Data obtained by sieving can of course provide information on particles up to a maximum of approximately 75 mm. Although the fewer numbers of particles in the larger size ranges create a less statistically sound basis for analysis, a better representation of the overall distribution is obtained. Normally sieving of clasts derived from till samples is confined to sizes between 22.8 mm (-4.5ϕ) and 63μm (+4.0ϕ).

However, laser analysis offers a chance to obtain data ranging across the fine sand/silt and clay ranges. The use of the conventional pipette method for particles smaller than 63μm is time consuming and laser analysis offers a rapid alternative. The matrix samples display variations that may well be of use in till differentiation and correlation.

This study concludes therefore, that laser diffraction particle size analysis of sand, silt and clay size range can provide useful additional information when attempting differentiation and correlation of tills. It is essential however, that such size analysis is carried out as part of a wider investigation of till properties. Particle size characteristics of a broad range of the coarser fraction obtained by sieve analysis, together with an assessment of lithology, till fabric, heavy mineral content, and colour should also be considered.

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APPENDIX 3

SMALL CLAST LITHOLOGY ANALYSIS: IDENTIFICATION AND SEPARATION OF CATEGORIES

FLINT : Found in four forms:

i) Angular, with very sharp edges, frequently conchoidal fractures, fresh, translucent, often grey or brown.

ii) Small rounded flint grains, or fragments of rounded clasts. Abraded surface texture on rounded face(s).

iii) Patinated, porous grains with rough surface texture, usually without form, frequently opaque white, more rarely brown.

iv) Composite grains consisting of any combination of i), ii) or iii) above.

No internal structure is usually seen in flint. The lower transmission of light than quartz results in a sharp penumbra being cast upon an illuminated grain, as tested upon fragments of crushed flint nodules.

QUARTZ : Found in four forms:

i) Well rounded grains with barely perceptible surface texture. Common.

ii) Subrounded/subangular grains, commonly with percussion fractures and faces, and more rarely crystal faces. Very common.

iii) Angular grains with few rounded edges. Uncommon.

iv) Euhedral crystals. Rare.

Quartz grains are usually transparent to translucent and are frequently characterised by internal refraction along crystal planes, cracks and boundaries with inclusions or vacuoles. More rarely grains are milky or smokey, usually distinguished from flint by smoother surface textures and form of i) or ii) above. Diffused penumbra cast upon an illuminated grain.

CHALCEDONIC SILICA : Silica of needle-like habit. Occurs as fragments of cavity or fossil infillings and replacements.

FERRUGINOUS NODULES : Limonite, occurs as soft yellow to harder dark brown amorphous hydrous iron oxides, frequently with impurities. Dull earthy varieties are probably fragments of limonitic concretions. Darker clasts have a sub-metallic lustre and contain more goethite. Some forms result from post—depositional oxidation of former pyrites. In fractions <710 μm sub-spherical framboids occur.

FERRUGINOUS AGGREGATES : Limonitic and goethitic matrix cementing smaller clasts into aggregate grains. Haematitic stained aggregates, as found in the Permian and Triassic, are grouped under aggregates.

FERRUGINOUS FOSSILS : Fossils in whole or substantial part composed of limonite.

FERRUGINOUS LIMESTONE : Clasts of limonite/goethite replaced limestone containing calcitic fossils or ooliths.

PYRITES : The typical brassy colour and lustre only occurs in larger crystals. When disseminated pyrites appears metallic grey, and its form is often determined by replacement of calcite fossils. Where disseminated pyrites occurred in a shale clast, it was classified by major component, pyrites or shale. Pyrites is characteristic of marine clays and shales, and its presence in till indicates insulation from oxygen.

PYRITIC FOSSIL : Fossils in whole or substantial part composed of pyrites.

PYRITIC AGGREGATE : Aggregate cemented by pyrites.

FOSSIL : Fossils in whole or substantial part composed of silica or other minerals except limonite and pyrites.

CARBON : Coal, not necessarily Carboniferous, lignite or charcoal. Black or very dark brown, often with bright vitreous lustre.

RHAXELLA CHERT : Cherts containing the casts of the spherical spicules of the sponge **Rhaxella perforata**.

SILICIFIED LIMESTONE : Clasts of silica replaced limestone, containing calcitic fossils or ooliths.

MUSCOVITE MICA : Characteristically bright lustre, colourless, and in thin laminae.

SHALE : Grey and mottled brown types observed. Both are soft and can be compressed with a seeker.

LOWER GREENSAND CHERT : Occurs in sands and gravels, but only in the most southerly tills. Yellow-brown cherts with a resinous lustre, usually with one or more elongate sponge spicules.

WOOD FRAGMENTS : Brown soft wood. Can be compressed with a seeker.

AGGREGATES : A broad group of rocks which includes all aggregates of grains and crystals not included above. It includes clasts of sedimentary, igneous and metamorphic origin.

OTHER MINERALS : This group does not include aggregates. It comprises all monomineralic clasts other than quartz, pyrites, limonite, carbon and muscovite mica.

(Cheshire, 1986).