CHAPTER 7
DISCRIMINATION BETWEEN TILL UNITS

PART 1: MULTIVARIATE ANALYSES
7.1 Introduction

One of the main aims of this study is to discriminate between till units present within the study area. To facilitate this, analyses of the data were performed using the series of datasets described in Chapter 4 (Table 4.4). Comparison was then made between data collected during this study and that of Cheshire (1986) relating to an area of southeast Hertfordshire. Tentative correlation between deposits of the two areas was then carried out.

The evidence for multiple till units at four sites is reviewed in this chapter. In Table 7.0 these are denoted by U (upper), M (middle) or L (lower) units.

The dendrograms produced by cluster analysis giving graphical descriptions of the clustering of data, are included, together with details of Database 1, in Appendix 4.

Sample no.	Site no.	Location
1	1	Knebworth Park
2		
3	2 (L)	Norton Green
4	2(U)	
5	3(L)	Cannocks Wood
6	3 (U)	
7		
8		
9		
10		
11		
12		
13		
14		
15		
16	4	Letchmore
17		
18		
19	5	St. Ibbs
20	6	Little Wymondley
21		
22		
23	7	Great Wymondley
24		
25		
26	8(L)	St Ippollitts
27	8(M)	
28	9	Maydencroft
29	10	Baldock
30		
31		
32		
33	11(L)	Primrose Hill Quarry
34	11(M)	
35		
36		

Sample no.	Site no.	Location
37	12	U. Stondon
38	14	Broom
39	15	Southill
40		
41	16	Moggerhanger
42	17	Sandy
43	18	Warden Street
44		
45	19	Edworth
46	20	Millowbury Farm
47		
48	21	Potton
49	22	Cockayne Hatley
50	23	Hatley
51	24	Longstowe
52	25	Caxton
53		
54		
55		
56		
57	26	Wrestlingworth
58	27	Milton Bryan
59		
60	28	Potsgrove
61		
62	29	Mundays Hill
63	30	Heath & Reach
64		
65		
66		
67		
68		

U = Upper till unit   M= Middle till unit   L = Lower till unit

Table 7.0. Samples used in statistical analyses.

7.2. Statistical Analyses – Database 1.

The following is a summary of the analyses of datasets A to H, being subsets of Database 1 as set out in Table 4.4 (Chapter 4).

7.2.1. Dataset A (all variates)

This is the main dataset comprising all 85 variates, details of which are shown in Table 4.4. The number of variates exceeds sample numbers, therefore principle co-ordinate analysis (PCO) was carried out (Section 4.6.3). The data were standardised prior to analysis and a similarity matrix was generated.

Principal co-ordinate analysis

The component loadings (Table 7.1) show the first axis to account for only 27.7 % of the variance, the second axis accounting for a further 23.7%. The total variance accounted for by the first three PCO axes is only 61.4%.

The similarity matrix shows 62 links between samples lying at a Euclidean distance of less than 6.0, shown on the scatterplot of PCO axes 1 and 2 (Figure 7.1). Of these, 42 between-site links are shown in Table 7.2 together with the respective Euclidean distance. Where there are several links between sites, an average has been calculated. At this level of similarity, all but three of the between–site links are connected, forming the main network in Figure 7.1. There appears to be no discernible grouping of the data.

Lower tills at Site 2 (Norton Green) and Site 8 (St Ippollitts) remain separated from other tills at these sites on principal component axis 1. The upper till at Site 2 (sample 4) and the middle till at Site 8 (sample 27) possess negative values on this axis, whilst samples of lower till (samples 3 and 26 respectively) have positive values (Figure 7.1). However, samples from both upper and lower tills at Site 3 (Cannocks Wood) are widely scattered on both axes.

Cluster analysis

A dendrogram, using similarity coefficients, produced by cluster analysis of this dataset (Appendix 4) divided the samples into three main clusters, shown in Table 7.3. Clusters 1 and 2 were created at roughly the same level of similarity (~83.5%) whilst Cluster 3 samples are more closely related at 86% similarity. Included in Cluster 1 are all the samples south of Hitchin with the exception of the lower tills at Sites 2 (Norton Green – sample 3) and 3 (Cannocks Wood – sample 5), samples 19 from Site 5 (St Ibbs) and 26 and 27 from Site 8 (St. Ippollitts).

An association is shown between the lower tills at Sites 3 and 8 which are both in Cluster 2. This cluster also includes samples from both middle and lower tills at Primrose Hill Quarry (Site 11) and all samples from Sites 19 to 24 (Edworth, Millowbury Farm, Potton, Cockayne Hatley, Hatley and Longstowe) on the Northeastern Plateau.

Several sites are split between clusters, as shown in Table 7.3, summarised below:

- **Site 10 (Baldock)**: Samples 30 and 31 are in Cluster 2 whilst sample 32 is in Cluster 3. The lowest sample at this site (sample 29) does not associate with any other sample at greater than 72.3% similarity, at which level it connects to a larger single cluster encompassing Clusters 1, 2 and 3.
- **Site 25 (Caxton)**: the lowest samples from this site (52 - 54) are found in Cluster 3, whilst samples 55 and 56 appear in Cluster 2.
- Samples 63, 64 and 66 to 68 from **Site 30 (Heath and Reach)** are in Cluster 1. However, sample 65 appears in Cluster 3.

Separation of the lower tills at Sites 2, 3 and 8 is indicated by this cluster analysis. Sample 3 representing the lower till from Site 2 (Norton Green) does not associate with any other sample above 82% similarity at which level it connects to Cluster 3. Sample 4, representing the upper till at this site, is found in Cluster 1. The two samples (26 and 27) representing the middle and lower tills at Site 8 (St Ippollitts) are found in different clusters. All the samples (6 - 15) from the upper till at Site 3 (Cannocks Wood) are contained within Cluster 1, where they show an association with other sites south of Hitchin, i.e. samples 1 and 2 at Knebworth Park (Site 1), sample 4 from the upper till at Norton Green (Site 2), samples 16 – 18 at Letchmore (Site 4), samples 20 – 22 from Little Wymondley (Site 6), samples 23 – 25 from Great Wymondley (Site 7) and sample 28 from Maydencroft (Site 9).

	Axis 1	Axis 2	Axis 3
Eigenvalues	1580.313	1347.200	569.880
Percentage	27.749	23.656	10.007
Cum. Percentage	**27.749**	**51.405**	**61.412**

Table 7.1 Dataset A: PCO component loadings.

1^{st} Site	**2^{nd} Site**	**No. of Links**	**Euclidean distance ***
3(U)	6	9	4.93
27	28	4	5.15
28	30	2	5.25
6	28	3	5.31
3(U)	28	7	5.32
17	21	1	5.45
9	17	1	5.47
25	27	2	5.51
5	11(L)	1	5.53
27	29	1	5.60
17	25	2	5.67
3(U)	4	1	5.77
1	30	1	5.79
28	29	1	5.82
3(U)	25	1	5.83
11(L)	23	1	5.83
10	23	1	5.85
2(U)	3(U)	1	5.85
9	25	1	5.89
3(U)	29	1	5.91

* average where more than one link is shown

Table 7.2. Dataset A
Between-site links Euclidean distances < 6.0.

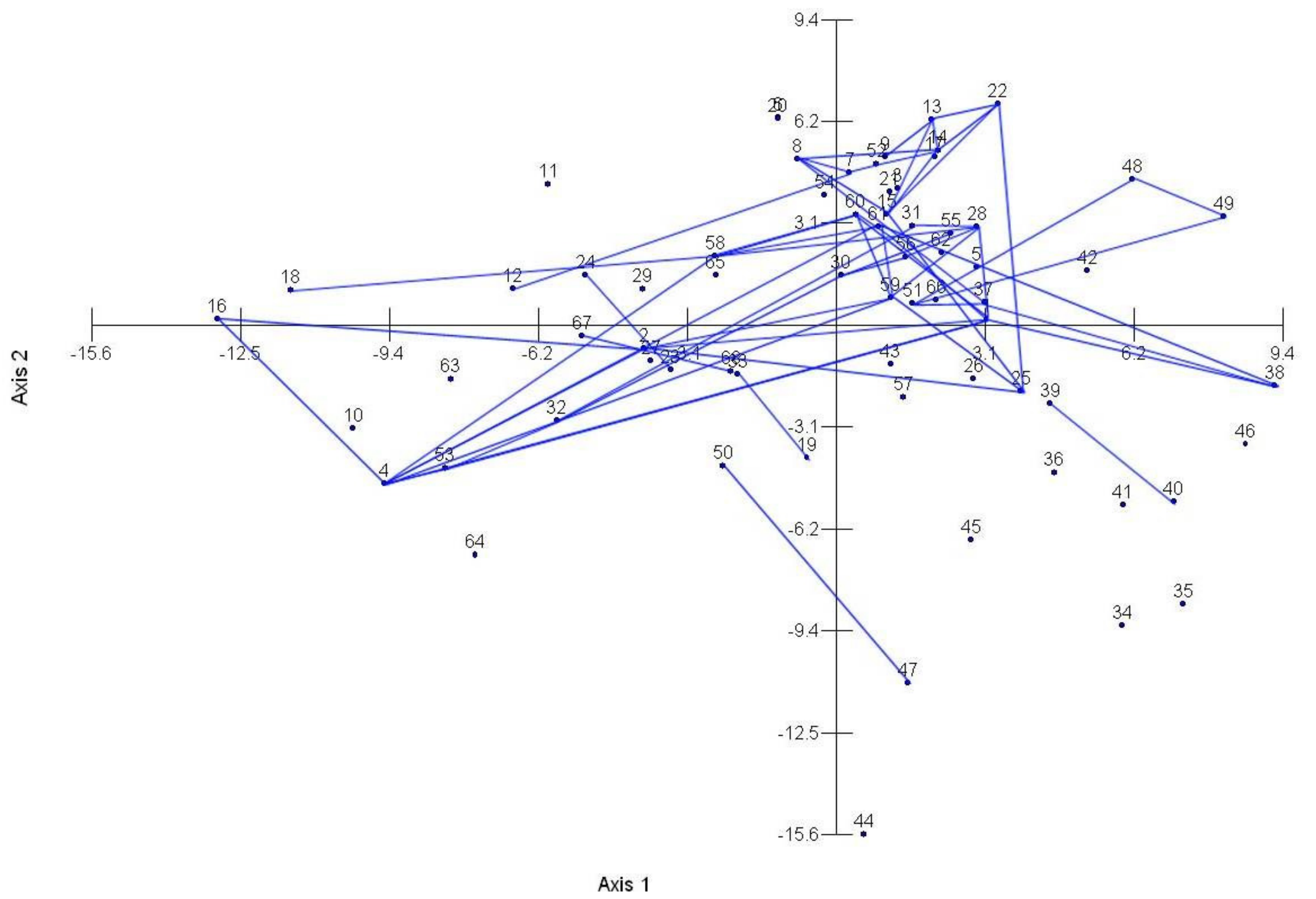


Figure 7.1. Dataset A
Samples linked by Euclidean distance of < 6.0 shown on PCO axes 1 & 2.

Cluster 1		Cluster 2		Cluster 3	
Sample No.	**Site No.**	**Sample No.**	**Site No.**	**Sample No.**	**Site No.**
1	1	5	3 (L)	27	8 (M)
2		19	5	32	10
4	2 (U)	26	8 (L)	52	
6		30	10	53	25
7		31		54	
8		33	11 (L)	65	30
9		34			
10		35	11 (M)		
11	3 (U)	36			
12		42	17		
13		43	18		
14		45	19		
15		46			
16		47	20		
17	4	48	21		
18		49	22		
20		50	23		
21	6	51	24		
22		55	25		
23		56			
24	7				
25					
28	9				
37	12				
38	14				
58	27				
59					
60	28				
61					
63					
64					
66	30				
67					
68					

Table 7.3 Dataset A.
Group membership suggested by cluster analysis (Similarities > 83.5%).

7.2.2. Dataset B (particle size distribution at half phi classes -2.5 to +4.0 phi)
Dataset B is composed of data from insoluble lithologies derived from the sieve analysis for all 68 samples. Because the number of variates was exceeded by the number of samples, PCA and cluster analysis were performed on this dataset.

Principal component analysis
The first principal component axis accounts for 87.2% of the variance. Component loadings show this to represent the relative proportions of medium and very fine sand (+1.5 to + 4.0 phi) to very coarse sand and fine gravel (+1.0 phi to -2.5 phi) (Figure 7.2a). The second principal component axis accounts for a further 11.6% of the variance and represents the ratio of medium/fine sand (+2.5 to +1.5 phi) to very fine sand (+3 to +4 phi) (Figure 7.2b). The third principal component axis accounts for only 0.54% of the total variance (Figure 7.2c). In total the percentage of variance accounted for by the first three axes is 99.6%. A comparison of loadings on all three axes is shown in Figure 7.2d.

A scatterplot of the component scores for each of the first two axes is shown in Figure 7.3. 120 links have been constructed between samples on this plot with similarity coefficients greater than 93.0%. 59 of these are between-site links (Table 7.4). Two major groups can be distinguished together with two minor groups. Group membership is shown in Table 7.5.

Group 1 includes a tightly clustered group of samples 6 – 15 from the upper till at Site 3 (Cannocks Wood), which is linked to surrounding sites in the Hitchin Gap, as well as sites 27 (Milton Bryan), 28 (Potsgrove) and 29 (Mundays Hill) lying to the west of the study area. A further single sample (64) from Site 30 (Heath and Reach) is also included in this group.

Group 2 covers a larger portion of the plot, the samples being less tightly constrained. It contains four samples from Site 30 in the west of the study area, as well as those from Sites 1, 2, 7, 11, 14, 16 and 19 within and to the north of the Hitchin Gap.

Group 3 comprises a tightly clustered group of samples (52 - 56) from Site 25 (Caxton) which are linked to the two samples (46 and 47) from Site 20 at Millowbury Farm, southeast of Biggleswade. Also included in this group is a single sample from the Hitchin Gap, i.e. sample 27 representing the middle till at St Ippollitts (Site 8).

Group 4 contains three samples from Baldock (Site 10) and a sample from the lower till unit at Site 11 within the Hitchin buried channel. Three samples from the northeastern plateau (from Sites 21, 22 and 24) also appear in this group.

Amongst samples not included in these groups are those from Site 15 at Southill (samples 39 & 40). These appear on the periphery of Figure 7.3, due to the extremely high medium to fine sand modes in these samples, which both possess well defined modes at 2.0 phi.

Figure 7.4 shows envelopes enclosing two or more adjacent samples from the same site, believed to represent single units. At Sites 2, 3 and 11, samples which possibly represent separate till units are clearly separated on this scatterplot. Figure 7.4, therefore, illustrates separation of the following units (shown in red) on the basis of particle size.

- The two samples (3 & 4) from **Site 2** (Norton Green) have very different particle size characteristics as can be seen by comparing Figures 5.7 and 5.8 (section 5.2). The upper sample (sample 4) possesses a much higher fine sand mode (at 2.2 phi) than the lower (sample 3), as defined mainly by the first principal component axis. Sample 3, shown as Site 2 (L), exhibits similar particle size characteristics to samples 30 - 32 at Site 10 (Baldock), all of which have modes in the very fine sand fraction (3.5 phi).

- The cluster of upper till samples 6 - 15 at **Site 3** (Cannocks Wood) are shown in section 5.2 as having very similar particle size distributions and are placed at a distance from the lower till at this site (sample 5).

- Samples 34 – 36 from the middle till at **Site 11** (Primrose Hill Quarry) are spread widely across axis 1 indicating dissimilarities in the ratios of medium/fine sand to coarse sand and fine gravel. However, their values on axis 2 indicate similar ratios of medium/fine sand to very fine sand. The single sample of the lower till at this site (sample 33), is isolated on this axis (shown as Site 11 L).

- The position of samples 26 and 27 from **Site 8** at St Ippollitts, however, does not indicate any great difference in the particle size distribution in the -2.5 to + 4.0 phi range. Both samples have modal values of 3.5 phi.

Cluster analysis

The dendrogram produced by cluster analysis of this dataset (Appendix 4) suggests three clusters of sites at greater than 75.0% similarity (Table 7.6).

Cluster 1 is composed of two smaller clusters each linked at a similarity level of ~84%, one of which includes all samples from Site 25 (Caxton) as well as both samples from Site 8 (St Ippollitts) and 6 samples of the upper till at Site 3 (Cannocks Wood). The other contains samples of both upper and lower tills at Site 3, samples from Sites 4, 6 and 7 south of Hitchin, Sites 16 (Moggerhanger) and 19 (Edworth), plus Sites 27 (Milton Bryan), 28 (Potsgrove) and the three lowest samples (63 - 65) from Site 30 (Heath & Reach) in the west of the study area.

Cluster 2 comprises a variety of samples (Table 7.6) from sites scattered about the study area, e.g. both samples from Site 1 (Knebworth Park), the upper sample (4) from Site 2 (Norton Green), all samples (34 - 36) from the middle till at Site 11 (Primrose Hill Quarry) and further samples from Sites 14, (Broom), 15 (Southill), 18 (Edworth) and the three upper samples (66 – 68) from Site 30 (Heath & Reach).

All samples from Site 10 (Baldock) are found in **Cluster 3** together with the lower till at Site 11 (Primrose Hill Quarry) and Sites 21 to 24 on the Northeastern Plateau and the lower till at Site 2 (Norton Green).

Figure 7.5 shows these clusters overlain on the PCA scatterplot. There appears to be reasonable agreement between the results of these two analyses. Comparison of Figures 7.3 and 7.5 shows similar groupings in each case.   Each cluster includes several unlinked sites as well as all or part of groups identified in Figure 7.3. Cluster 1 encompasses all of Groups 1 and 3 and the lower part of Group 2 on Figure 7.3. Cluster 2 takes in the upper part of Group 2 and Cluster 3 comprises the whole of Group 4. The highest similarity links between the lower part of Group 2 and Group 1 (both part of Cluster 1) are shown on the similarity matrix to lie at 92.85%.   The results from the cluster analysis agree with 98.3% of the sample associations produced by PCO analysis (Table 7.5) and is therefore considered to support the findings of the principal component analysis.

a

b

c

d

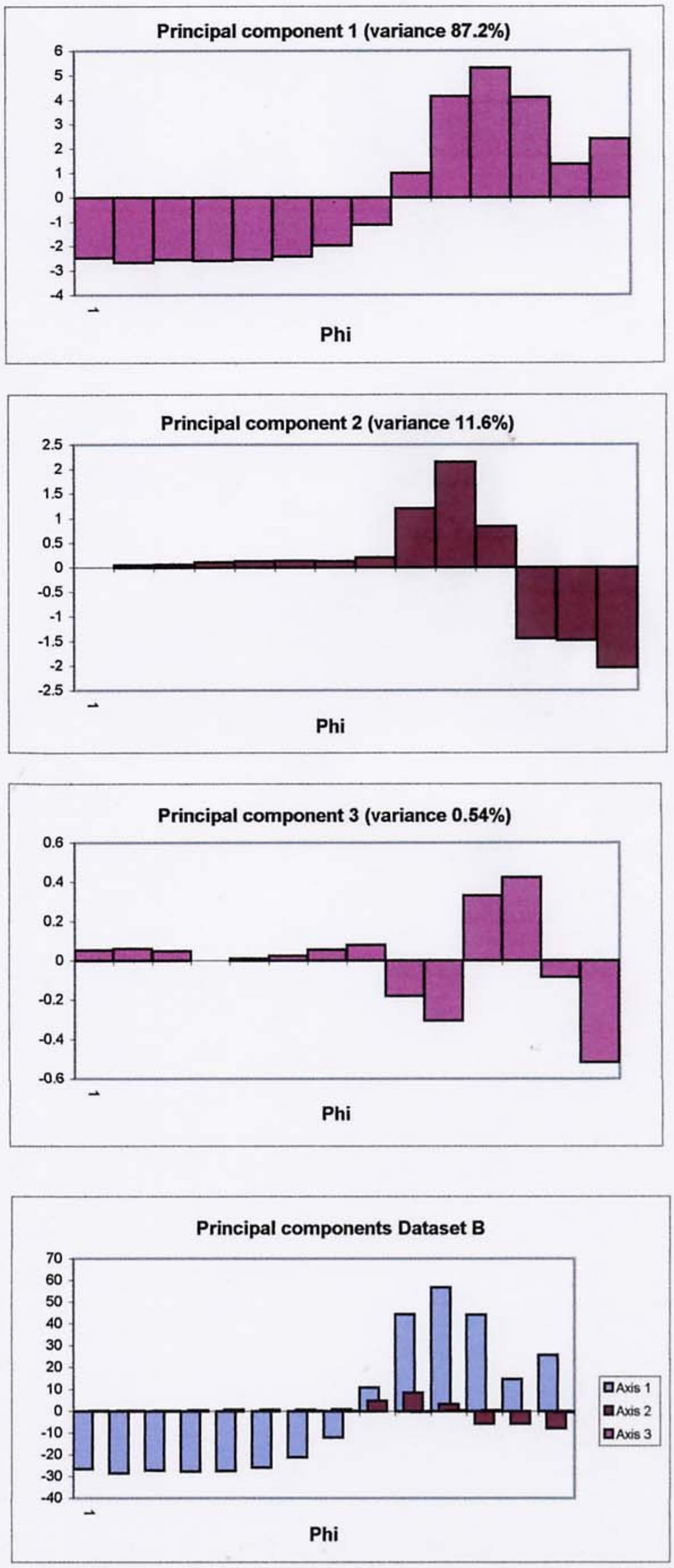


Figure 7.2. Dataset B

a - c Component loadings on the first three principal components.

d Comparison of loadings on the first three axes.

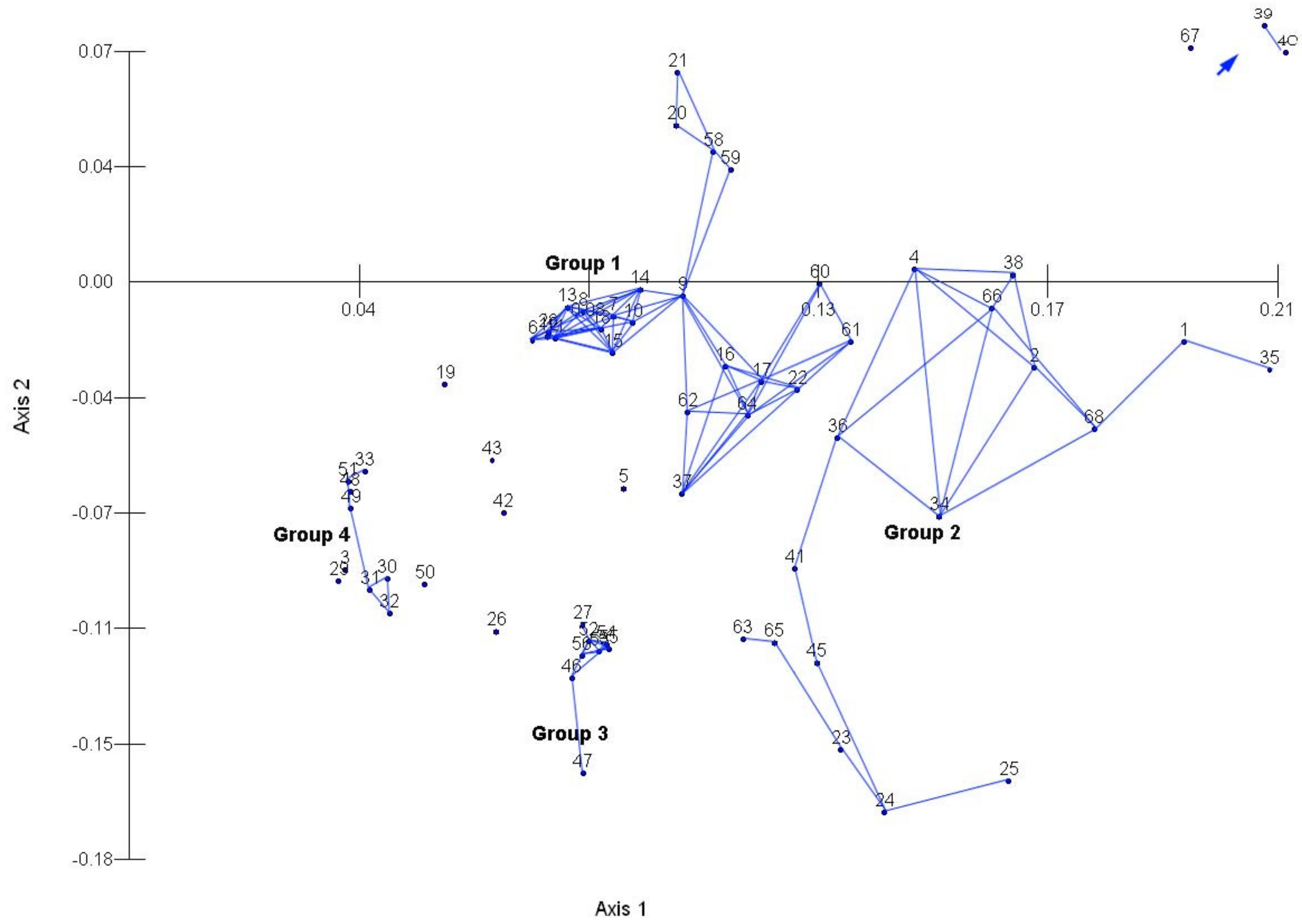


Figure 7.3. Dataset B
Similarity Coefficients > 93.0% plotted on PCA axes 1 & 2

Group 1			
1st Site	2nd Site	No. of links	Similarity* %
4	6	2	97.3
3(U)	4	9	95.2
6	22	2	94.5
4	29	1	94.3
3(U)	9	4	94.1
6	30	1	93.9
12	30	1	93.8
4	12	2	93.7
6	28	1	93.7
12	29	1	93.7
4	30	1	93.6
4	9	1	93.6
3(U)	29	1	93.6
6	27	1	93.2
29	30	2	93.2
28	30	1	93.1
4	28	1	93.0
6	12	1	92.9
3(U)	27	2	92.8
Group 2			
1	14	1	95.7
2(U)	14	1	94.9
7	30	1	94.5
1	11(M)	2	94.1
2(U)	30	1	94.0
1	2(U)	1	93.5
11(M)	30	3	93.4
1	30	1	93.3
7	19	1	93.2
2(U)	11(M)	2	93.0
16	19	1	92.8
11(M)	16	1	92.5
Group 3			
19	20	1	93.4
20	25	2	93.1
8 M	25	1	92.5
Group 4			
21	24	1	97.2
21	22	1	95.0
11(L)	24	1	93.0
10	22	1	92.5

* average where more than one link is shown

Table 7.4. Dataset B.
Between-site links for groups 1 to 4 based on PCA (Similarities > 93.0%.)

<table>
<tr><th colspan="2">Group 1</th><th colspan="2">Group 2</th><th colspan="2">Group 3</th><th colspan="2">Group 4</th></tr>
<tr><th>Sample No.</th><th>Site No.</th><th>Sample No.</th><th>Site No.</th><th>Sample No.</th><th>Site No.</th><th>Sample No.</th><th>Site No.</th></tr>
<tr><td>6</td><td rowspan="10">3(U)</td><td>1</td><td rowspan="2">1</td><td>27</td><td>8(M)</td><td>30</td><td rowspan="3">10</td></tr>
<tr><td>7</td><td>2</td><td>46</td><td rowspan="2">20</td><td>31</td></tr>
<tr><td>8</td><td>4</td><td>2(U)</td><td>47</td><td>32</td></tr>
<tr><td>9</td><td>23</td><td rowspan="3">7</td><td>52</td><td rowspan="5">25</td><td>33</td><td>11(L)</td></tr>
<tr><td>10</td><td>24</td><td>53</td><td>47</td><td>21</td></tr>
<tr><td>11</td><td>25</td><td>54</td><td>49</td><td>22</td></tr>
<tr><td>12</td><td>34</td><td rowspan="3">11(M)</td><td>55</td><td>51</td><td>24</td></tr>
<tr><td>13</td><td>35</td><td>56</td><td></td><td></td></tr>
<tr><td>14</td><td>36</td><td></td><td></td><td></td><td></td></tr>
<tr><td>15</td><td>38</td><td>14</td><td></td><td></td><td></td><td></td></tr>
<tr><td>16</td><td rowspan="3">4</td><td>41</td><td>16</td><td></td><td></td><td></td><td></td></tr>
<tr><td>17</td><td>45</td><td>19</td><td></td><td></td><td></td><td></td></tr>
<tr><td>18</td><td>63</td><td rowspan="4">30</td><td></td><td></td><td></td><td></td></tr>
<tr><td>20</td><td rowspan="3">6</td><td>65</td><td></td><td></td><td></td><td></td></tr>
<tr><td>21</td><td>66</td><td></td><td></td><td></td><td></td></tr>
<tr><td>22</td><td>68</td><td></td><td></td><td></td><td></td></tr>
<tr><td>28</td><td>9</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>37</td><td>12</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>58</td><td rowspan="2">27</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>59</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>60</td><td rowspan="2">28</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>61</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>62</td><td>29</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>64</td><td>30</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Table 7.5. Dataset B.
Group membership suggested by PCA.

<table>
<tr><th colspan="2">Cluster 1</th><th colspan="2">Cluster 2</th><th colspan="2">Cluster 3</th></tr>
<tr><th>Sample No.</th><th>Site No.</th><th>Sample No.</th><th>Site No.</th><th>Sample No.</th><th>Site No.</th></tr>
<tr><td>5</td><td>3L</td><td>1</td><td rowspan="2">1</td><td>3</td><td>2L</td></tr>
<tr><td>6</td><td rowspan="10">3U</td><td>2</td><td>29</td><td rowspan="4">10</td></tr>
<tr><td>7</td><td>4</td><td>2U</td><td>30</td></tr>
<tr><td>8</td><td>34</td><td rowspan="3">11M</td><td>31</td></tr>
<tr><td>9</td><td>35</td><td>32</td></tr>
<tr><td>10</td><td>36</td><td>33</td><td>11L</td></tr>
<tr><td>11</td><td>38</td><td>14</td><td>48</td><td>21</td></tr>
<tr><td>12</td><td>39</td><td rowspan="2">15</td><td>49</td><td>22</td></tr>
<tr><td>13</td><td>40</td><td>50</td><td>23</td></tr>
<tr><td>14</td><td>44</td><td>18</td><td>51</td><td>24</td></tr>
<tr><td>15</td><td>66</td><td rowspan="3">30</td><td></td><td></td></tr>
<tr><td>16</td><td rowspan="3">4</td><td>67</td><td></td><td></td></tr>
<tr><td>17</td><td>68</td><td></td><td></td></tr>
<tr><td>18</td><td></td><td></td><td></td><td></td></tr>
<tr><td>19</td><td>5</td><td></td><td></td><td></td><td></td></tr>
<tr><td>20</td><td rowspan="3">6</td><td></td><td></td><td></td><td></td></tr>
<tr><td>21</td><td></td><td></td><td></td><td></td></tr>
<tr><td>22</td><td></td><td></td><td></td><td></td></tr>
<tr><td>23</td><td rowspan="3">7</td><td></td><td></td><td></td><td></td></tr>
<tr><td>24</td><td></td><td></td><td></td><td></td></tr>
<tr><td>25</td><td></td><td></td><td></td><td></td></tr>
<tr><td>26</td><td>8L</td><td></td><td></td><td></td><td></td></tr>
<tr><td>27</td><td>8M</td><td></td><td></td><td></td><td></td></tr>
<tr><td>28</td><td>9</td><td></td><td></td><td></td><td></td></tr>
<tr><td>37</td><td>12</td><td></td><td></td><td></td><td></td></tr>
<tr><td>41</td><td>16</td><td></td><td></td><td></td><td></td></tr>
<tr><td>42</td><td>17</td><td></td><td></td><td></td><td></td></tr>
<tr><td>43</td><td>18</td><td></td><td></td><td></td><td></td></tr>
<tr><td>45</td><td>19</td><td></td><td></td><td></td><td></td></tr>
<tr><td>46</td><td rowspan="2">20</td><td></td><td></td><td></td><td></td></tr>
<tr><td>47</td><td></td><td></td><td></td><td></td></tr>
<tr><td>52</td><td rowspan="5">25</td><td></td><td></td><td></td><td></td></tr>
<tr><td>53</td><td></td><td></td><td></td><td></td></tr>
<tr><td>54</td><td></td><td></td><td></td><td></td></tr>
<tr><td>55</td><td></td><td></td><td></td><td></td></tr>
<tr><td>56</td><td></td><td></td><td></td><td></td></tr>
<tr><td>58</td><td rowspan="2">27</td><td></td><td></td><td></td><td></td></tr>
<tr><td>59</td><td></td><td></td><td></td><td></td></tr>
<tr><td>60</td><td>28</td><td></td><td></td><td></td><td></td></tr>
<tr><td>61</td><td rowspan="2">29</td><td></td><td></td><td></td><td></td></tr>
<tr><td>62</td><td></td><td></td><td></td><td></td></tr>
<tr><td>63</td><td rowspan="3">30</td><td></td><td></td><td></td><td></td></tr>
<tr><td>64</td><td></td><td></td><td></td><td></td></tr>
<tr><td>65</td><td></td><td></td><td></td><td></td></tr>
</table>

Table 7.6. Dataset B.
Group membership suggested by cluster analysis (Similarities > 75.0%).

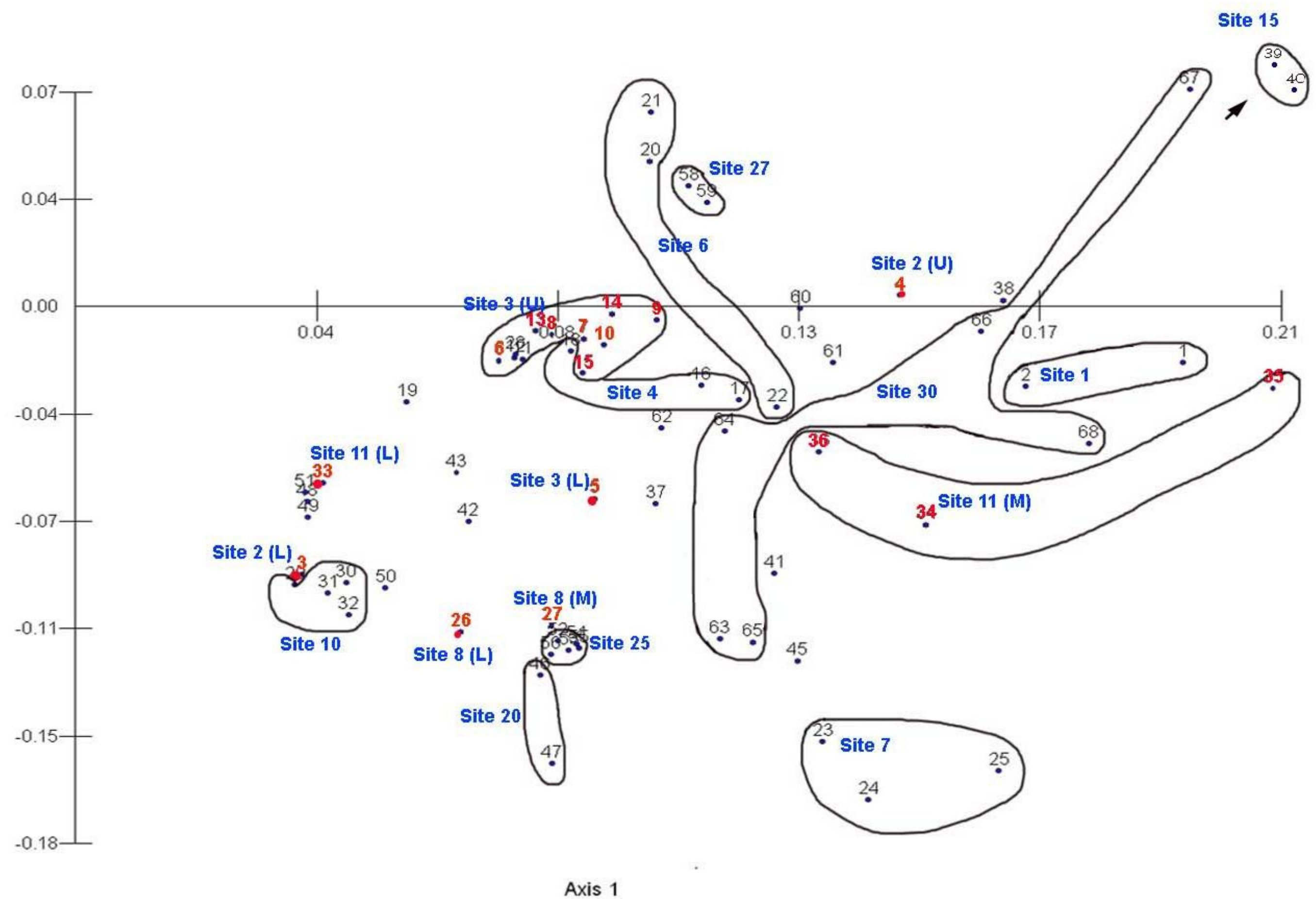


Figure 7.4. Dataset B.
PCA scatterplot of axes 1 & 2 with envelopes enclosing multiple samples from the same till unit.

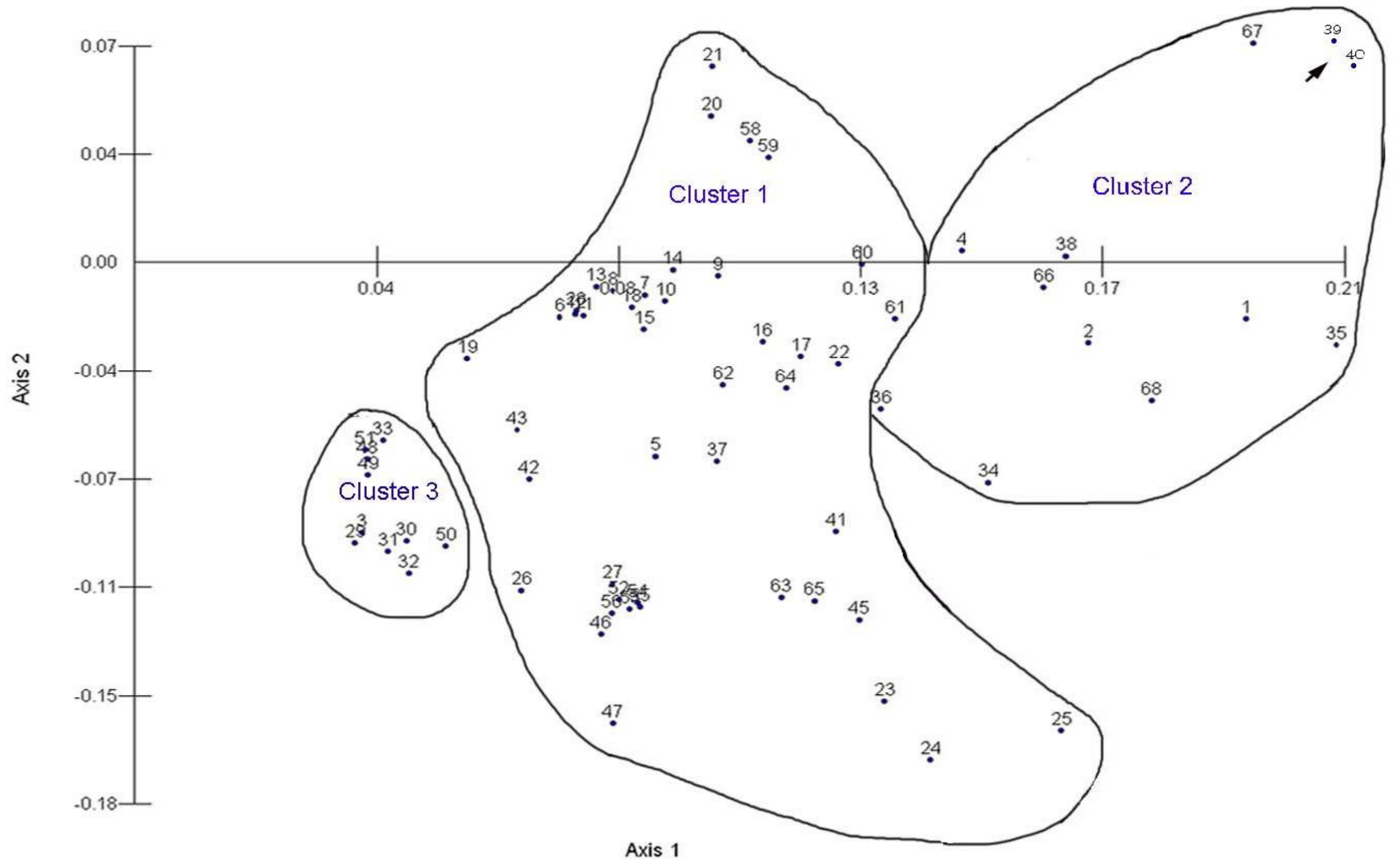


Figure 7.5. Dataset B.
Results of cluster analysis overlain on PCA scatterplot of axes 1 & 2.

7.2.3. Dataset C (acid-soluble lithologies at half phi classes -2.5 to +4.0 φ)
Analysis of this dataset provides information on the acid-soluble content of the samples.

Principal component analysis
The first principal component axis accounts for 79.1% of the variance but Figure 7.6a shows this to be concentrated in the very fine sand class. The second principal component (Figure 7.6b) is concerned mainly with the ratio of fine/very fine gravel and very coarse sand (-2.5 to 0 phi) to medium to fine sand (1 to 3.5 phi). This accounts for a further 8.1% of the variance. A further 3.1% of variance is explained by the third component (Figure 7.6c) in the fine to very fine gravel / coarse sand and medium/fine to very fine sand fractions. The total variance described by the first three principal components is 92.3%.

When links are drawn between samples possessing similarities above 91% on the scatterplots of principal component axes 1 & 2 and 2 & 3, numerous short links are established and no systematic grouping of samples emerges (Figures 7.7 and 7.8).

Cluster analysis
Cluster analysis (see Appendix 4) resulted in the division of sites shown in Table 7.7. Four clusters can be recognised at similarities greater than 77.0%. It can be seen that samples from sites 4, 3(U), 7, 18, 27 and 30 are divided into more than one cluster resulting in no clear division of samples.

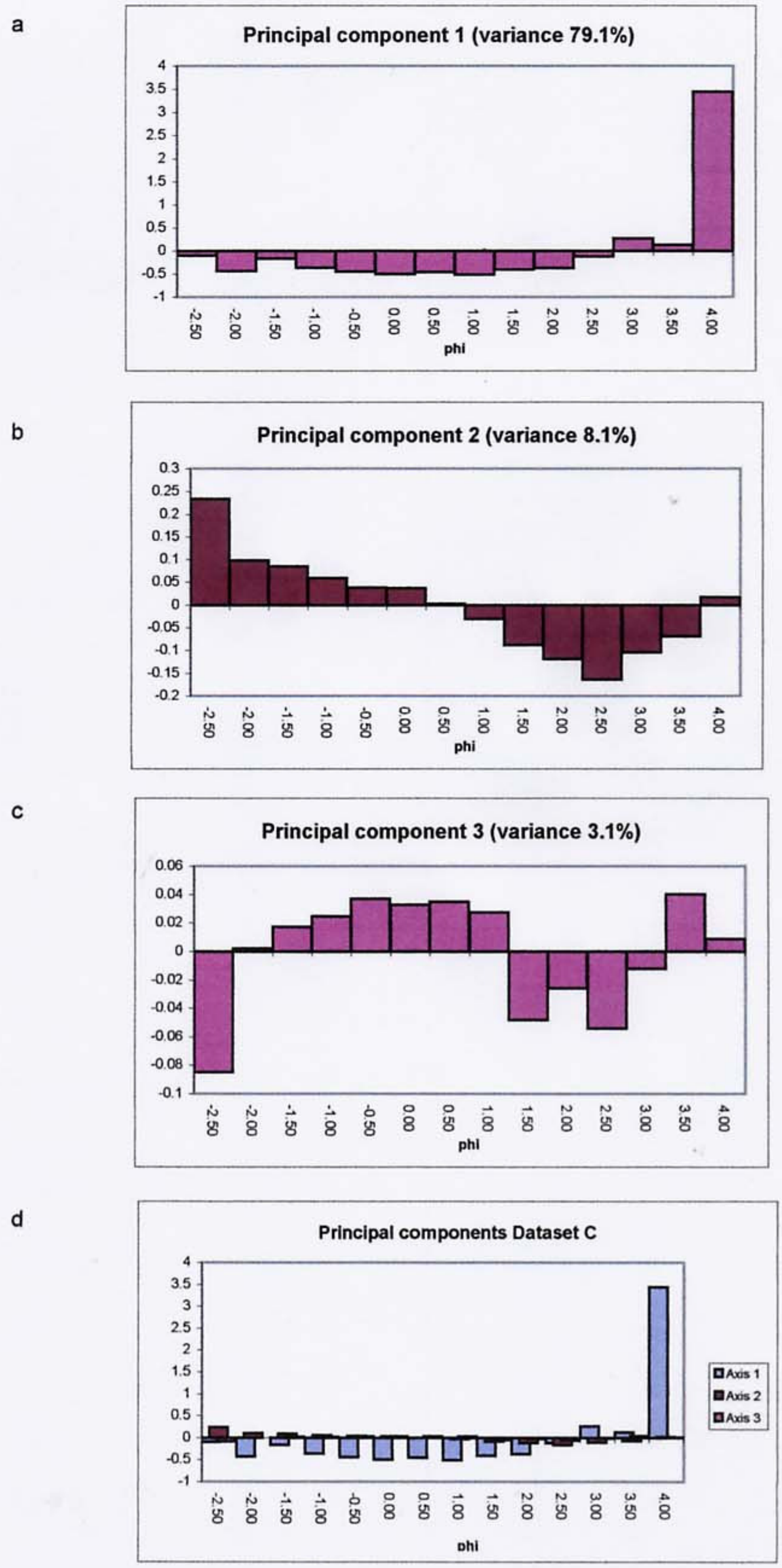


Figure 7.6. Dataset C.

a - c Component loadings on the first three principle components.

d Comparison of loadings on the first three axes.

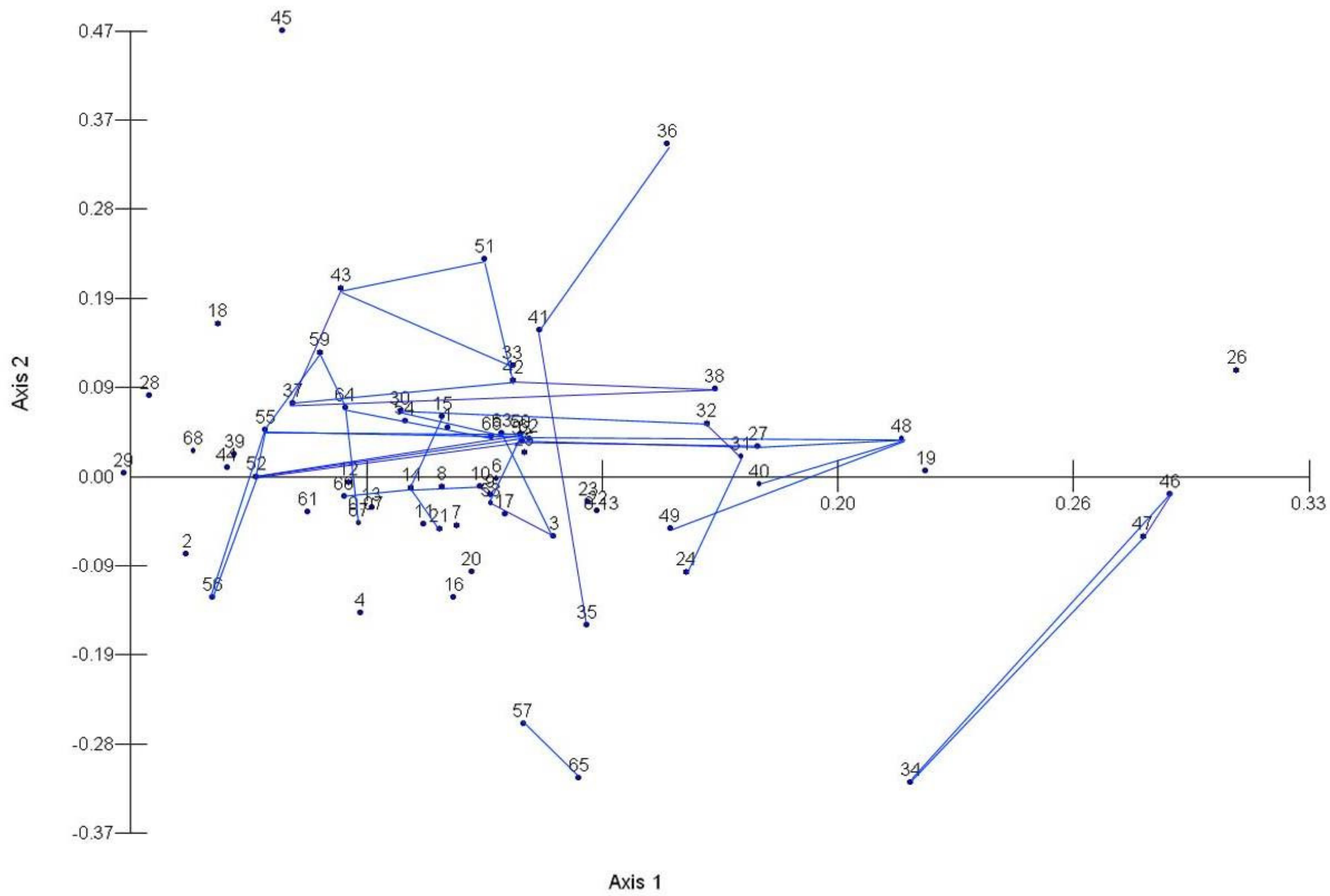


Figure 7.7 Dataset C.
Similarity coefficients > 91.0% plotted on PCA axes 1 & 2.

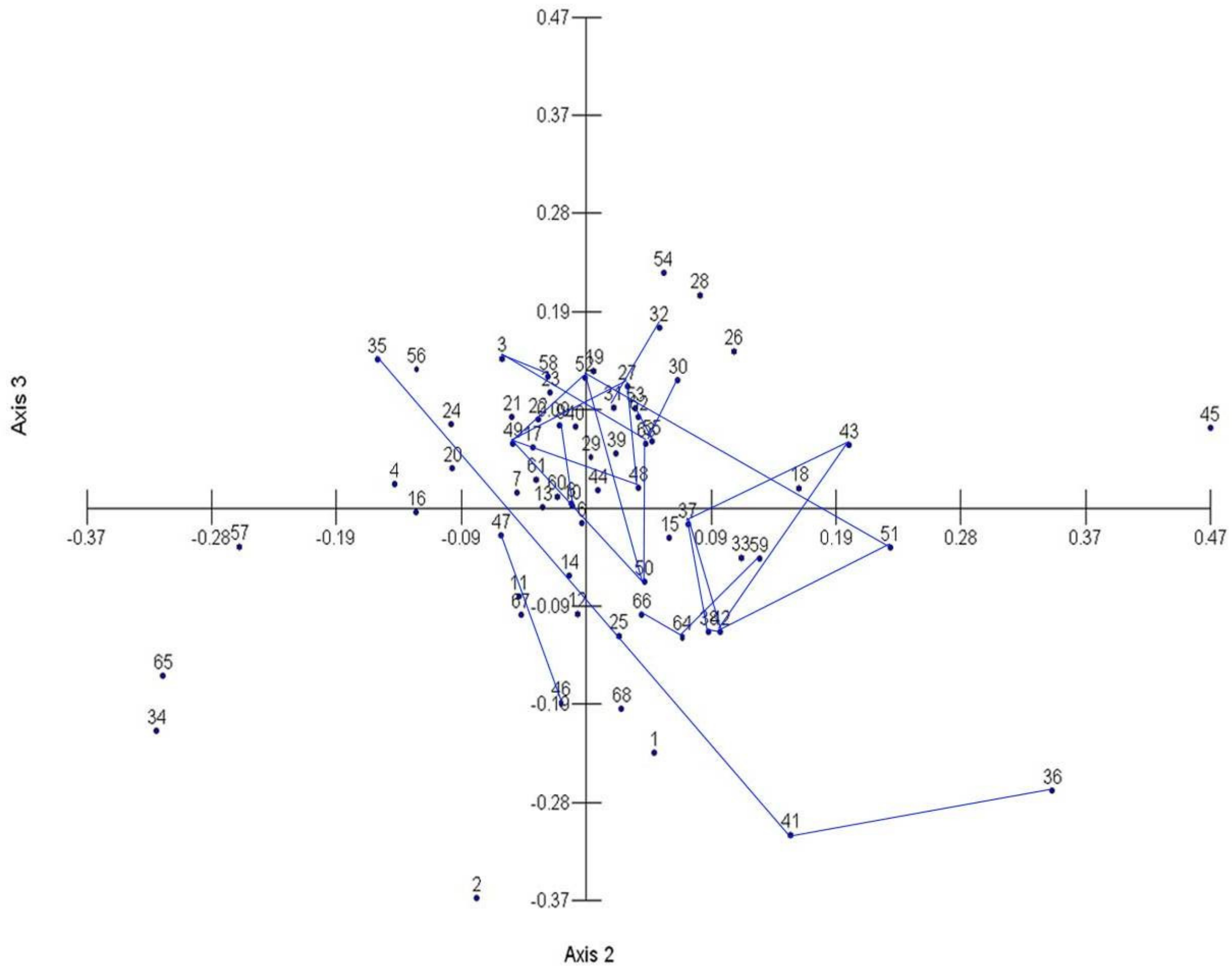


Figure 7.8 Dataset C.
Similarity coefficients > 91.0% plotted on PCA axes 2 & 3.

Cluster 1		Cluster 2		Cluster 3		Cluster 4	
Sample No.	Site No.	Sample No.	Site No.	Sample No.	Site No.	Sample No.	Site No.
28	9	18	4	8	3(U)	1	1
34	11(M)	19	5	16	4	3	2(L)
35		25	7	17		4	2(U)
36		27	8(M)			6	3(U)
37	12	26	8(L)			7	
38	14	39	15			9	
41	16	40				10	
42	17	44	18			11	
43	18	48	21			12	
45	19	49	22			13	
46	20	50	23			14	
47	24	52	25			15	
51		53				20	
		54				21	6
		55				22	
		56				23	7
		57	26			24	
		59	27			30	
		62	29			31	10
		65	30			32	
		68				33	11(L)
						58	27
						60	28
						61	
						63	30
						64	
						66	
						67	

Table 7.7 Dataset C.
Group membership suggested by cluster analysis (Similarities > 78.0%).

7.2.4. Dataset D (particle size distribution 0.08 - 56.2 µm)

This dataset deals with the acid insoluble finer matrix components of the till.

Principal component analysis

Figure 7.9 shows the first three principal axes of the PCA to account for over 99% of the variance. A scatterplot of the first two principal component axes, amounting almost to 97% of the variance, is shown in Figure 7.10. Similarity links above 96.5% are shown, producing one large and one smaller group. Additional groups are shown to have three or less members at this level of similarity. 140 links are identified, of which 107 are between-site from Groups 1 and 2 (Table 7.8). Group membership is shown in Table 7.9. As with previous datasets, samples from known individual stratigraphic units appear to be split between groups. These are:

- **Site 1 (Knebworth Park):** Each of the two samples (1 and 2) appears in a different group, even though they are taken from less than two metres apart in a continuous section of till.
-
- **Site 7 (Great Wymondley)**: Two of these samples (sample numbers 23 and 25) are in Group 1. These come from depths of 6.5 m and 2.5 m respectively, but sample 24 from a depth of 4.5 m is found in Group 2.
-
- **Site 27 (Milton Bryan)**: Each of the two samples (58 and 59) appear in a different group. Again, these samples were taken at less than two metres apart from a continuous unit.
-
- **Site 30 (Heath and Reach):** Three samples (65, 67 and 68) at depths of 8.8, 6.8 and 2.8 m are found in Group 2 whereas that from 6.8 m depth (sample 66) is in Group 1.

In addition, samples from the upper till at Site 3 and tills at Sites 7, 8 and 27 are split between the groups.

Cluster analysis

The results of a cluster analysis of this dataset are shown in Table 7.10 and are shown overlain on the PCA scattergraph in Figure 7.11. The dendrogram is given in Appendix 4. All the sites listed in Cluster 3, except the upper till at Site 2, are also found in other clusters, thus samples are not grouped by site. The results from the cluster analysis agree with 82.8% of the sample associations shown in the principal component analysis.

a

b

c

d

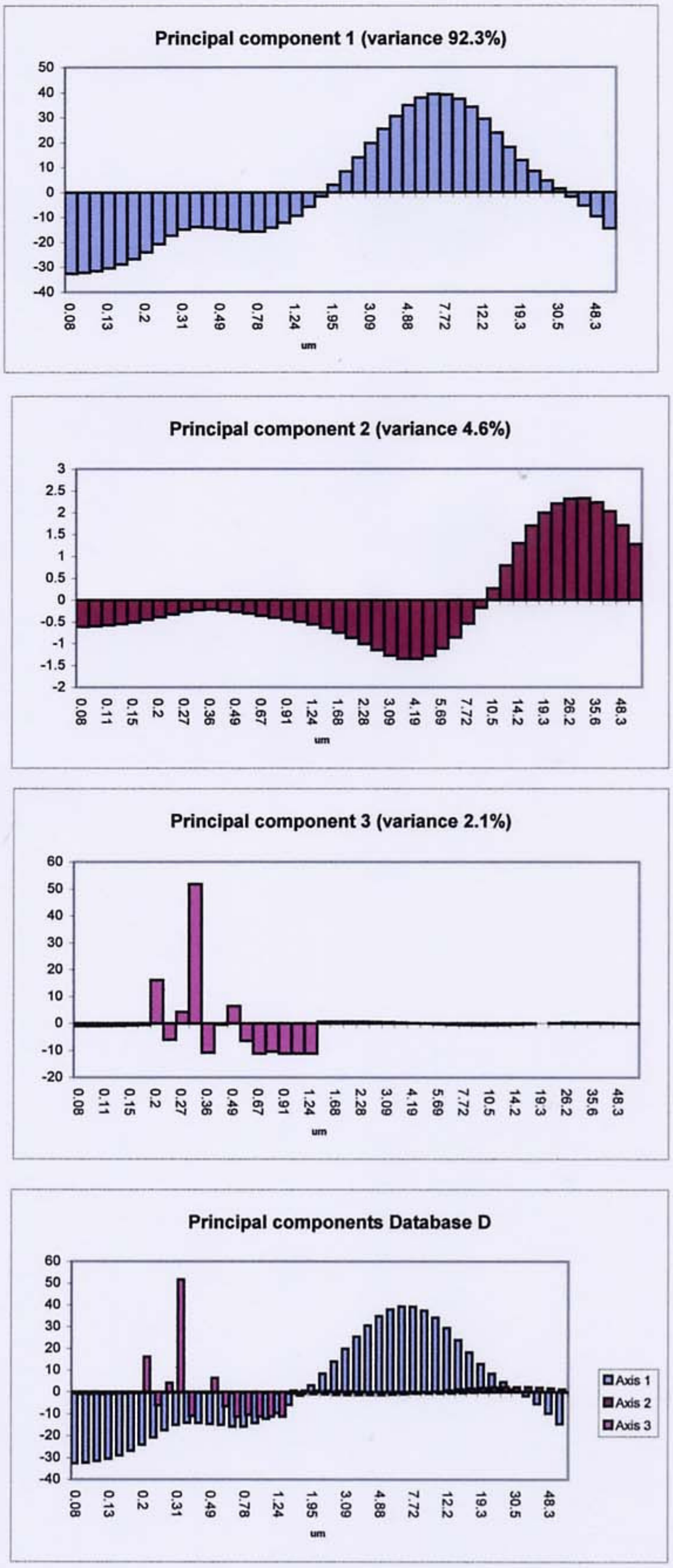


Figure 7.9. Dataset D.

a - c Component loadings on the first three principal components.

d Comparison of loadings on the first three axes.

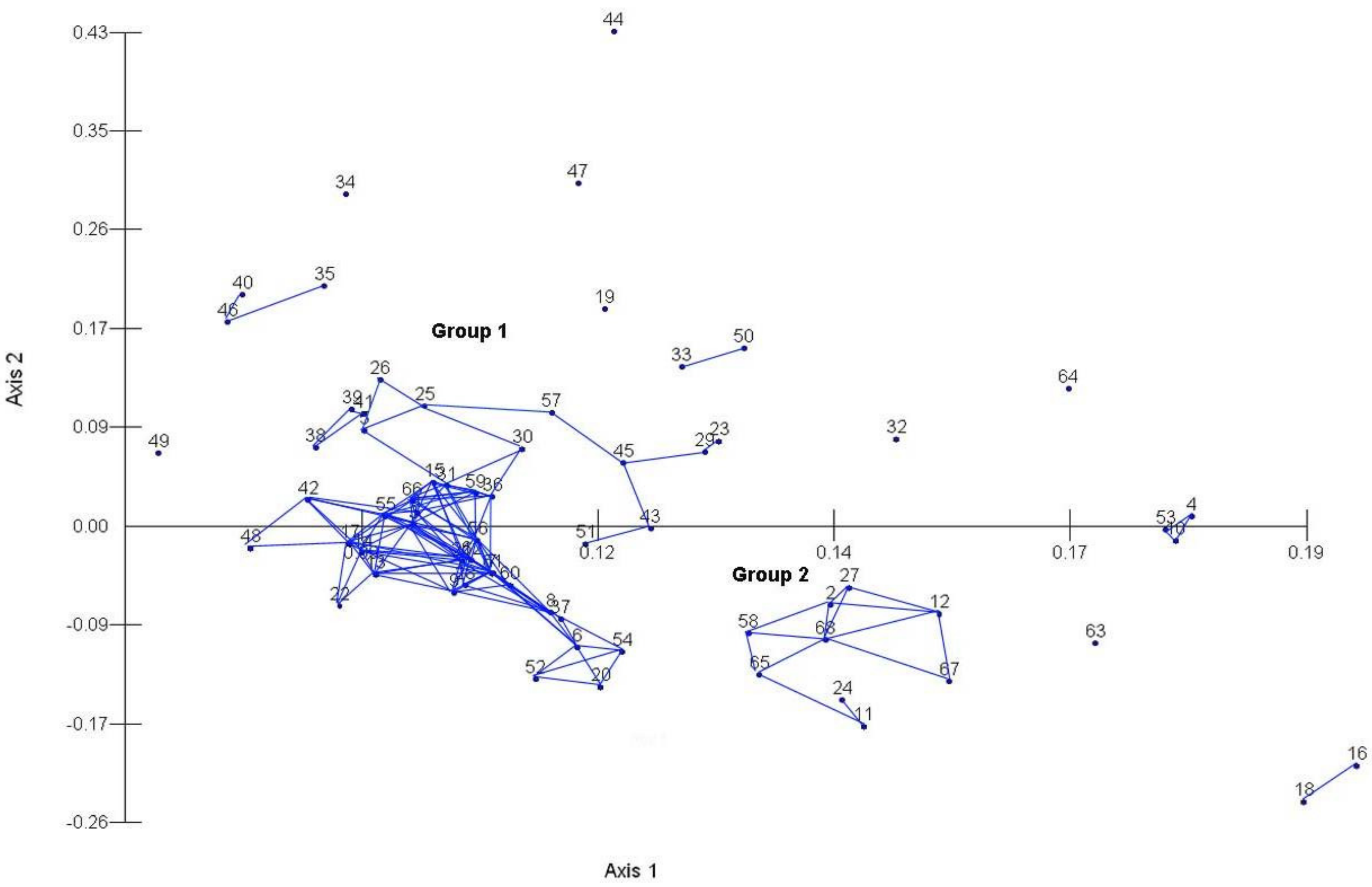


Figure 7.10 Dataset D.
Similarity coefficients > 96.5 % plotted on PCA axes 1 &

Group 1			
1st Site	2nd Site	No. of links	Similarity* %
6	29	1	99.1
7	10	1	98.7
25	29	2	98.5
2(U)	25	1	98.4
2(L)	25	1	98.4
3(U)	29	3	98.4
1	10	1	98.2
2(L)	6	1	98.1
1	2(L)	1	98.0
3(U)	10	2	98.0
4	17	1	98.0
1	25	2	97.9
3(U)	4	2	97.8
4	25	1	97.8
18	24	1	97.8
10	11(M)	2	97.7
10	27	1	97.7
12	28	2	97.7
1	3(U)	4	97.6
2L	29	1	97.6
3(U)	27	1	97.6
12	25	1	97.6
15	20	1	97.6
3(U)	6	9	97.5
3(U)	25	10	97.5
3(U)	12	2	97.5
3(U)	9	2	97.5
4	21	1	97.5
6	25	5	97.5
9	29	1	97.5
17	25	1	97.5
25	28	2	97.5
3(L)	8(M)	1	97.5
1	30	1	97.4
2L	4	1	97.4
7	3(L)	1	97.3
11(M)	30	1	97.3
25	27	2	97.3
10	30	1	97.2
19	26	1	97.2
1	6	1	97.1
10	15	1	97.1
3(U)	17	1	97.1
3(U)	28	8	97.1
14	16	1	97.1
25	30	1	97.1
1	29	2	97.0
3(U)	30	1	96.8
Group 2			
1	30	1	98.3
1	8(M)	1	98.1
27	30	1	97.5
1	27	1	97.4
3(U)	7	1	97.2
3(U)	30	3	97.2
3(U)	8(M)	1	97.1
8(M)	30	1	97.1

*average where more than one link shown

Table 7.8. Dataset D
Between-site links for Groups 1 & 2.

Group 1		Group 2	
Sample No.	Site No.	Sample No.	Site No.
1	1	2	1
3	2 (L)	11	3(U)
5	3 (L)	12	
6		24	7
7		27	8(M)
8	3 (U)	58	27
9		65	
12		67	30
13		68	
14			
15			
17	4		
20			
21	6		
22			
23	7		
25			
26	8(M)		
28	9		
29			
30	10		
31			
36	11(M)		
37	12		
38	14		
39	15		
41	16		
42	17		
43	18		
45	19		
48	21		
51	24		
52			
54	25		
55			
56			
57	26		
59	27		
60	28		
61			
62	29		
66	30		

Table 7.9. Dataset D.
Group membership suggested by PCA.

Cluster 1		Cluster 2		Cluster 3	
Sample No.	Site No.	Sample No.	Site No.	Sample No.	Site No.
3	2(L)	1	1	2	1
6	3(U)	5	3(L)	4	2(U)
7		15	3(U)	10	3(U)
8		19	5	11	
9		23	7	12	
13		25		24	7
14		26	8L	27	8(M)
17	4	29	10	32	10
20	6	30		53	25
21		31		58	27
22		33	11(L)	63	
28	9	36	11(M)	64	
37	12	43	18	65	
38	14	45	19	67	
39	15	50	23	68	
41	16	51	24		
42	17	57	26		
48	21	59	27		
49	22	66	30		
52	25				
54					
55					
56					
60	28				
61					
62	29				

Table 7.10. Dataset D.
Group membership suggested by cluster analysis (Similarities > 89.9%)

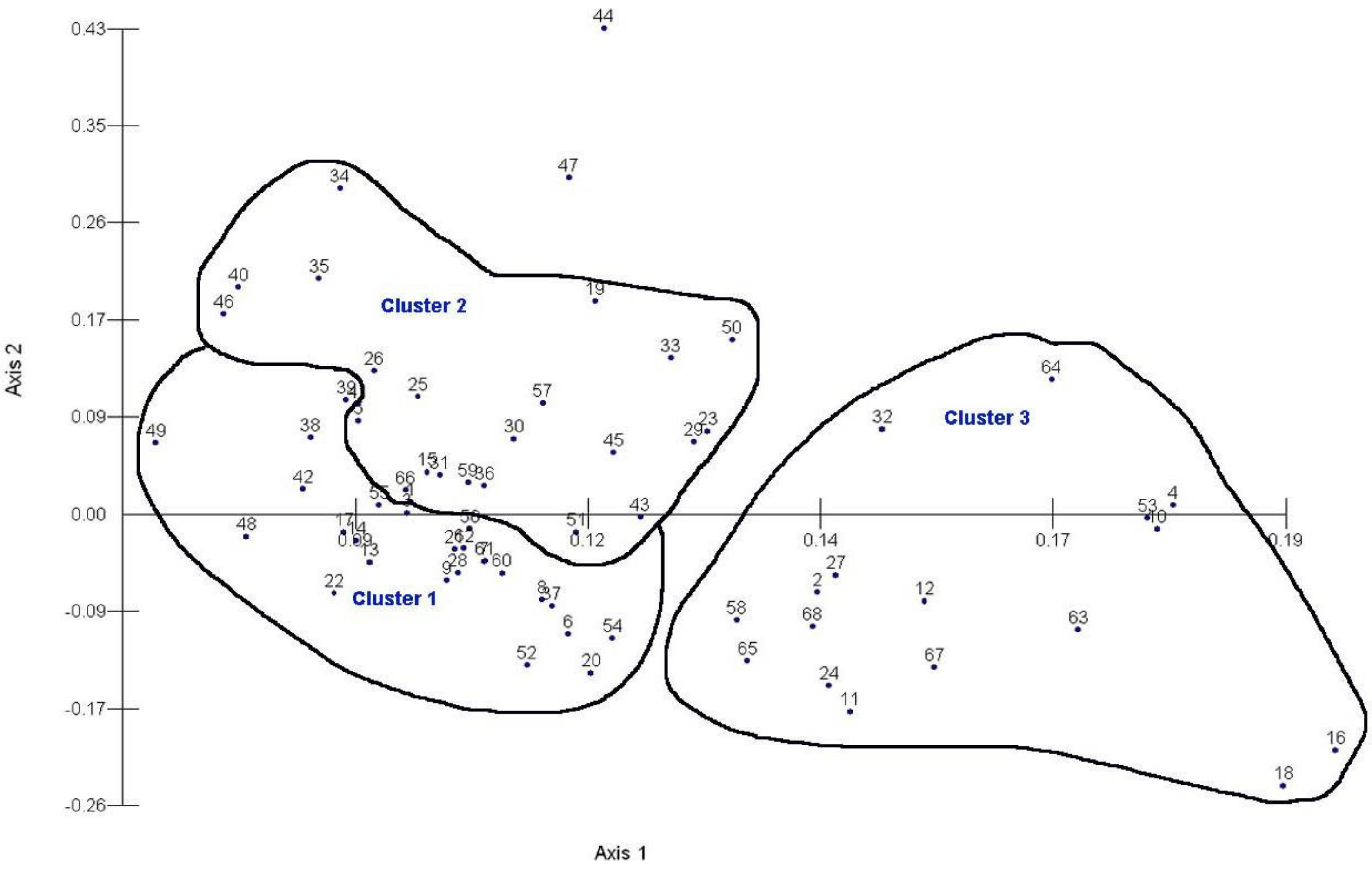


Figure 7.11. Dataset D.
Results of cluster analysis overlain on PCA scatterplot

7.2.5. **Dataset E** (small clast lithologies)

This dataset was used to investigate the possibility of dividing samples on the basis of their contained small clast lithologies. The data were standardised before a PCA analysis was carried out.

Principal component analysis

Component loadings are shown in Figure 7.12. The first PCA axis, accounting for over 90% of the variance, is dominated by variation in quartz clast content (Figure 7.12a). The second component (variance 3.5%) shows iron aggregates to be important (Figure 7.12b). The third component (variance 2.5%) is concerned mainly with aggregates and shale. However, unlike the findings of Cheshire (1986) in the neighbouring Lea Basin, it appears that very little of the variation measured here is due to differences in flint content. Figure 7.12d provides a comparison of the three principal component axes, again illustrating the importance of the quartz content.

Sample pairs with coefficients greater than 98% are shown on the PCA scatterplot (Figure 7.13). These 80 links fail to discriminate groups and it would appear that a PCA analysis of Dataset E does not facilitate discrimination of till units.

Cluster analysis

The structure of the dendrogram resulting from cluster analysis of this dataset (Appendix 4) indicates a large number of small clusters at similarities above 92%, each comprising only two or three samples. Five clusters can be identified at the 79.5% similarity level and are shown in Table 7.11. The four largest of these are shown overlain on the PCA scattergraph in Figure 7.14. Features of the cluster analysis are detailed below.

Cluster 1 includes all samples from Sites 1 (samples 1 & 2) and 4 (samples 16 – 18) within the Hitchin Gap, as well as samples 58 and 59 from the west of the study area at Milton Bryan (Site 27), samples 60 and 61 at Potsgrove (Site 28) and four samples (64 – 68) from Site 30 at Heath and Reach.

Cluster 2 includes many samples from within the Hitchin Gap, including eight upper till samples (6 - 8 and 11 - 15) from Site 3 together with the single sample (5) of lower till from Site 3. This cluster also includes all the samples from Site 6 (samples 20 – 24) and the middle and lower tills (samples 34 – 36) from Site 11. The inclusion of a sample from Site 17 at Sandy represents the only site north of Holwell to feature in this cluster.

Cluster 3 appears to contain a random collection of samples.

Cluster 4. Interestingly, this cluster groups together all the samples from the Northeastern Plateau, i.e. from Sites 19 to 24 and four out of the five samples at Site 25 (Caxton) plus three samples from Baldock (Site 10). There is no obvious characteristic which explains this clustering of data, but it may be due to broad similarities across a range of variables.

Cluster 5 This contains the two samples (43 & 44) from Site 18 (Warden Street) and the single sample from Sites 16 (Moggerhanger) and 29 (Sandy).

In cluster analysis of this dataset (Table 7.11) samples from the upper till at Site 3 (Cannock Wood) are found in Clusters 1, 2 and 3 and those from Site 7 (Great Wymondley) are found in Clusters 1 and 2. Cluster 4 contains four samples from Site 25, whilst sample 52 from this site is found in Cluster 3. Samples from Site 7 are also divided between Clusters 1 and 2. Thus, there is much overlap and no distinct grouping of samples.

a

b

c

d

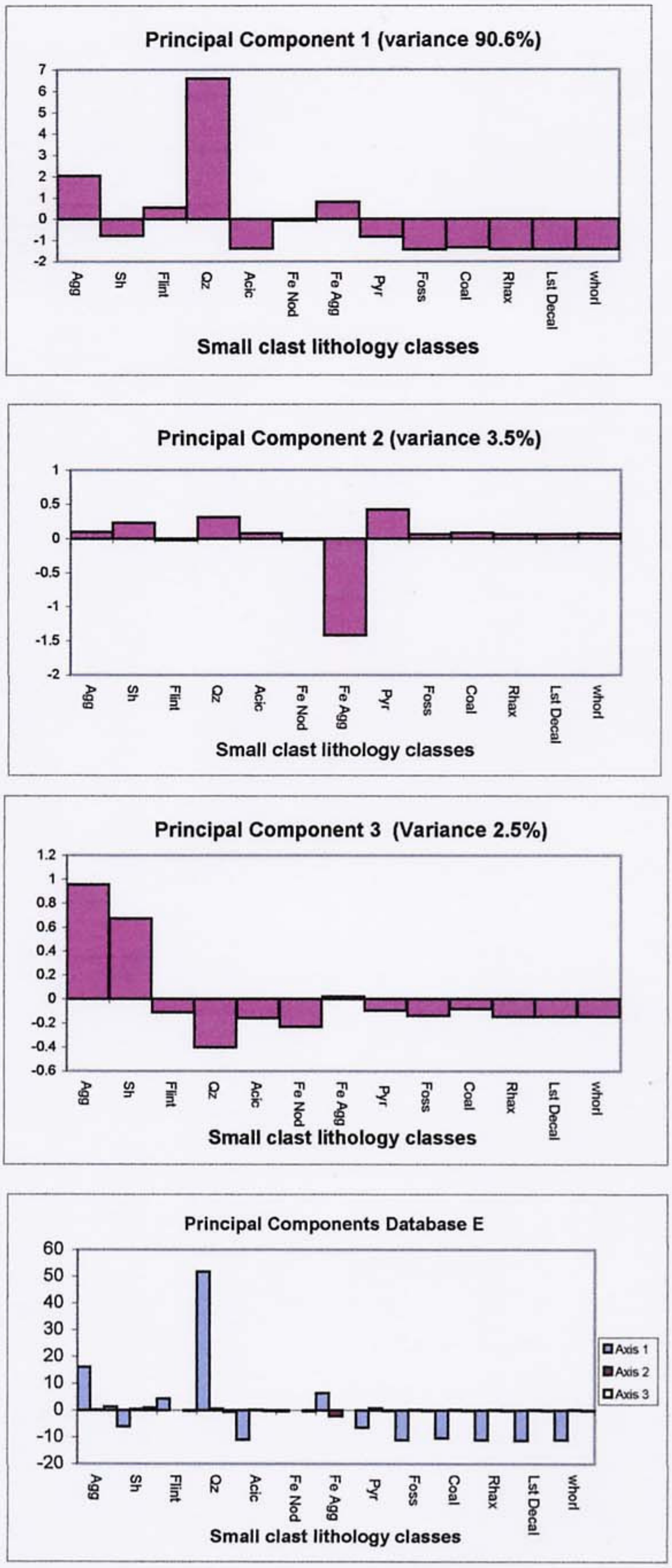


Figure 7.12. Dataset E.
a - c Component loadings on the first three principal components.
d Comparison of loadings on the first three axes.

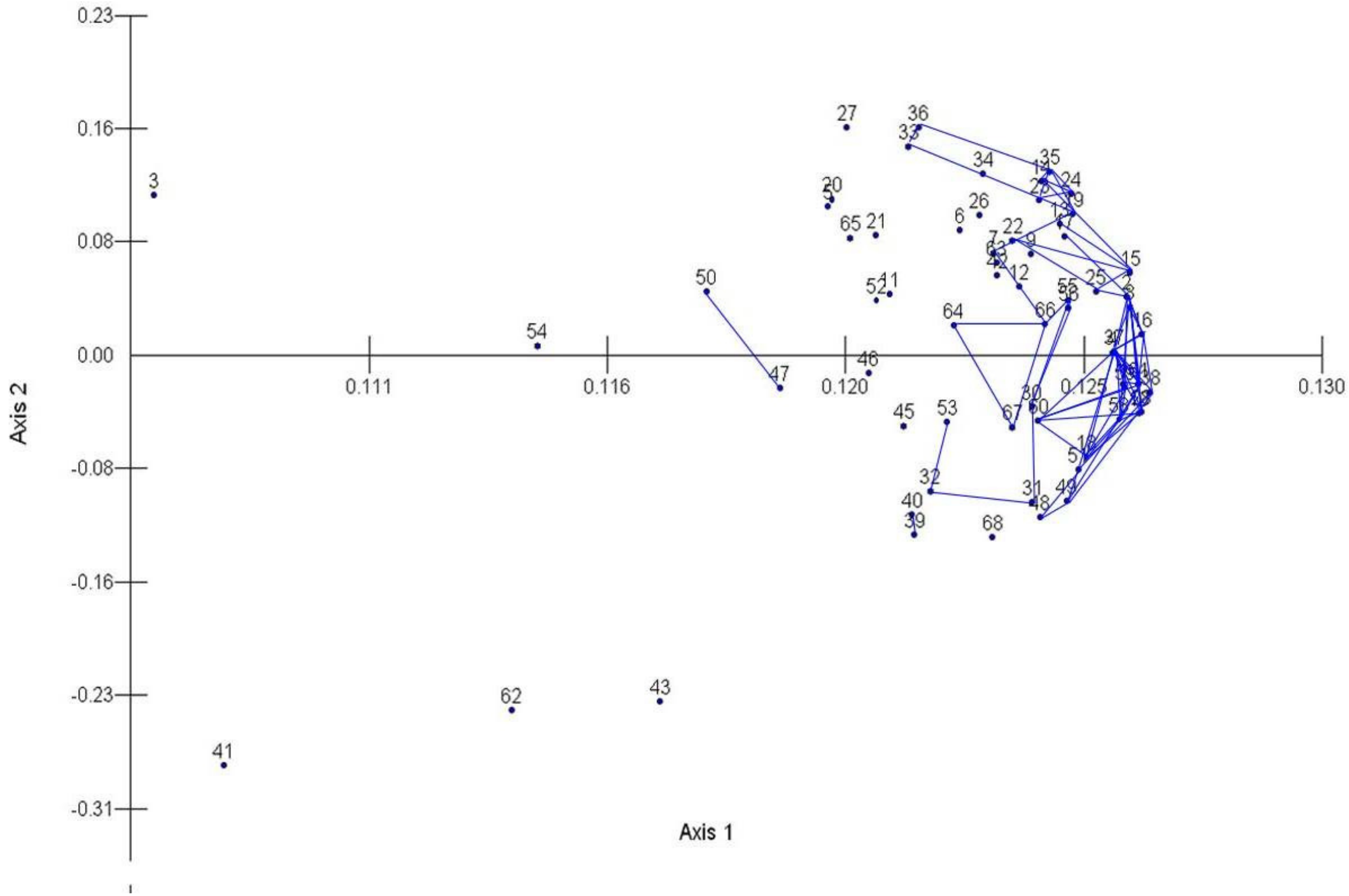


Figure 7.13 Dataset E.
Similarity coefficients > 98.0% plotted on PCA axes 1 & 2.

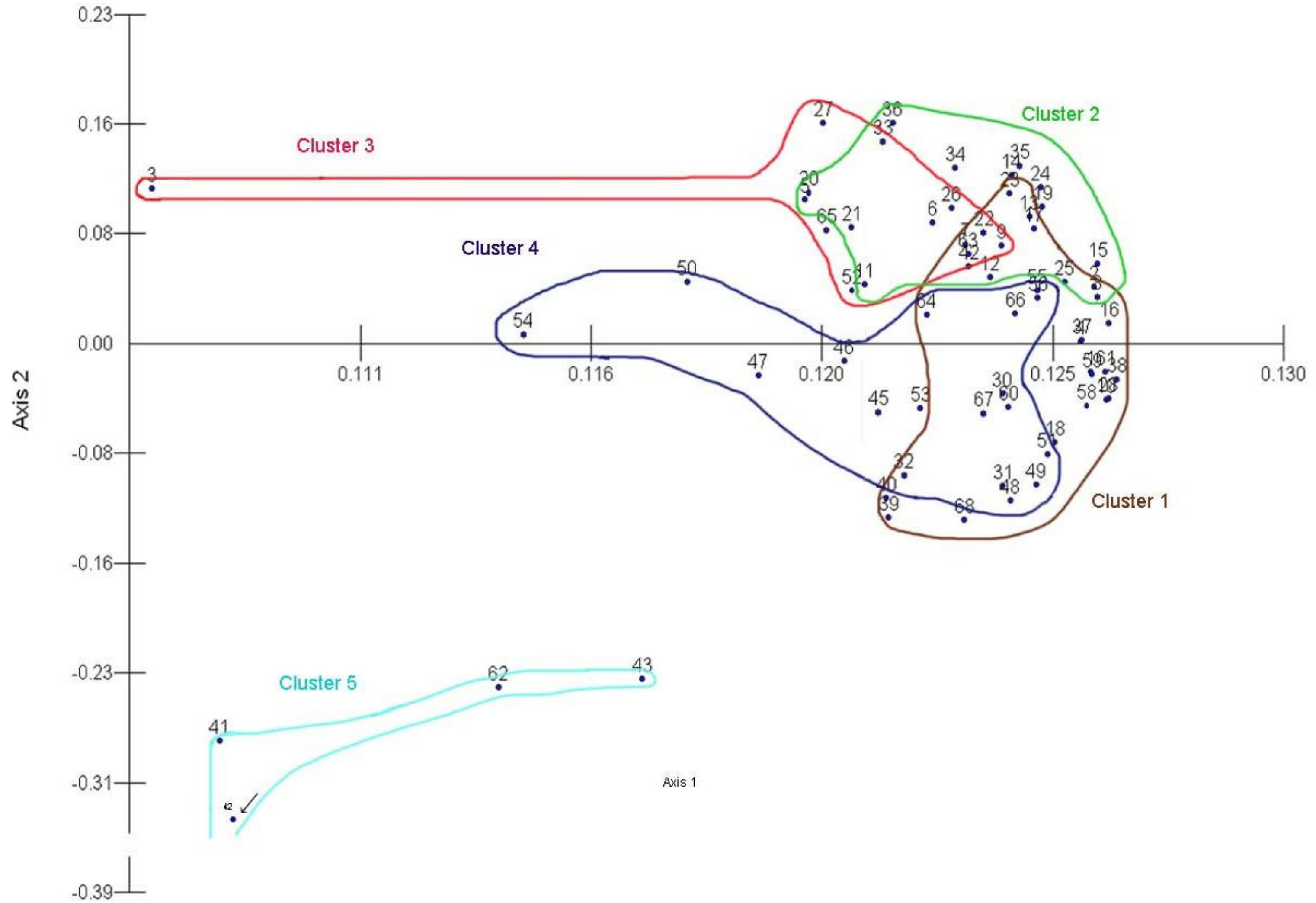


Figure 7.14 Dataset E.
Results of cluster analysis overlain on PCA scatterplot

Cluster 1		Cluster 2		Cluster 3		Cluster 4		Cluster 5	
Sample No.	Site No.	Sample No.	Site No.	Sample No.	Site No.	Sample No.	Site No.	Sample No.	Site No.
1	1	5	3(L)	3	2(L)	30	10	41	16
2		6	3(U)	9	3(U)	31		43	18
4	2(U)	7		27	8(M)	32		44	
10	3(U)	8		26	8(L)	45	19	62	29
16	4	11		52	25	46	20		
17		12		63	30	47			
18		13		65		48	21		
23	7	14				49	22		
25		15				50	23		
28	9	19	5			51	24		
37	12	20	6			53	25		
38	14	22				54			
39	15	24				55			
40		34	7			56			
58	27	35	11(M)						
59		36							
60	28	33	11(L)						
61		42	17						
64	30								
66									
67									
68									

Table 7.11. Dataset E.
Group membership suggested by cluster analysis (similarities > 79.5%).

7.2.6. **Dataset F** (all variates, excluding Sites 1-8)

It was considered that data from sites within the Stevenage and Hitchin Channels, where tills may have been subject to considerable disturbance, might be obscuring patterns which would otherwise be apparent. For this reason data relating to Sites 1 to 8 have been removed from this dataset and are considered separately in Dataset G. However, data from Sites 9 and 11 are included in both datasets F and G. These two sites lie at the northern edge of the Hitchin Channel and thus may possess similarities with sites both north and south of Hitchin. Therefore, Dataset F comprises the same variates as Dataset A, but with 41 samples. Data were standardised prior to PCO analysis.

Principal co-ordinate analysis

The first three axes account for only ~63% of the variance (Table 7.12). A scatterplot of the PCO axes 1 and 2 is shown in Figure 7.15. However, the latter accounts for only a little over half (51.9%) of the variance. The similarity matrix shows 81 links at a Euclidean distance of less than 8.0 and these are drawn on Figure 7.15. The network of links shows no systematic grouping of the data. The points representing individual samples cannot be grouped according to site or (presumed) till unit in the same manner as in Dataset B.

Cluster analysis

Despite the above, results of the cluster analysis (Table 7.13) proved more successful in that fewer sites appear in more than one cluster. The most noticeable feature of this analysis is that all the samples (33 – 36) from Site 11 at Primrose Hill Quarry (Cluster 2) are closely linked and do not show any connections with other sites at greater than 82.0% similarity. Of the remaining two clusters, Cluster 3 contains the three lower samples (52 - 54) from Site 25 (Caxton), the highest sample (32) from Site 10 (Baldock) and all samples from Site 30 (Heath & Reach) (63-68) in the west of the study area. The largest cluster (Cluster 1) includes all other tills except the lowest sample (29) at Site 10, a further single sample (57) from Site 26 (Wrestlingworth), the upper sample (44) from Site 18 (Warden Street) and the two samples (39 & 40) from Site 15 (Southill).

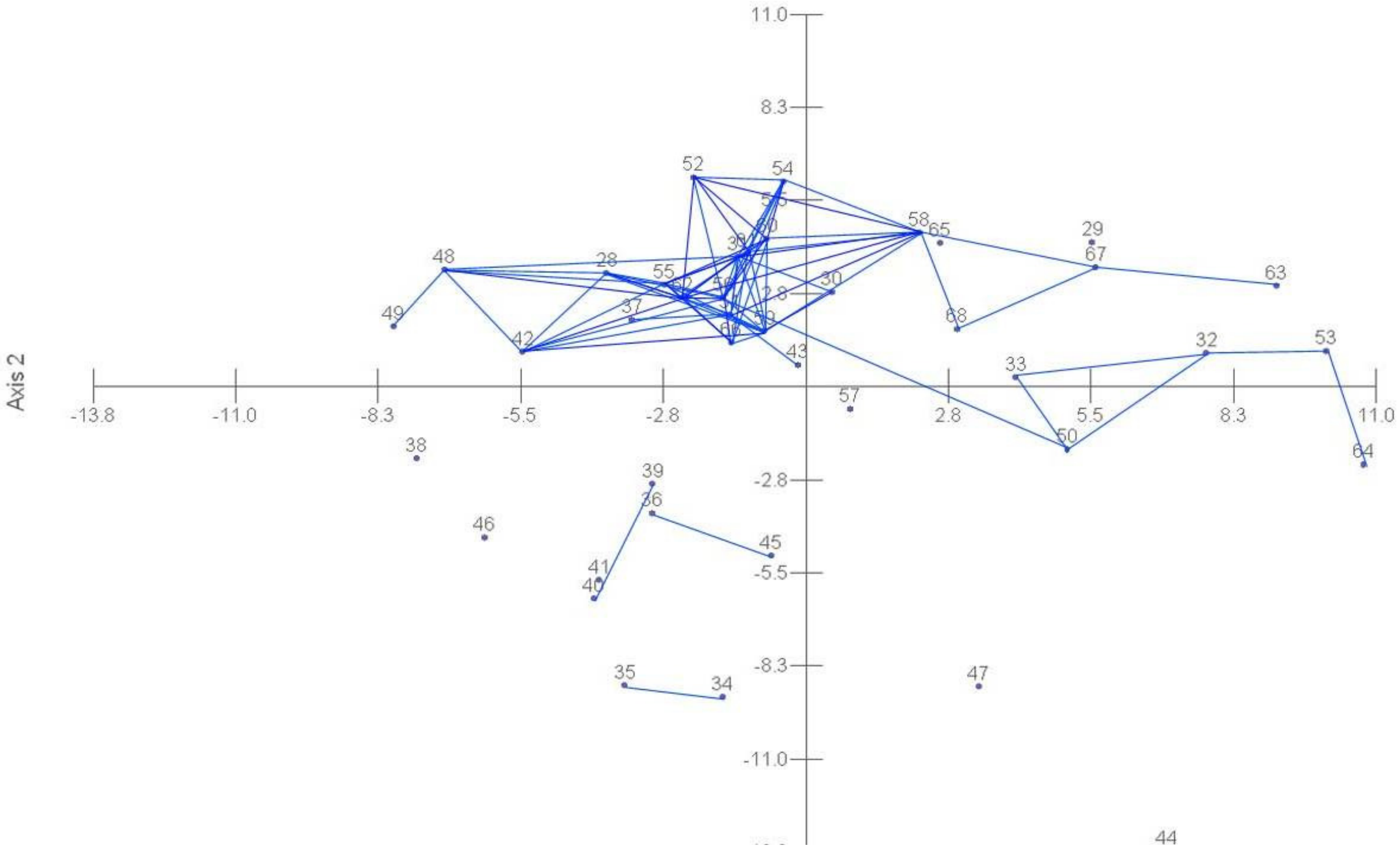


Figure: 7.15 Dataset F
Samples linked by Euclidean distance of < 8.0 shown on PCO axes 1 & 2

	Axis 1	Axis 2	Axis 3
Eigenvalues	902.104	861.890	375.001
Percentage	26.532	25.349	11.030
Cum. Percentage	26.532	51.882	62.911

Table 7.12 Dataset F. PCO Component loadings.

Cluster 1		Cluster 2		Cluster 3	
Sample No.	Site No.	Sample No.	Site No.	Sample No.	Site No.
28	9	33	11(L)	32	10
30	10	34	11(M)	52	25
31		35		53	
37	12	36		54	
38	14			63	30
41	16			64	
42	17			65	
43	18			66	
45	19			67	
46	20			68	
47					
48	21				
49	22				
50	23				
51	24				
55	25				
56					
58	27				
59					
60	28				
61					
62	29				

Table 7.13. Dataset F
Group membership suggested by cluster analysis (Similarities > 83.0%).

7.2.7. Dataset G (Sites 1 to 9 & 11).

This dataset is complementary to Dataset F, being comprised of data from within and adjacent to the Hitchin Gap. For reasons already mentioned, tills within the Hitchin Gap may bear few similarities to those elsewhere in the study area and by limiting data to those contained within the limited area of the Gap and channels, correlation between tills is more likely to be achieved.

Data from Sites 9 and 11 are included in both Datasets F and G. These two sites lie at the northern edge of the Hitchin Channel and thus may possess similarities with tills both north and south of Hitchin.

The dataset comprised all 85 variates for 32 samples and 75 variates for 1 sample (Table 4.4), the latter being omitted from the PCO analysis. The data were standardised prior to analysis.

Principal co-ordinate analysis

Eigenvalues for the first 3 principal component axes are shown in Table 7.14, from which it can be seen that the first axis accounts for only 33.5% of the variance. The PCO scatterplot of axes 1 and 2 is shown in Figure 7.16 with 67 links drawn between samples with Euclidean distance of less than 8.72. The 44 between-site links are shown in Table 7.15. However, of the 36 samples included in this analysis, only 24 possessed sufficiently strong links to be included in the groups.

The plot reveals a particularly dense network of links involving samples from 13 sites (Group 1) which include five of the ten samples from the upper till at Site 3 (Cannocks Wood), two of the three samples from Site 4 (Letchmore Farm) and all of the samples from Site 6 (Little Wymondley), plus the lower sample from Site 2 (Norton Green). Group 2 is more widely dispersed and includes three samples from the middle of the section at Site 3(U) (samples 12, 11 and 10). This analysis confirms the separation of upper and lower samples from Sites 2 and 11, although both upper and lower samples at Site 8 are found within the same group. Group membership suggested by PCO analysis is given in Table 7.16. These two groups are connected by three links (shown in red on Figure 7.16). These are due to high similarities between samples 11 and 12 of Group

1 and 8 and 20 of Group 2. The first three of these are from the upper till at Site 3 which as explained above, is divided between the two groups. Euclidean distances between these samples are 7.8 and 8.3 (sample 8 linked to samples 11 and 12 respectively). Sample 20 relates to Site 6 and this is separated from sample 11 by a shorter distance of 7.3. Samples from the middle till at Primrose Hill Quarry (Site 11) lie at the high end of axis 1 and do not possess any similarities with other samples at a Euclidean distance of less than 8.7.

Cluster analysis

Cluster analysis shows these samples to be more clearly grouped. Table 7.17 lists clusters identified with greater than 84.0% similarity.

These clusters are superimposed on the PCO scatterplot of axes 1 and 2 in Figure 7.17. A certain amount of agreement exists between the results of these two analyses - the cluster analysis agreeing with 61% of the sample links suggested by PCA. Group 1 consists of all sites found in Cluster 1 with the exception of Sites 1 and 7. All sites found in Clusters 2 and 3, with the exception of the lower tills at Site 3 and the middle till at Site 11, are in Group 2. Site 4 is shown in red on Figure 7.17 as it does not form part of Cluster 2. The upper till at Site 3 is represented in both groups and in clusters 1 and 3.

.

	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	856.013	649.579	263.381	172.388
Percentage	33.569	25.474	10.328	6.7603
Cum. Percentage	**33.569**	**59.043**	**69.371**	**76.131**

Table 7.14 Dataset G. PCO component loadings.

Group 1			
1st Site	**2nd Site**	**No. of Links**	**Euclidean distance ***
3(U)	9	4	8.30
4	6	2	7.07
3(U)	6	18	6.68
3(U)	4	7	6.12
Group 2			
8(M)	4	1	8.72
1	3(U)	1	8.71
7	8(M)	1	8.63
5	8(M)	1	8.61
5	8(L)	1	8.60
3(U)	4	2	8.24
1	7	1	8.02
3(U)	7	1	7.54
3(U)	2(U)	1	6.74
3(U)	8(M)	1	6.74
5	11(L)	1	5.93
Link between the two groups			
3(U)	6	1	7.31

*average where more than one link is shown

Table 7.15. Dataset G.
Between-site links with Euclidean distances < 8.7.

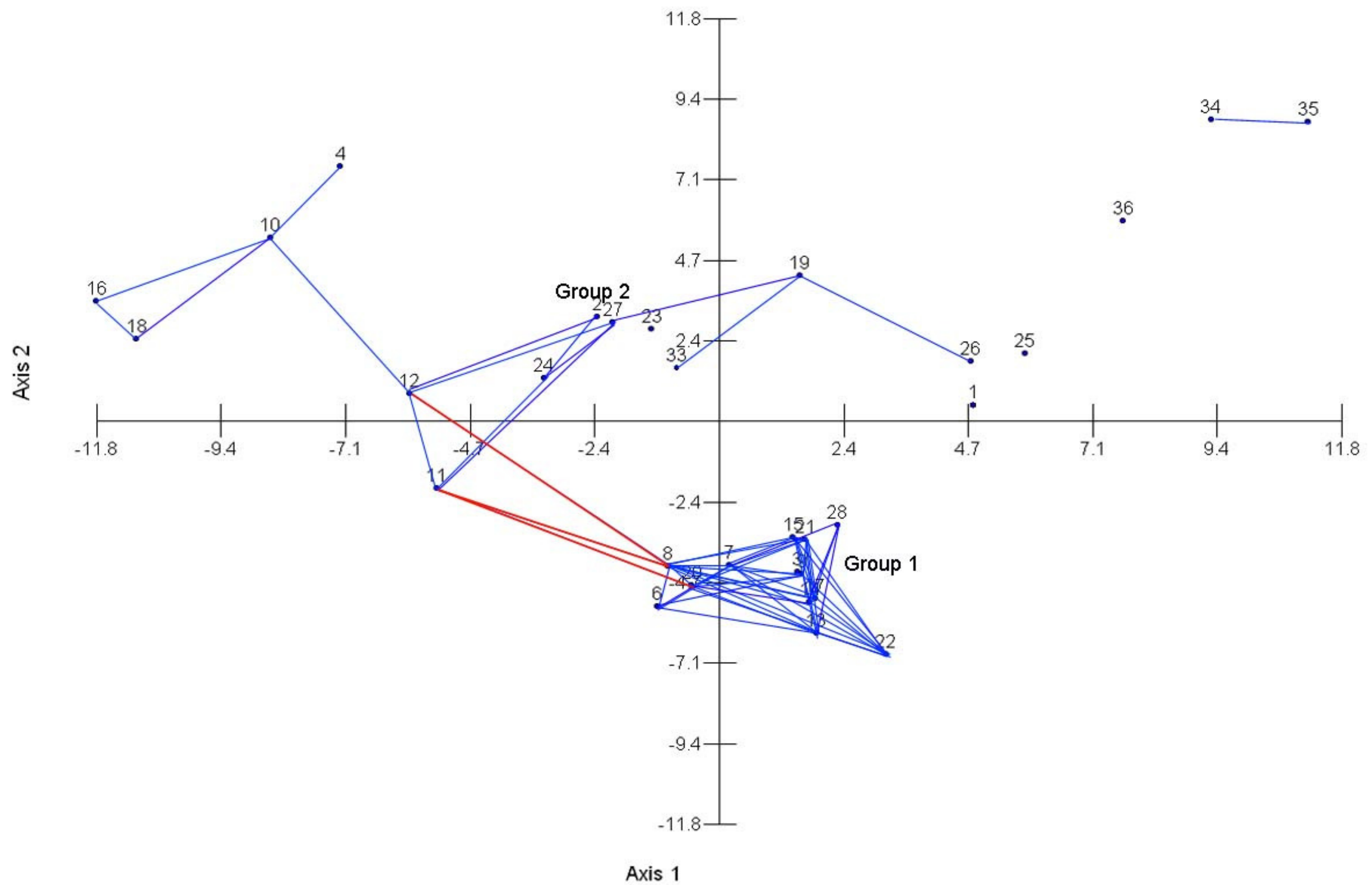


Figure 7.16. Dataset G.
Samples linked by Euclidean distances of < 8.7 shown on PCO axes 1 & 2.
(Those linking Group 1 & Group 2 are shown in red)

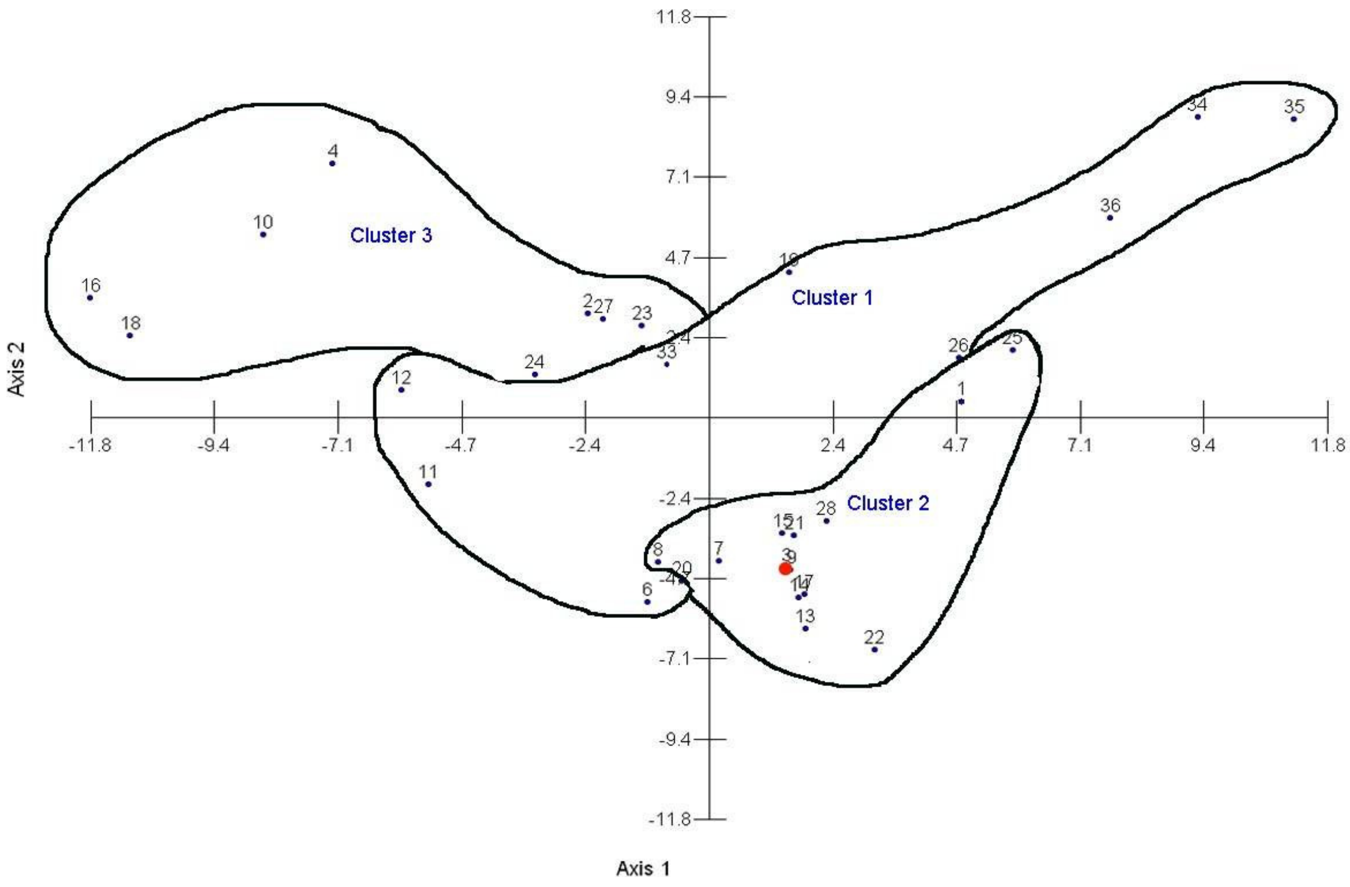


Figure 7.17. Dataset G.
Results of cluster analysis overlain on PCO scatterplot axes 1 & 2
(Site 4 shown in red – see text).

Group 1		Group 2	
Sample No.	Site No.	Sample No.	Site No.
6	3(U)	2	1
7		4	2(U)
8		10	3(U)
9		11	
13		12	
14		16	4
15		18	
17	4	19	5
20	6	24	7
21		26	8(L)
22		27	8(M)
28	9	33	11(L)

Table 7.16. Dataset G
Group membership suggested by PCA.

Cluster 1		Cluster 2		Cluster 3	
Sample No.	Site No.	Sample No.	Site No.	Sample No.	Site No.
1	1	19	5	2	1
6	3(U)	26	8(L)	4	2(U)
7		34	11(M)	10	3(U)
8		35		16	4
9		36		18	
11		33	11(L)		
12		5	3 (L)		
13					
14					
15					
17	4				
20	6				
21					
22					
25	7				
28	9				

Table 7.17. Dataset G
Groupings suggested by cluster analysis (Similarities > 84.0%).

7.3. Comparison Dataset - Database 2.

In order to compare the tills in this study with those found to the southeast, data were made available by Dr D.A. Cheshire. Tills from 27 sites (77 samples) were selected, details of which appear in Table 4.4 (Chapter 4).

These data were added to those from the 68 samples in Dataset A. Variates concerned with particle size distribution of the matrix fraction (Dataset D) not included in Cheshire's study, were omitted and small clast lithological data were re-formulated to conform to the format of Cheshire's data. A new dataset was thus constructed with a total of 145 samples and 39 variates.

A similarity matrix was generated, the resulting similarity coefficients ranging between 67.40 and 99.93%. This investigation concentrated only on coefficients linking comparison sites to those from the current study. Using a threshold similarity coefficient of 99.6% (Chapter 4), 193 similarities were recorded. These are summarised in Table 7.18 and discussed in detail in Section 7.5.

Similarity matrix																				
SAMPLE	**BARK1**	**BARK2**	**BIGR1**	**CCL1**	**CCU1**	**COT1**	**COT3**	**COT5**	**DLL1**	**DLL2**	**EGJR7**	**EGJR8**	**FOXS1**	**FOXS3**	**FROL2**	**HC1**	**HC8**	**HHF8**	**HHL**	**HH6**
2			99.8		99.8						99.7		99.6	99.7		99.6			99.7	99.7
4			99.7		99.7									99.7						
6	99.9	99.6			99.6										99.6					99.8
7					99.8				99.8	99.7			99.8		99.6					
8		99.7	99.9		99.9								99.8	99.7						99.6
10										99.6					99.7					
12					99.7				99.7	99.6			99.7							99.6
13			99.8		99.8	99.7					99.7	99.8				99.6			99.7	99.7
14												99.6				99.9				
15																				
16										99.6		99.7			99.7	99.6		99.8		
17												99.8			99.7	99.6				
19			99.9		99.7		99.7				99.7	99.7				99.6			99.6	
20																99.7				
22			99.6				99.7	99.6							99.7	99.7	99.7			
23			99.7								99.7				99.8	99.9				
24															99.7					
25			99.8		99.7						99.8				99.8	99.8				
26				99.8						99.6										
28			99.7		99.7					99.7					99.9	99.6				
30																				
33		99.7																		
34											99.6	99.7								
35										99.6										
36												99.7								
37		99.7	99.7		99.8					99.7	99.6		99.8							
49		99.7																		
50																				
51		99.8																		
58																				
59															99.7					
60			99.7		99.7									99.7						
61			99.7		99.7						99.6		99.8	99.7		99.7			99.6	99.7

Table 7.18

Comparison Dataset : Summary of Similarity Coefficients > 99.6% *(continued on next page).*

SAMPLE	LG	LWF	PHQU1	PHQU2	PHQU4	PHQUS	PLPL	WES	WHP	WMU1	WMU5	WMW1	WMW2	WMW3	WMW4	WMW5
2		99.7	99.7	99.6	99.6	99.9	99.8	99.6				99.7	99.7			99.7
4			99.8	99.8	99.6	99.8							99.6			
6																99.8
7						99.6	99.8					99.7				99.9
8				99.6		99.8	99.8	99.7				99.7	99.6	99.7	99.6	99.8
10																
12				99.6	99.7		99.7									99.7
13						99.7	99.8	99.6							99.7	99.8
14																
15		99.6			99.7											
16		99.6														
17							99.7									
19						99.6	99.7	99.8							99.6	99.6
20						99.6										
22						99.6										
23		99.7					99.6									
24								99.7								
25						99.6	1.0									99.7
26																
28		99.9			99.7		99.7									99.7
30										99.8						
33																
34							99.6				99.6					99.6
35					99.7											
36																
37		99.7			99.7		99.8									99.8
49																
50									99.6							
51	99.9								99.6							
58			99.8	99.8	99.7											
59		99.8		99.7	99.7	99.7										
60			99.8	99.7	99.7	99.5							99.6			
61		99.8	99.8	99.7	99.7	99.6	85.5	99.8				99.7	99.6			

Table 7.18

Comparison Dataset : Summary of Similarity Coefficients > 99.6% *(continued from previous page)*

CHAPTER 7
DISCRIMINATION BETWEEN TILL UNITS

PART 2: DISCUSSION AND FURTHER ANALYSIS OF DATA

7.4 Introduction

A summary of the division of data suggested by various PCO/PCA and cluster analyses of the datasets is provided in Table 7.19. This shows that grouping of samples was possible in 10 out of the total of 14 analyses. For ease of reference, a separate copy of this table is provided in a pocket at the back of this thesis.

Although principal coordinate analysis of the main dataset (Dataset A) did not indicate a subdivision of tills within the study area, division of this dataset into subsets with a smaller number of variates enabled the use of principal component analysis which provided more detailed information. Results from analysis of these individual datasets are discussed below.

7.4.1. Discrimination between tills based on particle size analysis.

The particle size distributions examined in Dataset B appeared to provide a good basis on which to divide the samples with only a few sites appearing in more than one group.

By subtraction of the total fractions from 100%, the results of sieve analyses of the samples (Dataset B) indirectly provide an indication of the percentage of fine material (particle sizes < +4.5 phi) for each sample; these are shown in Figures 7.18 and 7.19. Samples 3, 26 and 33, representing the lower tills from Sites 2, 8 and 11 respectively, (shown in green), consistently possess larger proportions (between 85.2 and 93.8%) of fine material than tills found higher in the sequence at these sites.

The finer content of the lower till at Site 3 could not be assessed, due to missing data.

Sample No.	Site No.	Dataset A CA			Dataset B PCA				Dataset B CA			Dataset C CA				Dataset D PCA		Dataset D CA			Dataset E CA					Dataset F CA			Dataset G CA			Dataset G PCA	
		CI A1	CI A2	CI A3	PCA B1	PCA B2	PCA B3	PCA B4	CI B1.	CI B2	CI B 3	CI C1	CI C2	CI C3	CI C4	PCA D1	PCA D2	CI D1	CI D2	CI D3	CI E1	CI E2	CI E3	CI E4	CI E5	CI F1	CI F2	CI F3	CI G1	CI G2	CI G3	PCA G1	PCA G2
1	1	1				1				1					1	1			1		1								1				
2		2				2				2							2			2	2										2		2
3	2(L)										3				3	3		3					3									3	
4	2(U)	4				4				4					4					4	4										4		4
5	3(L)		5						5							5			5			5								5			
6	3(U)	6			6				6						6	6		6				6							6			6	
7		7			7				7						7	7		7				7							7			7	
8		8			8				8					8		8		8				8							8			8	
9		9			9				9						9	9		9					9						9			9	
10		10			10				10						10					10	10										10		10
11		11			11				11						11		11			11		11							11				11
12		12			12				12						12	12	12			12		12							12				12
13		13			13				13						13	13		13				13							13			13	
14		14			14				14						14	14		14				14							14			14	
15		15			15				15						15	15			15			15							15			15	
16	4	16			16				16					16						16	16										16		16
17		17			17				17					17		17		17			17								17			17	
18		18			18				18				18							18	18										18		18
19	5		19						19				19						19			19								19			19
20	6	20			20				20						20	20		20				20							20			20	
21		21			21				21						21	21		21											21			21	
22		22			22				22						22	22		22				22							22			22	
23	7	23				23			23						23	23			23		23												
24		24				24			24						24		24			24		24											24
25		25				25			25				25			25			25		25								25				
26	8(L)		26						26				26			26			26				26								26		26
27	8 (U)			27			27		27				27				27			27			27										27
28	9	28			28				28			28				28		28			28					28			28			28	
29	10										29					29			29														
30			30					30			30				30	30			30					30		30							
31			31					31			31				31	31			31					31		31							
32				32				32			32				32					32				32				32					
33	11L		33					33			33				33				33			33					33			33			33
34	11M		34			34				34		34										34					34			34			
35			35			35				35		35										35					35			35			
36			36			36				36		36				36			36			36					36						

Table 7.19. Summary of results from cluster analyses (CA), PCA and PCO - Datasets A to G. (continued on next page)

Sample No.	Site No.	Dataset A CA			Dataset B PCA				Dataset B CA			Dataset C CA				Dataset D PCA		Dataset D CA			Dataset E CA					Dataset F CA			Dataset G CA			Dataset G PCA	
		CI A1	CI A2	CI A3	PCA B1	PCA B2	PCA B3	PCA B4	CI B1.	CI B2	CI B3	CI C1	CI C2	CI C3	CI C4	PCA D1	PCA D2	CI D1	CI D2	CI D3	CI E1	CI E2	CI E3	CI E4	CI E5	CI F1	CI F2	CI F3	CI G1	CI G2	CI G3	PCA G1	PCA G2
37	12	37			37				37			37				37		37			37					37							
38	14	38				38				38		38				38		38			38					38							
39	15									39			39			39		39			39												
40										40			40						40		40												
41	16					41			41			41				41		41							41	41							
42	17		42						42			42				42		42				42			42	42							
43	18		43						43			43				43			43						43	43							
44										44			44												44								
45	19		45			45			45			45				45			45					45		45							
46	20		46				46		46			46												46		46							
47			47				47	47	47			47												47		47							
48	21		48								48		48			48		48						48		48							
49	22		49					49			49		49					49						49		49							
50	23		50								50		50						50					50		50							
51	24		51					51			51	51				51			51					51		51							
52	25			52			52		52				52			52		52					52					52					
53				53			53		53				53							53				53				53					
54				54			54		54				54			54		54						54				54					
55			55				55		55				55			55		55						55		55							
56			56				56		56				56			56		56						56		56							
57	26												57			57			57														
58	27	58			58				58						58		58			58	58					58							
59		59			59				59				59			59			59		59					59							
60	28	60			60				60						60	60		60			60					60							
61		61			61				61						61	61		61			61					61							
62	29				62				62				62			62		62							62	62							
63	30	63				63			63						63	63				63			63					63					
64		64			64				64						64					64	64							64					
65				65		65			65				65				65			65			65					65					
66		66				66				66					66	66			66		66							66					
67		67								67					67		67			67	67							67					
62		68				68				68			68				68			68	68							68					

Table 7.19. Summary of results from cluster analyses (CA), PCA and PCO - Datasets A to G. (continued from previous page).

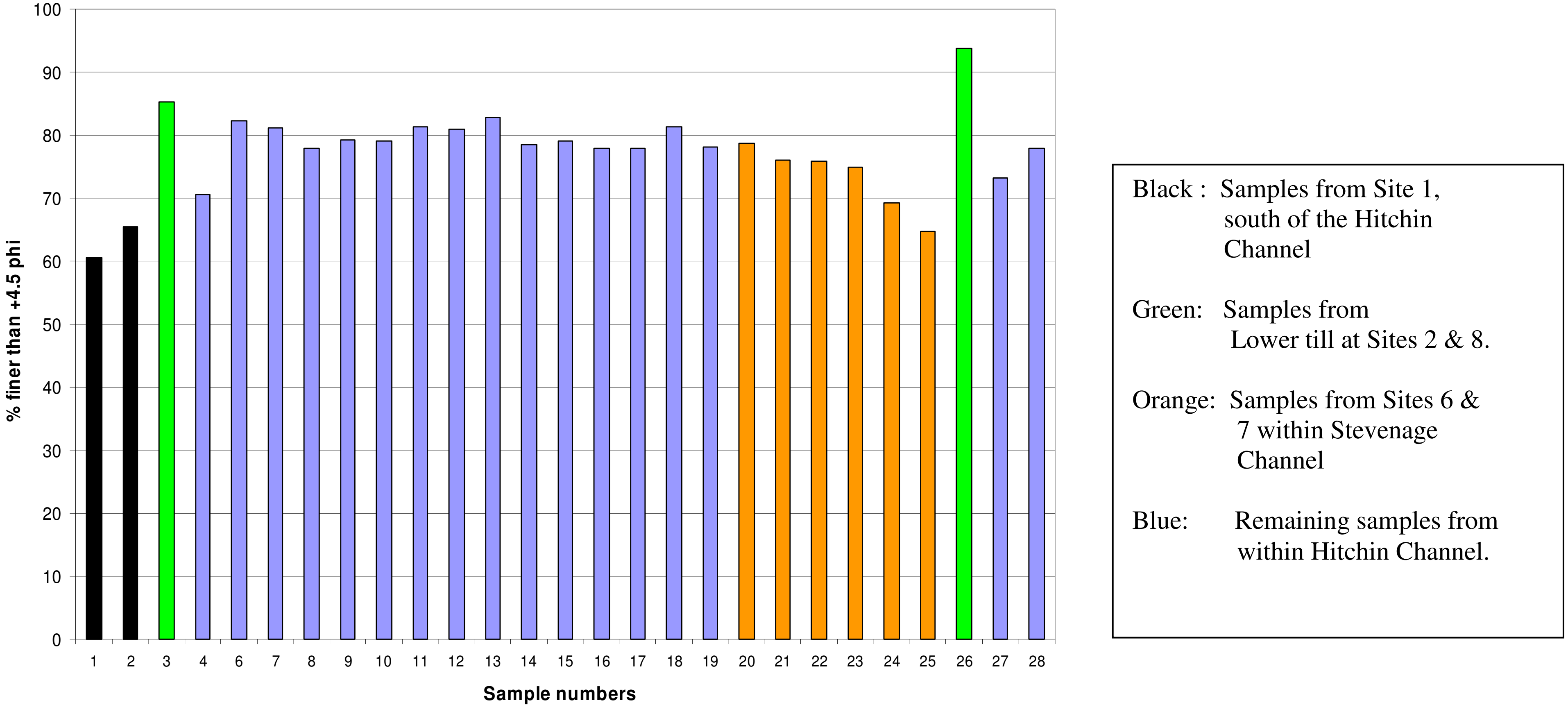


Figure 7.18 Percentage (by weight) of fine fraction (<+4.5 phi) of samples from Sites 1 – 9 .
(NB data not available for the Lower Till at Site 3 (Sample 5).

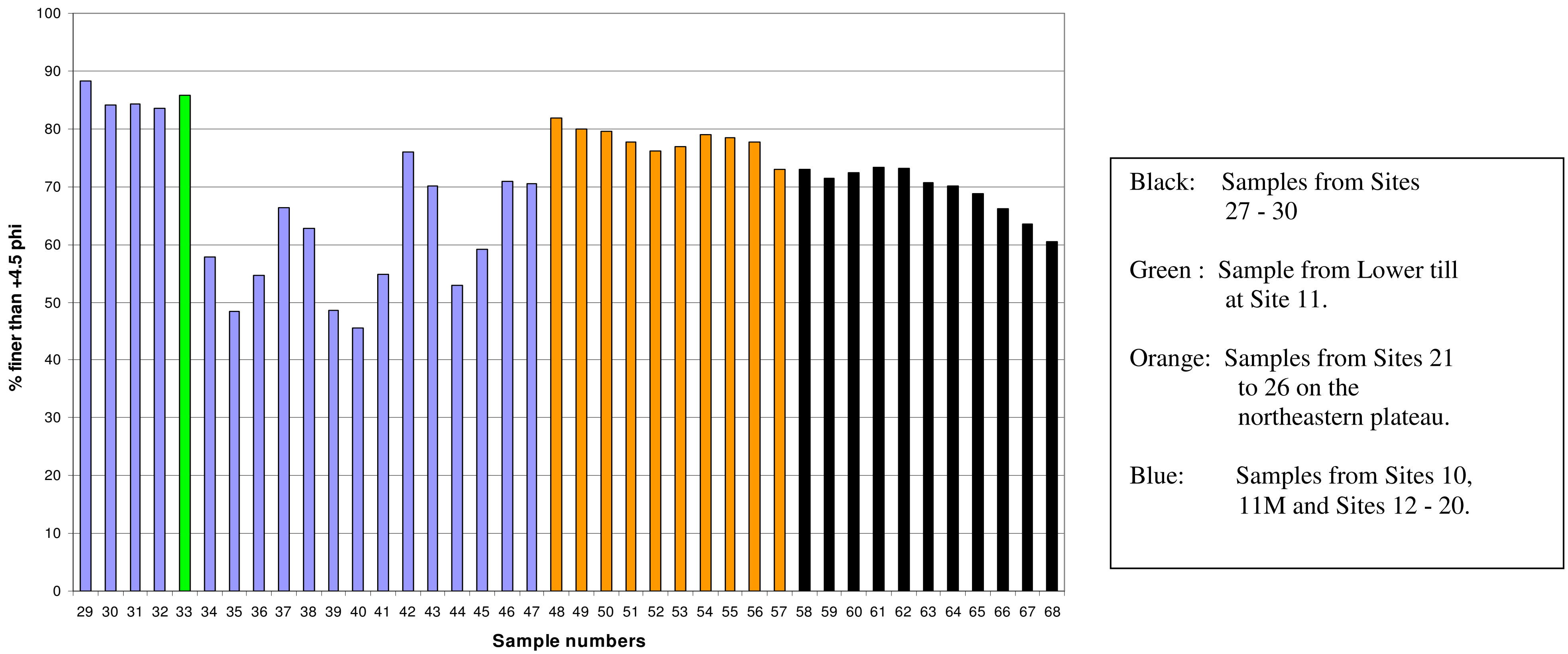


Figure 7.19 Percentage (by weight) of fine fraction (<+4.5 phi) of samples from Sites 10 – 30.

	South of Hitchin	Central Corridor	Northeastern Plateau	West
Sites (sample numbers)	1 – 9 (1 - 28)	10 – 20 (29 - 47)	21 – 26 (48 - 57)	27 – 30 (58 - 68)
Average %	77.1	66.9	77.8	69.7
Range %	60.6 – 93.8	48.3 – 88.2	76.5 - 81.9	60.5 – 73.3

Table 7.20:
Averages & ranges of fine material (< +4.5 phi)
in different geographical areas

Table 7.20 divides the study area geographically into 4 sectors giving averages and ranges for each sector.

South of Hitchin samples with relatively small quantities (< 65%) of fine material include those from Site 1 (samples 1 & 2), lying to the south of the Hitchin Channel (Figure 7.18). The lowest value within this channel (70.6%) is found in Sample 4 from the slumped/flow till at Site 2. Samples 23 – 25 from Site 7, lying within the Stevenage Channel also contain relatively small proportions of fine material, with values ranging from to 64.7% at 85.5 m O.D.(sample 25) to 75% at 81.5 m O.D (sample 23). Macrofabric data from Site 7, discussed in Section 6.6.1, suggest that this may be a slumped till and depletion in fine material is consistent with this suggestion. Little variation is found in the fine content of tills of the remaining samples south of Hitchin, which ranges from 70.6 to 82.8% with an average of 79% (Figure 7.18).

The widest range of values shown in Table 7.20 and Figure 7.19 are in a corridor running along the centre of the study area northward from Hitchin, encompassing Sites 10 – 20. These include flow or slumped tills at Site 16 and a possible flow till (Unit 8, Site 11). Values are highest on the Northeastern Plateau. Whilst the average for samples in the west of the study area lies close to that of the central corridor (Table 7.20) the range is much smaller.

In general tills south of Hitchin (Sites 1 – 9) possess a minimum of 60% fines (Figure 7.18) whereas to the north there are several samples with lower values (Figure 7.19) as detailed below.

Samples 34 – 36 (Site 11 – Primrose Hill Quarry) These represent units 8 and 10 from the middle till at Primrose Hill Quarry (Section 5.2).

These samples, although taken from what appeared to be a homogeneous massive till, possess macrofabrics that may be characteristic of a flow /slumped till (Section 6.6.2). In particular, unit 8 from which sample 34 was extracted, consists of a 2.4 m thick unit of till noted to be interleaved with bands of sandy silt, perhaps indicative of deposition by running water. The latter may therefore account for the removal of fines from this sample.

Sample 41 (Site 16 - Moggerhanger). This sample has been shown in Section 6.6.2 to be a slumped or flow till. It is not surprising therefore, that depletion of fines occurred during deposition.

Samples 39 & 40, (Site 15 - Southill) & 44 (Site 18 – Warden Street).
The samples from Southill and the upper sample from Warden Street possess a high proportion of sand-size grains attributed to assimilation of the local deposits of Lower Greensand. This enlargement of the medium-fine sand modes accounts for the apparent depletion of fines in this till. It is noted however, that the lower sample (43) at Site 18 has a much higher percentage of fine material (70.2%), whereas the two samples 43 and 44 would be expected to exhibit similar characteristics.

Sample 45 (Site 19 – Edworth).
The sample at Edworth, with 59% fines, lies approximately 1.7 km south of Site 20 where two samples (46 & 47) from Millowbury Farm each possess over 70% of fine material, indicating a very local textural variation.

Values of fine material at Site 30 (Heath & Reach) shown in Figure 7.19 gradually decline from 70.7% at 130.3 m O.D. in sample 63 to 60.5% at 140.2 m O.D. in sample 68. This could be due to a gradual decline in the amount of fine material deposited by the ice, although this is not evident at Caxton where a further vertical succession of samples was analysed.

Summary

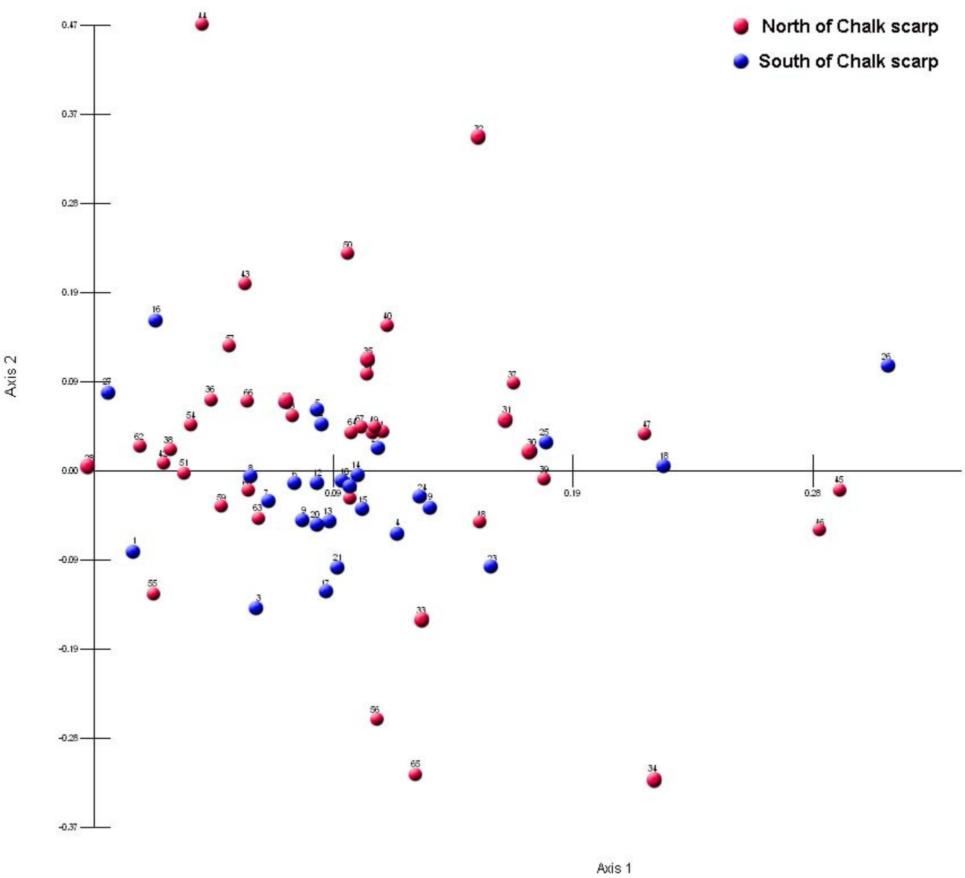
With the exception of samples 3 and 26 (the lower tills at Sites 2 and 8 respectively), samples from within the Hitchin Channel have fairly consistent quantities of fine material varying from 70.6 to 82.8%. The two samples of lower till have higher values at 85.2% (sample 3) and 93.8% (sample 26). Of the sites north of Hitchin, those with less than 60% of fine material can be accounted for by assimilation of large amounts of coarser material (Lower Greensand) or by slump/flow processes. Samples of the Middle Till at Site 11 within the Hitchin Channel (Primrose Hill Quarry – samples 34 - 36), in common with samples 37 to 47 at Sites 12 -20 north of Hitchin, have variable amounts of fine material, ranging from 45.5 to 70.8%. In some cases (mentioned above) depletion of fines probably occurred during deposition.

7.4.2. Discrimination between tills based on acid-soluble content (Dataset C)

It might be expected that acid-soluble contents would show a simple division between sites lying north and south of the position of the Chalk scarp during the Anglian. However, this is not the case. Figure 7.20a & b are scatterplots of principal component axes 1 & 2 and 2 & 3, with samples coloured according to location in relation to the Chalk scarp. Neither plot shows a clear difference between samples north and south of the scarp.

Differences between samples lying northwest of the Chalk scarp, with potentially lower chalk content, and those to the southeast could be masked by the presence of acid-soluble limestone in samples from the northwest of the study area. Limestone and chalk could not be separated in the analyses and both are included in the acid-soluble fraction in Dataset C (Section 4.4.4). However, a qualitative visual assessment of the composition of the acid-soluble fractions of samples from sample 63 at Site 30 (Heath and Reach) in the extreme west of the study area and sample 53 from Site 25 (Caxton) in the east of the study area (Plate 4.1) suggests larger quantities of limestone and less chalk in the western till. Nevertheless, some division of this dataset is possible on the basis of geographical location. The percentage of acid-soluble lithologies within the sand fraction (-1.0 to +4.0 phi) for all samples is shown in Figure 7.21.

a.



b.

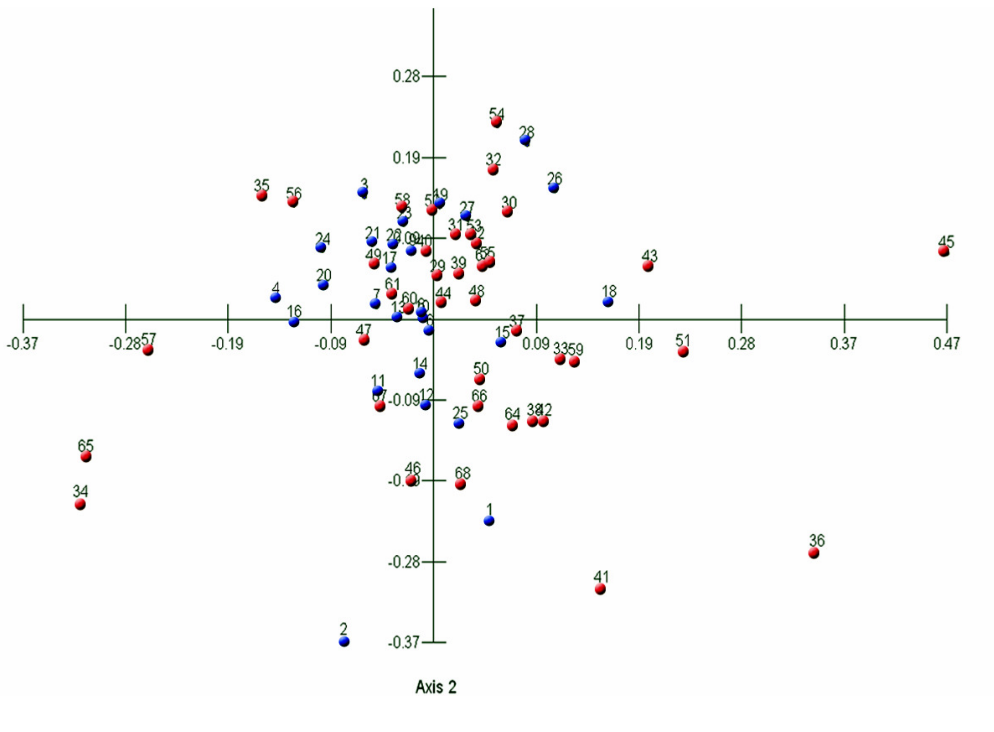


Figure 7.20. Scatterplot of results of PCA of Dataset C on (a) axes 1 & 2 and (b) axes 2 & 3 showing location of site relevant to chalk scarp

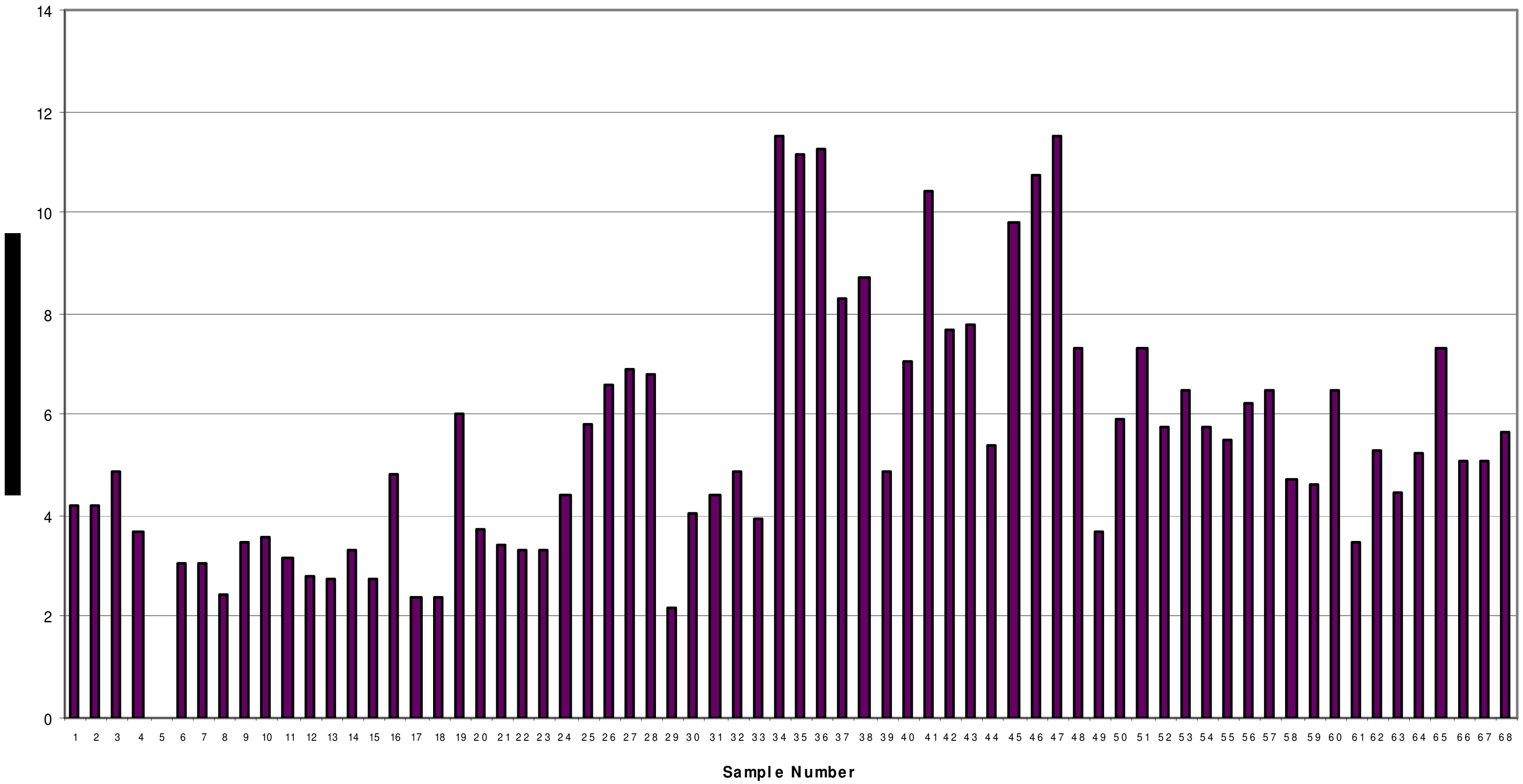


Figure 7.21. Percentage of acid-soluble lithologies present in the sand fraction (-1.0 to +4.0 phi).

Values for samples range between 2.45% and 11.5%, values above 10.0% being restricted to Sites 11 (Primrose Hill Quarry – samples 34-36), 16 (Moggerhanger – sample 41) and 20 (Millowbury Farm – samples 46 & 47).

Values from the Northeastern Plateau (samples 48-57 from Sites 21 to 26) range between 3.7% and 7.4%, whilst in the west of the study area (Sites 27 to 30 - samples 58-68), the range is between 3.5% and 5.6% with the exceptions of samples 60 at Site 26 (Potsgrove) with 6.5%, and 65 at Site 30 with 7.3%. In a corridor running up the centre of the study area northwards from Hitchin, Sites 10 – 20 (samples 29 to 47) show the widest range of values (2.2% - 11.5%), with sample 29 from Site 10 at Baldock possessing the lowest value at 2.2%. However, the sample 29 is not typical of the Baldock site, the overlying samples having an average of 4.5%. Within the Hitchin Gap values range between 2.4% and 6.9%, many of the lowest values occurring at the southern end of the Hitchin Channel. Table 7.21 summarises averages and ranges in each part of the study area.

	South of Hitchin	**Central Corridor**	**Northeastern Plateau**	**West**
Sites (sample numbers)	1 – 9 (1 - 28)	10 – 20 (29 - 47)	21 – 26 (48 - 57)	27 – 30 (58 – 68)
Average %	3.9	7.6	6.3	4.8
Range %	2.4 – 6.9	2.2 – 11.5	5.2 – 7.4	3.6 – 7.3

Table 7.21:
Averages & ranges of acid-soluble content of the -1.0 to +4.0 phi fraction in different geographical areas

Fish (2000) observed two layers of Lowestoft till across the study area and its surroundings, which he considered to be the result of a changing ice flow trajectory during a single advance. A gradational boundary was reported to separate a limestone-rich darker lower layer from a paler upper layer with a higher chalk content. Recording a gradual decline in carbonate content west of the Chalk scarp, he noted only the lower till to be present at Heath and Reach (Site 30). At Barrington approximately 9 km from the easternmost site investigated in this study (Site 23, Hatley), two layers were present, the upper possessing more chalk and markedly less limestone content. Although this study has not detected two layers of till, it does support Fish's conclusions in that a limestone-rich less chalky till is seen in the west and a till with a higher chalk content at sites to the east.

The large quantities (11.2 to 11.5%) of acid-soluble sand in samples 34 – 36 at Holwell (Site 11) are confined to the Middle Till (units 8 and 10) at this site. Etienne (2001) reported that the Upper Till (unit 15) here is chalk depleted, and previous work by the writer showed values in the Upper Till to range from 4.9 to 5.8% (Brownsell, 1996) which, by comparison with Figure 7.21, can be seen to represent mid-range values. The value in the Lower Till (sample 33) is slightly less at 3.94%. It is possible that the large quantities in the Middle Till are in part due to the incorporation of fragments of chalk from the walls of the Hitchin Channel which, according to the BGS 1:50,000 Sheet 221, runs in a north-south direction adjacent to this site. However, this would not account for the high levels that continue in tills lying at a similar height to the north, notably in sample 41 from Moggerhanger (Site 16), sample 45 at Edworth (Site 19) and samples 46 and 47 from Millowbury Farm (Site 20). The flint content of the -1.0 to +1 phi fraction at Sites 19 and 20 averages 21.6% and 22.4% respectively, whilst that for the Middle Till at Primrose Hill Quarry averages 14.3% and at Site 16 is 11.3%. It may be, therefore, that the high acid-soluble content found at Sites 11 and 16 may be due to lithologies other than chalk (e.g. limestone or phosphate nodules, etc.) This is borne out by the high proportions of limestone and phosphate clasts within the gravel lying between the Middle and Upper Tills at Site 11 (Cheshire, pers. comm).

Many of the lowest values of acid-soluble content occur in samples 8, 11, 12, 13 and 15 from the Upper Till at Site 3 (Cannocks Wood). These deposits were laid down above sands and gravels, which originated either during a previous ice advance down this Channel or by drainage waters from the approaching ice sheet flowing into the Channel. It may be therefore that the ice travelled for some distance over these deposits rather than the Chalk bedrock, resulting in the limited assimilation of chalk and subsequent subglacial deposition of low-chalk tills.

The acid-soluble content of the tills does not appear to be related in a consistent way to sample depth. At Sites 7 (Great Wymondley) and 15 (Southill) samples

(23 and 39 respectively) contain smaller quantities of acid-soluble lithologies than samples 25 and 40 found at shallower depths at these sites. This situation is reversed at Sites 6 (Little Wymondley) and 28 (Potsgrove) where samples from greater depths (20 and 60 respectively) have higher acid-soluble contents than the shallower samples i.e. 21 and 22 from Site 6 and sample 61 from Site 28.

Summary

The acid-soluble content of the tills varies considerably but does not appear to be related to distance from the pre-Anglian Chalk scarp, nor is it related to sample depth.

Putting aside tills south of Hitchin, the average acid-soluble content of tills in the western part of the study area is lower than tills found elsewhere (Table 7.21). Discussion in Section 4.4.4 and variations in the chalk content shown in Plate 4.1 suggest that the western tills contain less chalk than tills in the east. Taking this into consideration, amounts of chalk in tills across the study area may vary from the distribution of acid-soluble content shown above, the reduced acid-soluble content of western tills being mainly composed of other limestones.

The lower chalk content of the western tills could be the result of two processes:

1. The generally low average of the chalk component found in the west of the study area can be accounted for if deposited by ice travelling along a trajectory west of that arriving in the northeast of the study area, i.e. across less Chalk bedrock.

2. Ice advancing from the north-northeast across an extensive area of Chalk outcrop would result in the erosion and transport of a great deal of chalk into the study area. However, ice approaching from the northwest or NNW would not cross the Chalk bedrock and would therefore deposit a chalk-free till. The presence of Chalk (including Red Chalk) in the western tills indicates that there is a northerly or northeastern component to these tills. Thus, the till deposited here may be the result of two advances, one from a direction between the northwest and NNW and the other from the north to northeast. If the two

advances had been contemporaneous it may be that the till deposited would not comprise a homogeneous mix of debris from these two directions, as is seen in the western tills, although this is uncertain. If the advances were temporally separated the till deposited by the first advance would be incorporated into the ice of the second. Resulting till deposition would thus include both the chalk-rich till from the north-northeast and the chalk-free till from the northwest-NNW, giving a final homogeneous deposit with lower chalk content than tills beyond the eastern limit of the chalk-free ice.

The evidence presented in this study does not favour either one of these proposals. These hypotheses are discussed further in Chapter 9.

7.4.3. Discrimination between tills based on small clast lithologies (Dataset E)

An attempt to discriminate till units from all sites by PCA of contained insoluble lithologies (Dataset B) was unhelpful in that it was unsuccessful. The cluster analysis proved a great many close links between samples apparently randomly scattered across the study area.

The small clast lithological data in Chapter 5 shows quartz to be the most dominant lithology in all samples except for sample 28 at Site 10 (Baldock) where values of shale are higher and sample 44 at Warden Street (Site 18) (Figure 5.69) where high values of iron aggregates are found. In the latter sample the high values are concentrated in the -1 phi fraction.

A plot of the flint/quartz ratios was constructed for the five clast sizes included in this database. A graph which included all samples failed to show any consistent pattern, but when data relating to samples from Sites 1 to 9 within the Hitchin Gap were removed, the results were more promising. Figure 7.22 shows flint/quartz ratios for the five half phi size fractions (-1.0 to +1.0 phi) for Sites 10 to 30.

The plot shows samples in general to be divided by geographical location, those from the west of the study area having lower flint/quartz ratios than those lying to the north and northeast of the Hitchin Gap. Much overlap occurs, but in general it is seen that, for example, samples from Sites 27 to 30 in the west of the study area have relatively low ratios throughout the range of five size fractions.

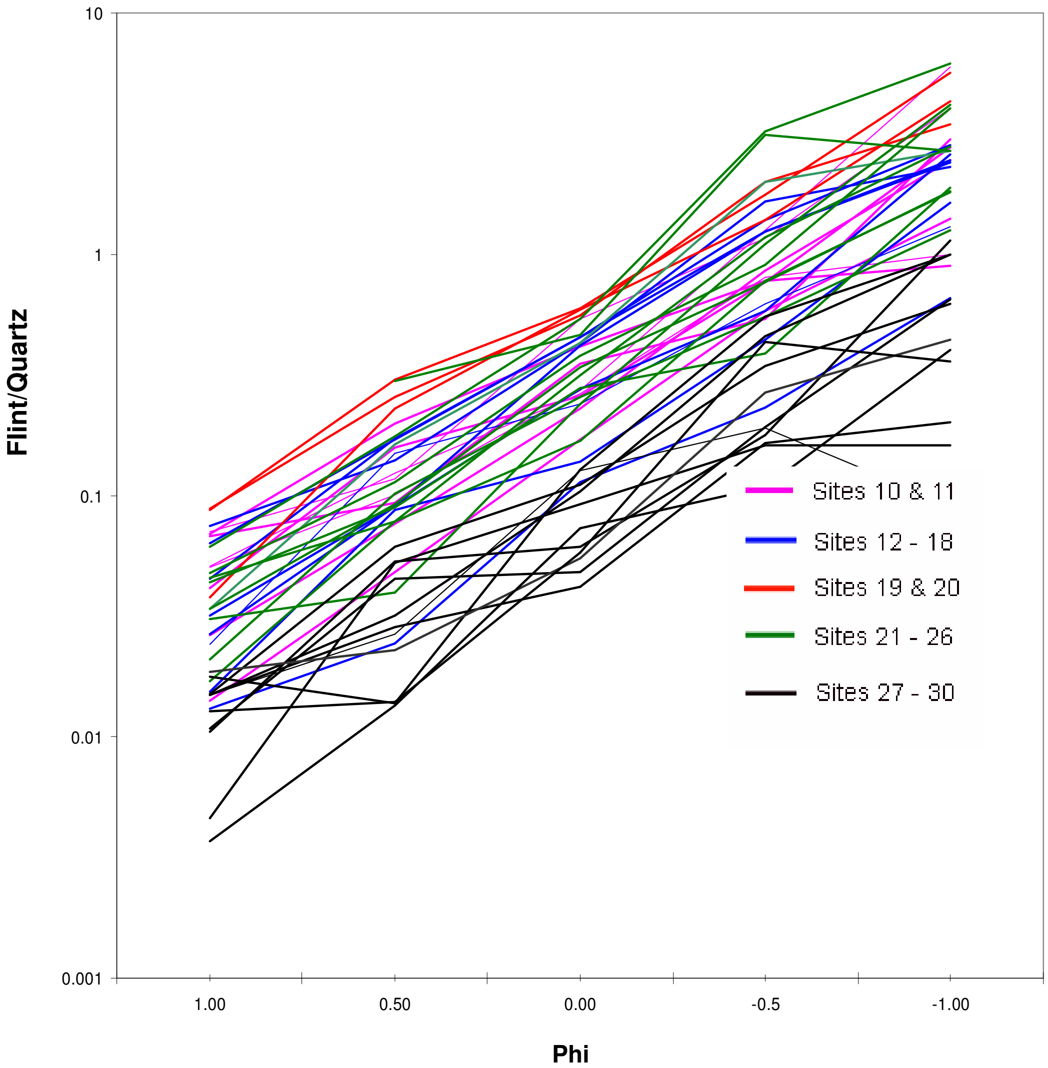


Figure 7.22.

Flint/Quartz ratios for samples from Sites 10 to 30.

	South of Hitchin	Central Corridor	Northeastern Plateau	West
Sites/(samples)	1 – 9 (1 – 28)	10 – 20 (29 – 47)	21 – 26 (48 – 57)	27 – 30 (58 – 68)
Average	0.085	0.135	0.122	0.041
Range	0.010 - 0.193	0.042 – 0.249	0.059 – 0.214	0.021 – 0.057

Table 7.22 :
Average & ranges of flint/quartz ratios in the -1.0 to + 1.0 phi size fractions in different geographical areas

Average flint/quartz ratios for all size fractions in four geographic groups of samples are summarised in Table 7.22 and the values for individual samples are shown in Figure 7.23. Table 7.22 shows low ratios in the west of the study area (average of 0.041) and south of Hitchin (average 0.085). The highest mean ratio (0.135) is found in the Central Corridor, north of Hitchin. The highest individual sample values are found in samples 47 at Site 20 (Millowbury Farm) and sample 57 at Site 26 (Wrestlingworth) at 0.249 and 0.214, respectively.

South of Hitchin the highest ratios are seen in samples 3, 5 and 27 from the lower tills at Sites 2, 3 and 8, respectively (Figure 7.23). These may be explained by assimilation of greater quantities of the flint-rich Upper Chalk. The lowest ratios are found in the Stevenage Channel (samples 20 & 21). The Stevenage Channel is shallower than the Hitchin Channel and the Chalk bedrock was not excavated by the ice to the same depth as at Hitchin where subglacial erosion occurred. Thus, less chalk and flint would have been incorporated into the tills within the Stevenage Channel.

Rhaxella chert has been used in the past to differentiate both tills and Pre-Anglian river gravels (Bridgland, 1986). This chert is composed of sponge spicules (*Rhaxella perforata* Hinde) of characteristic shape and size originating mainly from the Jurassic of north Yorkshire. In the present study the highest recorded Rhaxella content was 0.6% in sample 37 at Site 12 (Upper Stondon). For the most part less than 0.4% was recorded. However in many instances identification was hampered by the small size and often worn appearance of the grains.

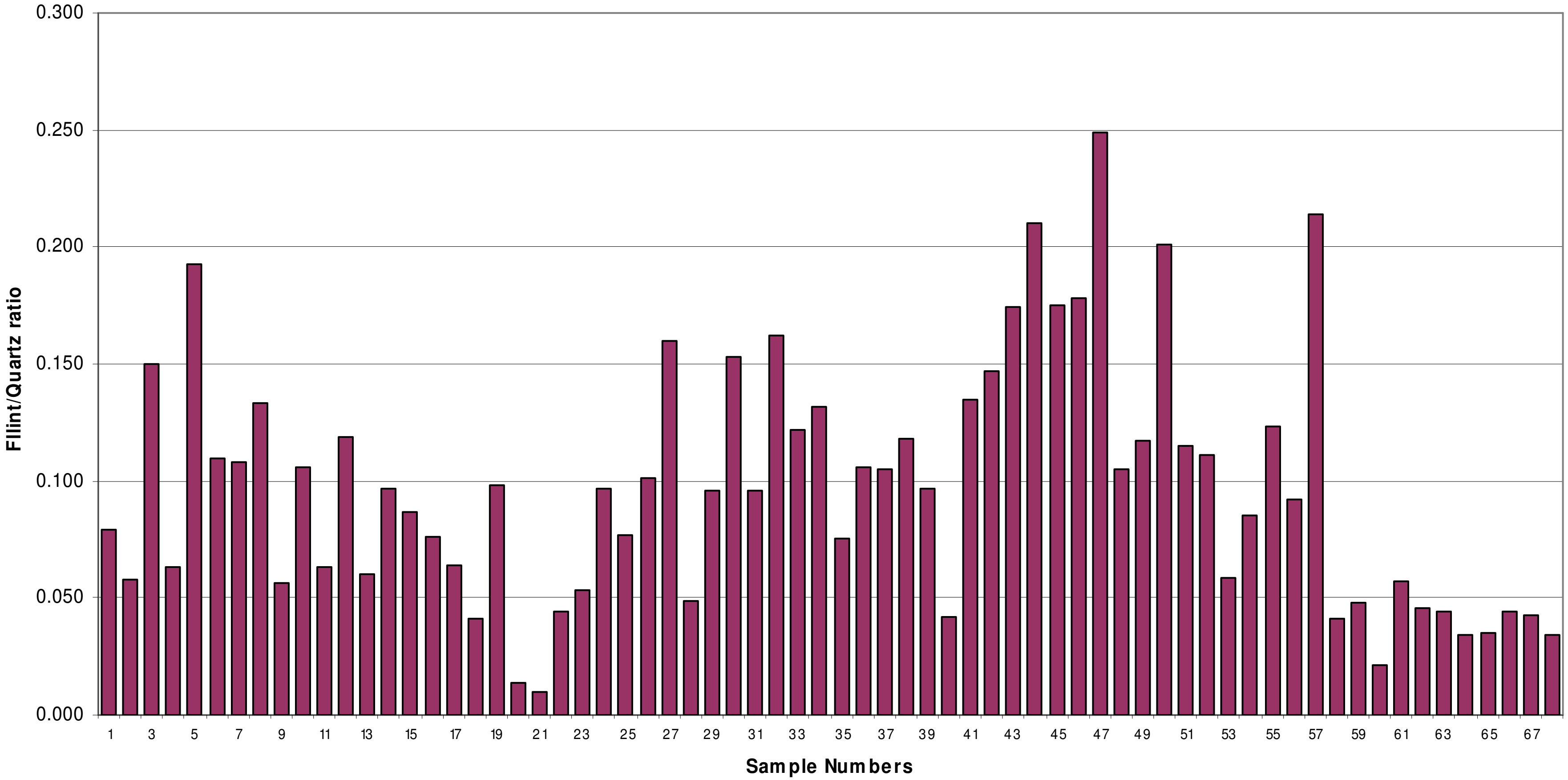


Figure 7.23. Flint/Quartz ratios

Therefore, although this lithology has a widespread distribution across the study area, the absence/presence of Rhaxella chert is not considered a reliable differentiating criterion due to its sporadic occurrence, uncertain identification and very low proportions.

In Section 7.4.2. it was suggested that assimilation of chalk by the ice was greater in the ice stream that reached the east of the study area. Tills in the central corridor and Northeastern Plateau would therefore possess the highest quantities of flint derived from the Upper Chalk. Ice streams moving from the north to Heath and Reach would pass over a shorter distance of the Upper Chalk bedrock and assimilate less flint. An alternative suggestion is that the chalk content of tills in the west is reduced due to the incorporation of chalk-free till deposited by ice from the northwest-NNW. It therefore follows that quantities of flint would be reduced for the same reason.

7.4.4. Discrimination between tills – Datasets F & G (all variates).

In the foregoing discussion, analyses of Datasets C and D (Sections 7.2.3 and 7.2.4) suggest that data from within the Hitchin Gap were masking trends in the remaining data. Therefore, in Dataset F (Section 7.2.6), these sites were removed to investigate the possibility of dividing the remaining 41 samples into different stratigraphic units.

However, in cluster analysis of Dataset F (Table 7.13), sample 32 from the upper part of the till at Site 10 (Baldock) appears in the same cluster (Cluster 3) as the lower samples (52 – 54) at Caxton, whilst Cluster 1 contains two of the lower samples (30 & 31) from Baldock and upper samples (55 & 56) from Caxton, i.e. the sequence reverses between the two sites. The uppermost sample (31) at a height of 71 m O.D. at Baldock was shown to possess similarities with the lowest samples (52 – 54) at 51.4 to 52.4 m O.D. at Caxton in cluster analyses of Datasets A, C and F. It may be that similar sedimentological characteristics of different stratigraphic units account for these anomalies, but there is also the possibility that folding or thrusting of strata has occurred at Baldock. This site lies approximately 10 km from Therfield where detachment of chalk rafts is reported (Hopson, 1995) and 4.7 km from Edworth where rafts of clay have been noted (Edmonds & Dinham (1965). Additional evidence of glacitectonic disturbance of deposits is found 8 km to the southwest of Baldock

(Site 11 of this study) where a structure resulting from an ice push from the north has been recorded (Hopson, 1992). A raft of till previously deposited north of Site 10 (Baldock) could have been detached and carried within the ice, to be subsequently deposited at a greater height. The presence of anomalously low values of acid-soluble lithologies in the lowest sample at Baldock (sample 29) (Figure 7.21) lends support to this hypothesis.

Dataset G (Section 7.2.7) contained only the 33 samples within the Hitchin Gap (Sites 1-9 and 11). Compared to other datasets, principal component analysis of this dataset produced a less logical division of samples. For example, samples from Site 4, which are shown to be closely associated in Datasets A, B and E, are split between the two PCA groups (Table 7.19). Also, of the three samples from Site 7, again showing close similarities in analyses of Datasets A and B, only one (sample 24) possesses a sufficiently high similarity coefficient to be linked to samples at Sites 4 and 8 in PCA Group 2. Cluster analysis of this dataset (Table 7.17) did, however, provide a better split, with nine of the ten samples from the upper till at Site 3 appearing in the same cluster. The lack of similarity of these nine samples in the principal component analyses may be due to slump or flow processes, as suggested by their macrofabric properties (Section 6.6.1) and their characteristics would be expected to be dissimilar from those of lodgement and deformation tills elsewhere in this study. However, cluster analysis of Dataset G associated them with samples from Sites 1, 4, 6, 7 and 9. Tills at these sites may also represent slumped/flow or melt-out tills for the following reasons. Sample 1 from Site 1 included in this cluster is shown in Section 6.6.1 to probably represent a melt-out till. The samples from Sites 6 and 7 lie within the Stevenage Channel, till from Site 7 (samples 23 - 25) being depleted in fine material (Figure 7.18, section 7.4.1.) and both sites possessing macrofabric characteristics not consistent with a lodgement till (Section 6.6.1).

Thus Datasets F and G provide discrimination of tills based on modes of deposition and/or post depositional processes and cannot be used to distinguish and correlate stratigraphic units.

7.4.5. Lower tills at Sites 2 (Norton Green), 3 (Cannock Wood), 8 (St Ippollitts) and 11 (Primrose Hill Quarry).

Several of the analyses in Section 7 (Part 1) have shown separation of lower samples at the above sites. The results of analyses of Datasets A-G are used in this section to assess the evidence for their status as separate lithostratigraphic units.

Site 2 (Norton Green)

Cluster analysis of Datasets B, D and E and PCA of Dataset G suggests separation of upper and lower tills at Site 2. The sample of lower till at this site (sample 3) and the upper till (sample 4) (Section 5.2 and Table 7.0), are separated by almost 10 m of fine to coarse sand and occasional gravel. These two samples are grouped separately in every analysis except that of Dataset C (acid-soluble content). In cluster analysis of this dataset the two samples are linked at a relatively low similarity level of 79.8%. Indeed, sample 3 from unit 4 is linked more closely to samples from Sites 7, 10, 11, 27 and 30 than it is to sample 4 representing Unit 1. This is because the two samples show considerable differences in their particle size and small clast lithological characteristics. This suggests the two samples probably originated from different ice advances.

Site 3 (Cannock Wood)

Cluster analysis of Datasets A, D and G suggest the separation of upper and lower tills at Site 3. The lower till (unit 1) lies at the base of this borehole and is separated from the upper till (unit 3) by 10 m of fine silty sand and gravel (Section 5.2, Figure 5.10). The lack of acid-soluble data for the lower till (sample 5) necessitated its omission from Dataset C. However, samples from the two tills are grouped together by PCA of the particle size distribution of the finer matrix component in Dataset D. The scatterplot of principal component axes 1 and 2 (Figure 7.10) shows a wide dispersion of all samples from this site. The sample from the lower till is only linked into this group via other sites and shows no direct link with samples from the upper till. In all other datasets, samples from the two tills are allocated to different groups, so clear separation of the upper and lower tills is indicated.

Site 8 (St. Ippollitts)

Cluster analysis of Datasets A and D and PCA of Datasets D and G suggest separation of the middle and lower tills at Site 8. The lower sample (sample 26 from Unit 2) is from a series of thin bands of till. The upper sample (sample 27) is from Unit 5 (Chapter 5, Section 5.2.) The intervening two units comprise silty clay and dense sand. The two samples show close associations in the cluster analyses of Dataset C, where they are linked at a similarity level of 89.4%. Sample 27 exhibits closer associations to samples from Site 15 at Southill (possibly due to high sand content) and Sites 21 and 22 on the Northeastern Plateau, than with the sample 26. They are however, placed in the same clusters in analyses of Datasets B, C and E. Although placed in the same group by PCA of Dataset G (Table 7.16), there is no direct link between the two samples.

As these two samples fall into the same groups/clusters in four of the nine multivariate analyses, the evidence for placing them into separate stratigraphic units is not as strong as for Sites 2 and 3.

Site 11 (Primrose Hill Quarry)

Three till units exist at this site and although only the lower and middle tills were sampled in this study, data from previous studies of the upper till are included for comparison purposes in Dataset 2. The lower till (sample 33, Unit 5 – Section 5.2) lies below approximately 7.5 m of glaciofluvial sands and gravels. The middle till samples were extracted from units 8 (sample 34) and 10 (samples 35 & 36) which are separated by a thin band of sandy silt (Unit 9).

Samples from the middle and lower till are closely associated in the analysis of Datasets A, E and F. Similarities between the two in Dataset A range between 87% and 93%. The dendrogram for Dataset E (Appendix 4), dealing with small clast lithology, show close grouping of all samples from this site at 86% similarity. The average flint content of the -1.0 to +1.0 phi fraction of the middle till ranges from 9.0% to 17.1% and the quartz content varies from 40.8 to 46.7%. Values for the lower unit are 14.3% and 43.5% respectively. In analysis of Dataset F a cluster is formed of all samples of the middle till at 88.6 % similarity which is then associated with the single sample from the lower till at a similarity of 84.5%.

However, particle size distributions for the middle till reveal broad modes between +2.2 and 2.7 phi (Figures 5.53 – 5.55) whilst a much narrower mode exists in the lower till at around +2.5 phi (Figure 5.52). The acid-soluble content also differs considerably, being 3.94% for the lower unit (sample 33) and averaging 11.3% for the middle unit (samples 34 – 36). The difference is apparent from the results of cluster analysis of Dataset C (acid-soluble content), in which the two units are assigned to separate groups (Table 7.7). Therefore, although showing broad similarities, the upper and lower tills have different acid-soluble contents and particle size modes, suggesting they originate from different ice advances.

7.4.6. Microfossil analyses

Details of species of ostracoda and foraminifera identified in a selection of till samples are found in Tables 7.23 and 7.24, respectively. The strata from which these microfossils originate ranges through Lower - Upper Jurassic and Early – Late Cretaceous (Bate & Robinson, 1978; Jenkins & Murray, 1981). Unfortunately, due to the geographic distribution of the outcrops of these strata, very little information is revealed regarding likely provenance of the till. The results are summarised in Figure 7.26. This does show, however, that species found in the more westerly sites (28 & 29) include several from the Late Cretaceous found to the north or northeast, as well as those from the northwest, suggesting the movement of ice from the north/northeast across the whole study area.

7.4.7. Summary

All till samples investigated during this study exhibited certain general similarities in that they all possessed a clay matrix with chalk both in the form of fine powder in the matrix and small and/or large clasts. The particle size distributions mostly follow similar patterns with broad primary modes between +1.5 phi and +3.0 phi and secondary modes at around +4.0 phi. However, there are also significant differences. In particular, tills at Site 10 (Baldock) and on the Northeastern Plateau at Site 16 (Potton), Site 22 (Cockayne Hatley), Site 23 (Hatley), Site 24 (Longstowe) and the Lower Till at Site 2 (Norton Green) have primary modes around +4.0 phi. At Southill (Site 15), Moggerhanger (Site 16) and Warden Street (Site 18) the +2.0 phi primary mode is narrower and stronger; the distributions at the last two sites probably result from assimilation

Site	Site number	*Bairdoppilata pseudoseptentrionalis (Mertens 1956)*	*Cardobairdia sp*	*Cytherella sp*	*Cytherella cf. contracta (van Veen)*	*Cytherella sp. (Late Cret)*	*Cytheris*	*Eucytherura sp*	*Galliaecytheridea sp*	*Mandocythere harrisiana (Jones 1870)*	*Mandocythere sp. (L. Cret)*	*Neocythere*	*Neocythere kayei (Weaver 1982)*	*Nubeculinella bigoti (Cushman 1930)*	*Paracypris sp*	*Protocythere sp*	*Schuleridea sp*
Knebworth Park	**1**		?	X		X			?								?
Cannocks Wood	**3**			X					?		X					?	X
Letchmore	**4**									X						X	
St Ibbs	**5**	X										X				X	
Little Wymondley	**6**			X					?	X							
Great Wymondley	**7**		?	X		X			?	X		X				X	
Maydencroft	**9**							?		X		X		X			
Primrose Hill Quarry	**11**	?	?			X					X	X					
Sandy	**17**			X				?									?
Warden Street	**18**					X											
Millowbury Farm	**20**											X					
Potton	**21**											X					
Cockayne Hatley	**22**					X											
Longstowe	**24**		?														?
Caxton	**25**						X	?									
Wrestlingworth	**26**					X											
Potsgrove	**28**			X													
Munday's Hill	**29**				X	X		X		X		X	X		X		

Table 7.23. Species of Ostracod identified in this study.

Site	Site Number	*Cibicides*	*Citharina*	*Dentalina*	*Eggerella*	*Epistomena sp.*	*Frondiculeria sp*	*Globotrunacania*	*Gryoidina*	*Hedbergella*	*Heterolhelix*	*Lenticulina quenstedti, (Gümbel)*	*Lenticulina cf volubilis (Dain)*	*Lenticulina sp (Late Cret)*	*Lingulina sp*	*Marginulina*	*Marginulinopsis*	*Nodosaria sp*	*Nodosariidae (Late Cret)*	*Opthalmidiumi*	*Planalura*	*Pseudotextularia*	*Quinqueloclina*	*Textularia*	*Turrilina*
Knebworth Park	**1**		X			X						X		X		X	?		X						
Norton Green	**2**							X																	
Cannocks Wood	**3**		X			X			?					X		X									
Letchmore	**4**																	?							
St Ibbs	**5**													X									?		
Little Wymondley	**6**		X				X									X							?		
Great Wymondley	**7**					X														?					
St Ippolltts	**8**								X	X						X								X	
Baldock	**10**															?									
Primrose Hill Quarry	**11**	X	X		X			X	X	X		X		X		X			X						
Sandy	**17**	X	X			X			X	X		X	X	X				?							
Millowbury Farm	**20**			X			X				X					?		?			X				?
Potton	**21**														X								?		
Hatley	**23**		X		?		?							X		X		X				X			
Munday's Hill	**29**		X															?						?	

Table 7.24 Species of Foraminifera identified in this study.

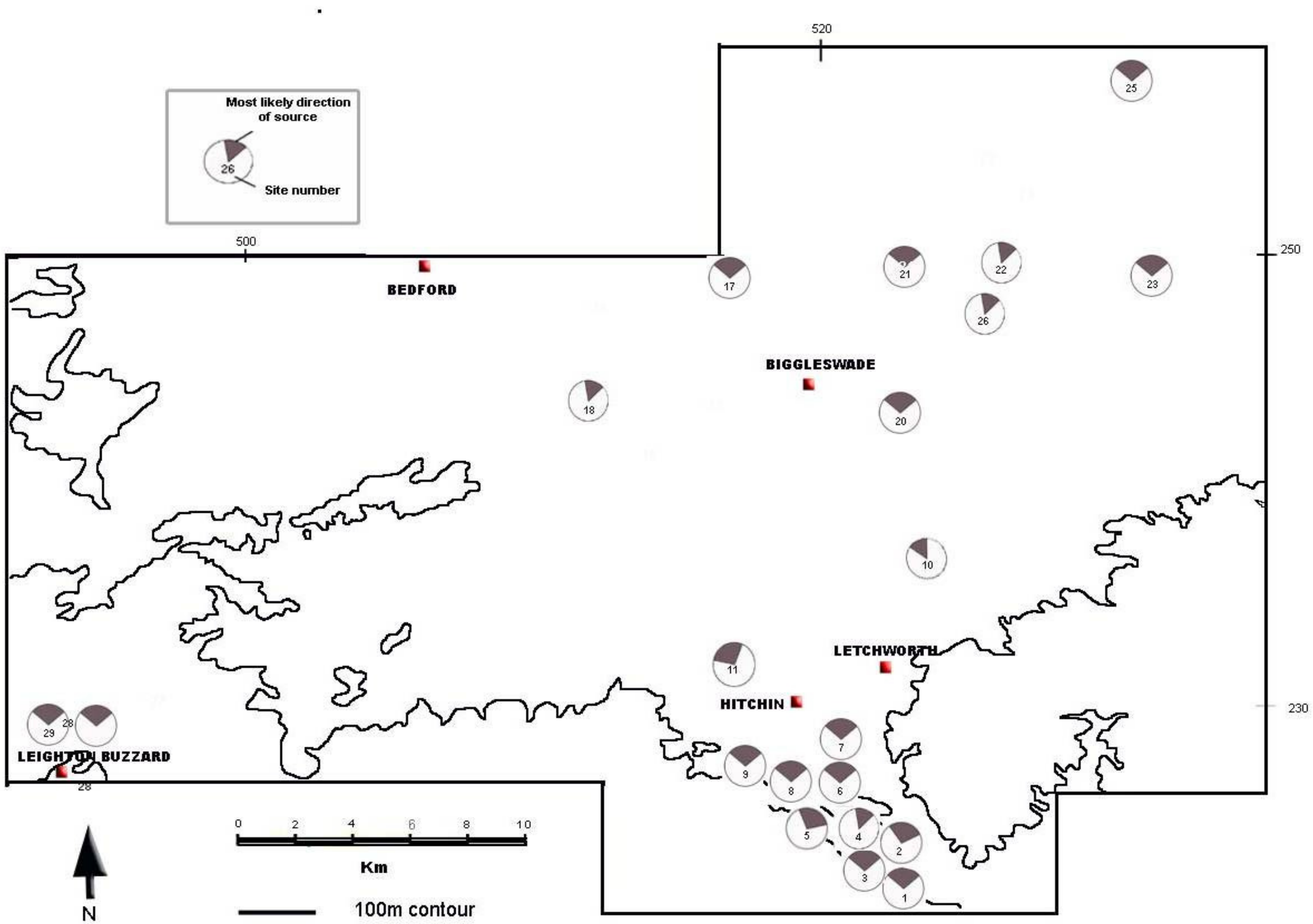


Figure 7.24 Provenance of tills suggested by results of microfossil analyses.

of adjacent underlying Woburn Sands. At Millowbury Farm (Site 20), two roughly equal modes are seen at around +2.5 and +3.5 phi.

Detailed textural and lithological variations indicate a range of depositional environments within the Hitchin Gap and the presence of tills of a different lithological nature in the west of the study area. Tills in the west are characterised by lower flint/quartz ratios and lower acid-soluble content. A visual assessment of the samples also indicates a higher proportion of limestone and less chalk in these tills. This could be due to the ice following a different trajectory from that responsible for till deposition in the east, or it could indicate an additional input provided by the re-working of a lower chalk-free till west of Milton Bryan.

Differentiation between lower and upper tills is evident at Sites 2 (Norton Green), 3 (Cannocks Wood), 8 St Ippollitts) and 11 (Primrose Hill Quarry) as indicated by multivariate analysis (Table 7.19). It appears that at Sites 2 and 3 the flint/quartz ratios in the lower tills are greater than those in the upper tills. At Site 3 no data were available relating to acid-soluble or fines content, but at Sites 2, 8 and 11 the lower tills contained a greater proportion of fine matrix material and a higher acid-soluble content was seen in the lower till at Site 2. At Site 8 the acid-soluble content of the lower till was roughly equal to that of the higher till. The acid-soluble content of the lower till at Site 11 was considerably less than that of the middle till at this site, but only slightly less than the upper till (Brownsell, 1996). It must be noted, however, that although these lower tills lie at similar heights at Sites 8 and 11 (i.e. between 28 and 29 m O.D.), at Site 3 the lower till is found at 52 m O.D. where the floor of the Hitchin Channel rises considerably (shown in Figure 8.4). Site 2 lies only approximately 530 m to the northeast of Site 3, near the junction of the Stevenage and Hitchin Channels. The present land surface lies at a similar height, but the two lower tills investigated here are found at very different altitudes, that at Site 2 being found at almost 86 m O.D. Therefore, in view of the differences in lithology and height between the lower tills at these two sites, it may be that the lower till seen at Site 2 is not part of the same lower till unit as seen elsewhere, but displays similar characteristics to the lower till at Site 3, owing to the variability of tills within the channel sequences.

CHAPTER 7

DISCRIMINATION BETWEEN TILL UNITS

PART 3: COMPARISON WITH DATA FROM CENTRAL AND EAST HERTFORDSHIRE

7.5. Multivariate Analysis of Database 2

To the east and south of the study area four tills were recognised by Cheshire (1986) as described in Section 3.12.4. The comparison data used in this dataset were from 17 sites where tills have been assigned to the Ware Member, 7 sites with tills assigned to the Wadesmill Member and 5 sites related to the Stortford Member. Cheshire's Ugley Member can be differentiated at only two sites, having a rather restricted outcrop at a distance to the east of the study area, and so is not represented here. The four tills are assigned by Cheshire to four re-advances of a parent ice sheet lying to the northeast. Data for samples PHQU1 - 4 at Primrose Hill Quarry (Site 11) correspond to samples from Unit 15 previously investigated by the writer (Brownsell, 1996) and correlated with Cheshire's Ware Member. The analytical data used for multivariate analyses are listed in Table 4.4.

Figures 7.25 – 7.27 are illustrations of the areas covered at the height of each advance, as suggested by Cheshire (1986). His limits have been extrapolated (shown by red pecked lines) to indicate likely ice limits in the study area. Sites from this study showing high similarities with Ware and Stortford Member tills are also shown in Figures 7.25 and 7.26, respectively.

A lack of data from tills lying further west or northwest of the study area prevents further comparison with deposits that may share characteristics with tills from Sites 27 – 30 in the west.

Table 7.25 shows links above 99.6% similarity (Section 4.6.4) between sites used for comparison and those investigated as part of this study. These have been ranked first in order of similarity, then in order of geographic distance between the sites concerned. The latter needs to be considered in order to

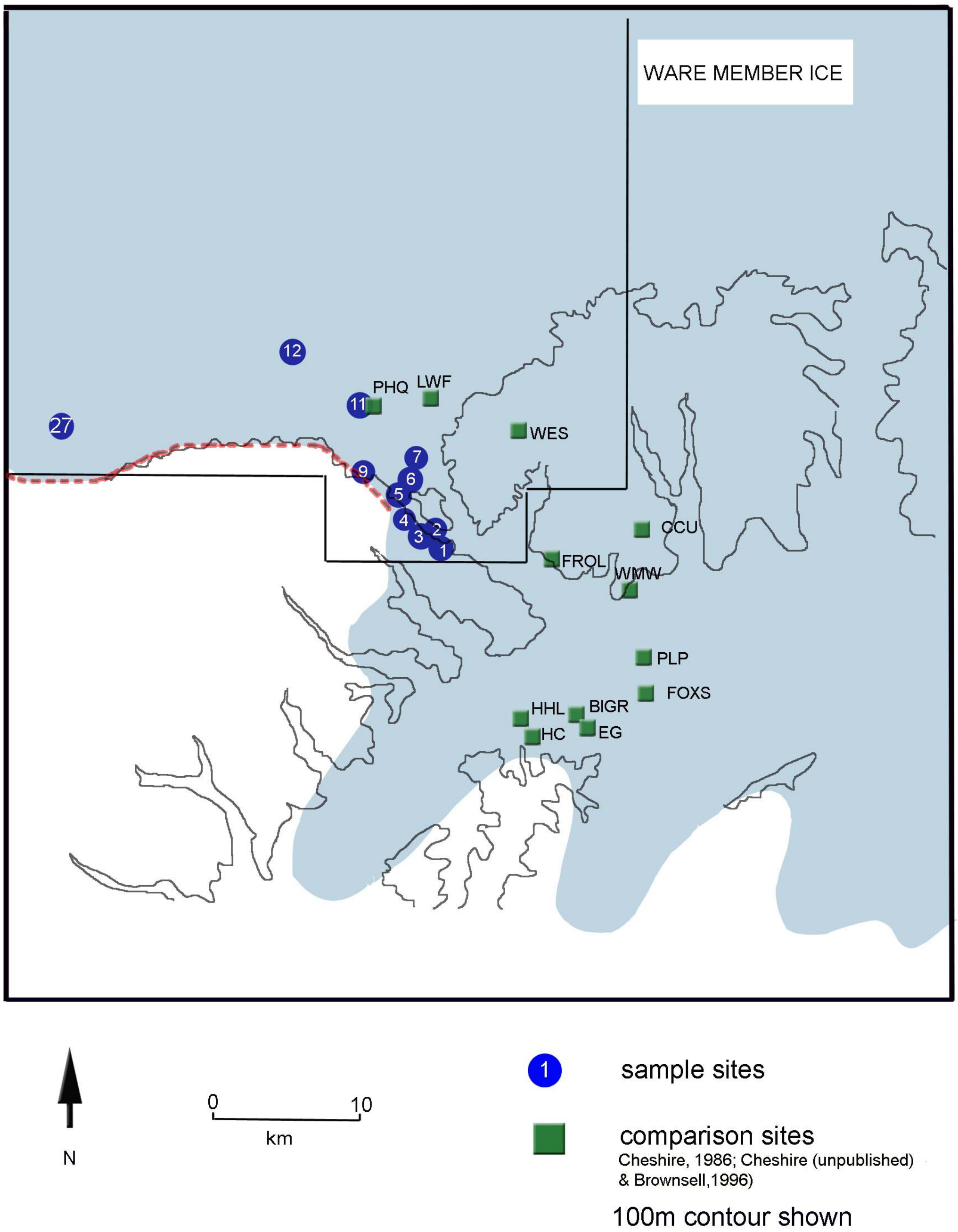


Figure 7.25 Extent of Ware Member ice (shaded blue) and sites from this study showing high similarities with Ware Member tills

Red line represents possible extent of ice in study area

Adapted from Cheshire (1986).

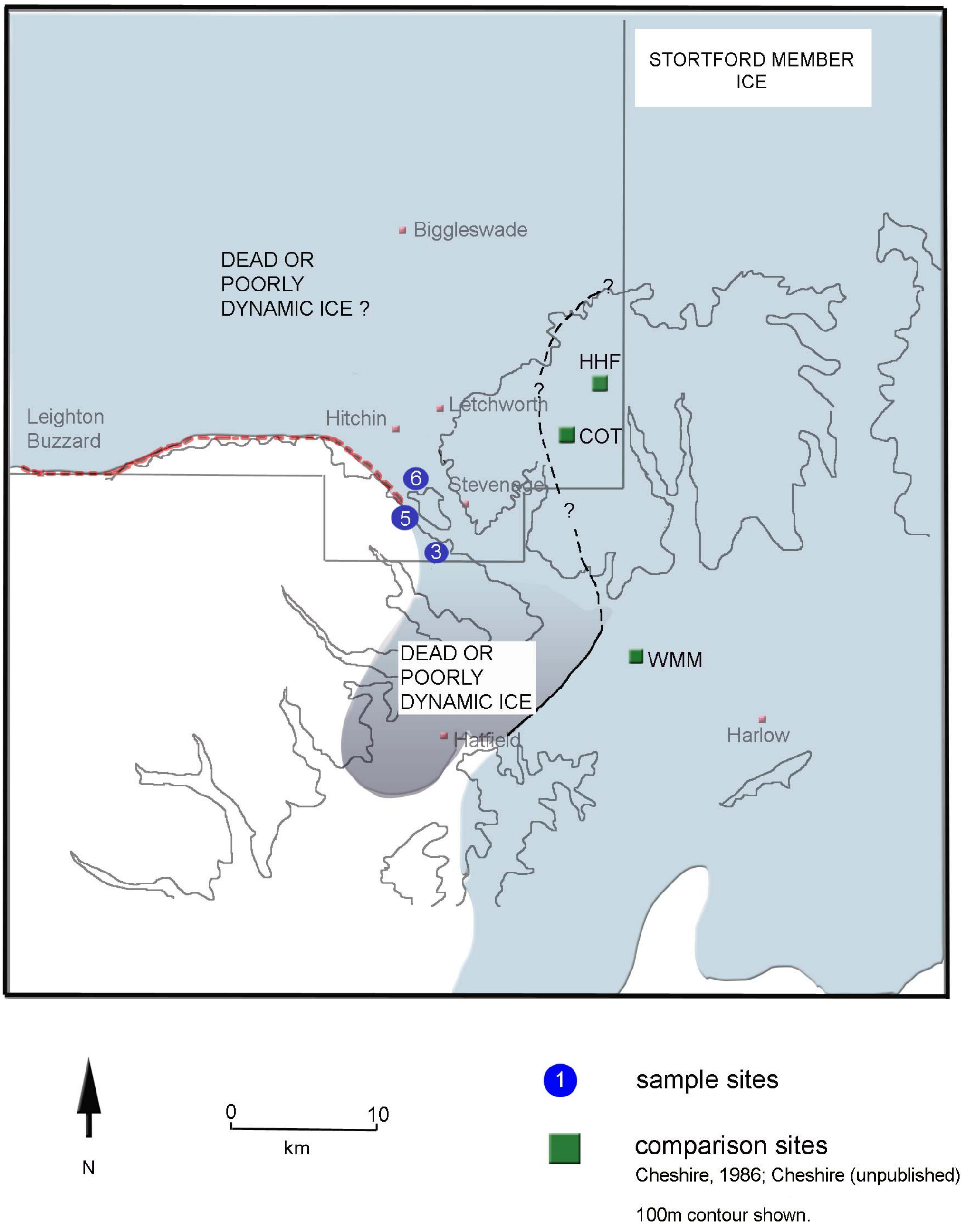


Figure 7.26 Extent of Stortford Member ice and sites from this study showing high similarities with Stortford Member tills.

Red line represents possible extent of ice in study area

(Adapted from Cheshire (1986)

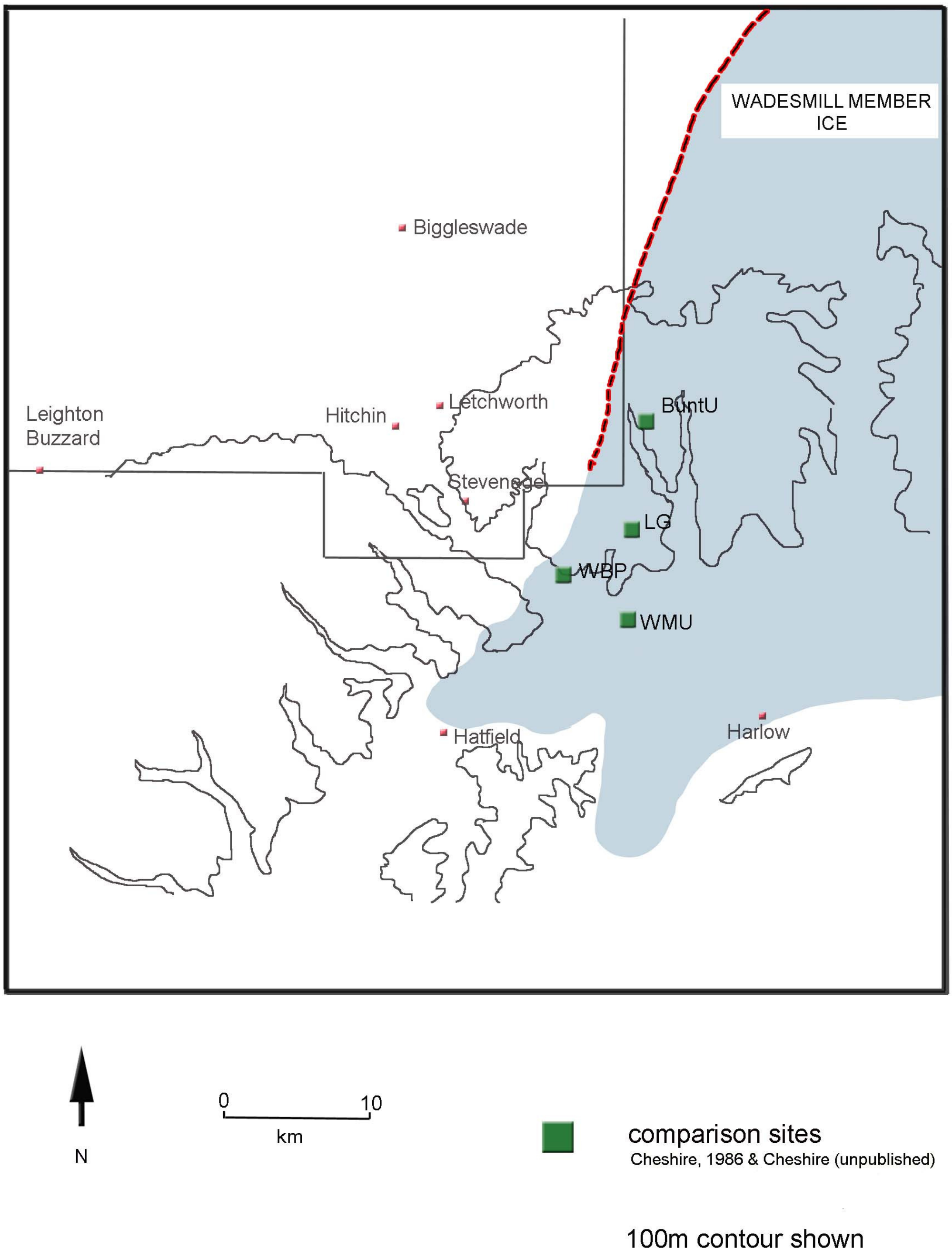


Figure 7.27 Maximum extent of Wadesmill Member ice.

Red line represents possible extent of ice in study area

(Adapted from Cheshire (1986).

SAMPLE 1	COMPARISON SITE LOCATION	MEMBER	SAMPLE 2	SITE NO.	DISTANCE (km)	SIMILARITY COEFFICIENT (%)
BIGR1	Birch Green	Ware	8	3(U)	13	99.9
BIGR1			19	5	17.5	99.9
BIGR1			2	1	12	99.8
BIGR1			13	3(U)	13	99.8
BIGR1			25	7	19	99.8
BIGR1			4	2(U)	13	99.7
BIGR1			23	7	19	99.7
BIGR1			28	9	19.5	99.7
BIGR1			22	6	14	99.6
CCU 1	Cold Christmas	Ware	8	3(U)	15	99.9
CCU 1			13	3(U)	15	99.8
CCU 1			7	3(U)	15	99.8
CCU 1			2	1	16	99.8
CCU 1			37	12	29	99.8
COT 1	Cottered	Stortford	13	3(U)	11.5	99.7
COT 3			22	6	11.5	99.7
COT 5			22	6	11.5	99.7
COT 3			19	5	13.0	99.7
EGJR 8	Eastend Green	Ware	13	3(U)	14	99.8
EGJR 8			17	4	16	99.8
EGJR 7			25	7	20	99.8
EGJR 7			2	1	14	99.7
EGJR 8			16	4	16	99.7
EGJR 7			19	5	20	99.7
EGJR 7			23	7	20	99.7
EGJR 8			19	5	20	99.7
EGJR 8			14	3(U)	14	99.6
FOXS 1	Foxholes, Hertford	Ware	8	3(U)	16	99.8
FOXS 1			7	3(U)	16	99.8
FOXS 3			8	3(U)	6.5	99.7
FOXS 3			2	1	15	99.7
FOXS 1			12	3(U)	16	99.7
FOXS 3			4	3(U)	16	99.7
FOXS 1			2	1	15	99.6
FROL 2	Frogmore Quarry	Ware	28	9	12.5	99.9
FROL 2			25	7	11	99.8
FROL 2			23	7	11	99.8
FROL 2			10	3(U)	6.5	99.7
FROL 2			17	4	8	99.7
FROL 2			16	4	8	99.7
FROL 2			22	6	9.5	99.7
FROL 2			7	3(U)	6.5	99.6
FROL 2			6	3(U)	6.5	99.6
FROL 2			2	1	5.5	99.6
FROL 2			24	7	9.5	99.6
HC 1	Holwell Court	Ware	14	3(U)	13.5	99.9
HC 1			23	7	19	99.9
HC 1			25	7	19	99.8
HHF8	Hyde Hall Farm	Stortford	6	3(U)	16	99.8
HH6	Holwell Hyde	Ware	6	3(U)	16	99.8
LWF	Lower Wilbury Farm	Ware	28	9	7.5	99.9
LWF			23	7	6.5	99.7
LWF			16	4	10.5	99.6
LWF			15	3(U)	11.5	99.6
LWF			2	1	13	99.7
WES	Weston	Ware	19	5	7	99.8
WES			24	7	4.7	99.7
WES			8	3(U)	8.4	99.7
WES			13	3(U)	8.4	99.6
WES			2	1	9.5	99.6

Table 7.25 Similarity Coefficients above 99.6% for Comparison Dataset (see text). (continued on next page)

SAMPLE 1	COMPARISON SITE LOCATION	MEMBER	SAMPLE 2	SITE NO.	DISTANCE (km)	SIMILARITY COEFFICIENT (%)
PHQUS	Primrose Hill Quarry	Ware	2	1	12.0	99.9
PHQUS			8	3(U)	10.5	99.8
PHQU2			4	2(U)	11.0	99.8
PHQUS			4	2(U)	11.0	99.8
PHQU1			4	2(U)	11.0	99.8
PHQU2			59	27	20.0	99.8
PHQU1			58	27	20.0	99.8
PHQU4			15	3(U)	10.5	99.7
PHQU4			35	11(M)	0.0	99.7
PHQU4			28	9	4.7	99.7
PHQU4			37	12	4.8	99.7
PHQUS			13	3(U)	10.5	99.7
PHQU4			15	3(U)	10.5	99.7
PHQU4			12	3(U)	10.5	99.7
PHQU2			8	3(U)	10.5	99.7
PHQU1			2	1	12.0	99.7
PHQU4			58	27	20.0	99.7
PHQUS			59	27	20.0	99.7
PHQUS			58	27	20.0	99.7
PHQU4			59	27	20.0	99.7
PHQUS			22	6	5.8	99.6
PHQUS			20	6	5.8	99.6
PHQUS			19	5	6.0	99.6
PHQUS			25	7	6.0	99.6
PHQU2			12	3(U)	10.5	99.6
PHQUS			7	3(U)	10.5	99.6
PHQU4			4	2(U)	11.0	99.6
PHQU4			2	1	12.0	99.6
PHQU2			2	1	12.0	99.6
PLPL	Poles Lane Pit	Ware	2	1	15	99.8
PLPL			13	3(U)	15	99.8
PLPL			8	3(U)	15	99.8
PLPL			7	3(U)	15	99.8
PLPL			25	7	17.5	99.8
PLPL			12	3(U)	15	99.7
PLPL			17	4	15.5	99.7
PLPL			19	5	19	99.7
PLPL			23	7	17.5	99.6
WMW5	Westmill Quarry	Ware	7	3(U)	14.5	99.9
WMW5			13	3(U)	14.5	99.8
WMW5			8	3(U)	14.5	99.8
WMW5			6	3(U)	14.5	99.8
WMW1			2	1	13.0	99.7
WMW2			2	1	13	99.7
WMW5			2	1	13.0	99.7
WMW1			8	3(U)	14.5	99.7
WMW1			7	3(U)	14.5	99.7
WMW3			8	3(U)	14.5	99.7
WMW4			13	3(U)	14.5	99.7
WMW5			12	3(U)	14.5	99.7
WMW5			25	7	17.0	99.7
WMW5			28	9	20.0	99.7
WMW2			4	2(U)	14.5	99.6
WMW2			8	3(U)	14.5	99.6
WMW4			8	3(U)	14.5	99.6
WMW4			19	5	14.5	99.6
WMW2			19	5	18.5	99.6
WMW5			19	5	18.5	99.6

Table 7.25 Similarity Coefficients above 99.6% for Comparison Dataset (see text). (continued from previous page)

allow for spatial variability in till characteristics, priority being given to those at the same similarity and the shortest distance apart. Comparisons with the data of Cheshire (1986) from sites between 10 and 17.5 km from the eastern side of the study area illustrate the nature of the variability and the difficulty of correlation. Also, the maximum lateral extent of till outcrops shown on the BGS maps (British Geological Survey, 1900; 1975; 1992; 1995; 2001) rarely exceeds 20 km, rendering till equivalence in a continuous lateral sheet less probable. This makes it unlikely that tills exhibiting similarities at distances of greater than 20 km signify the presence of a laterally continuous unit. For this reason sample pairs separated by more than 20 km are omitted from this table.

7.5.1. Ware Member

Of the 118 similarities > 99.6% in Table 7.25, 114 represent links between sites with tills representative of Cheshire's Ware Member. A summary of links with sites believed to represent this member is given in Table 7.26.

Site No.	Sample Nos.	Location	Number of links	Number of comparison sites
1	2	Knebworth Park	16	9
2(U)	4	Norton Green	7	4
3(U)	6 -14	Cannocks Wood	44	12
4	16 - 18	Letchmore	7	5
5	19	St Ibbs	9	6
6	20 -22	Little Wymondley	4	3
7	23 – 25	Great Wymondley	15	9
9	28	Maydencroft	5	5
11(M)	34 – 36	Primrose Hill Quarry	1	1
12	37	Upper Stondon	2	2
27	58, 59	Milton Bryan	6	1

Table 7.26. Comparison data links (Ware Member) from Table 7.25

The type site for the Ware Member is at Westmill Quarry, represented by samples WMW1 – 5 in this dataset. There are a total of 20 links with these five samples, with similarity coefficients ranging from 99.6 and 99.9%. The highest similarity is between the uppermost of these samples (WMW5) and a sample (sample 7) of the upper till from deep within the Hitchin Channel at Site 3 (Cannocks Wood), lying at a distance of 14.5 km. A further ten links exist between this till, lying at depths of between 14.4 m and 33.9 m, and the Ware Member at Westmill.

Geographically closer sites representing the Ware Member are found at Frogmore Quarry (FROL1 & 2) and Weston (WES). Frogmore lies within the Lower Beane Valley approximately 12.5 km southeast of Site 9 (Maydencroft), with which it possesses the highest similarity coefficient (99.9%). Other high level (99.8%) links associate sample FROL 2 with Site 7 (Great Wymondley) at a distance of 11 km. A shorter distance (6.5 km) separates Frogmore Quarry and Site 3(U) at Cannocks Wood, with which three links exist. Other associations are shown between sample FROL2 and those from Sites 4 (Letchmore) and 6 (Little Wymondley). Weston, on the North Hertfordshire Chalklands, produced a strong link (99.8%) with Site 5 (St Ibbs) on the margin of the Hitchin Channel south of Hitchin. Weaker links were formed with Site 7 (at Wymondley) within the Stevenage Channel and Sites 1 (Knebworth Park) and 3(U) (Cannocks Wood) at the southern end of the Hitchin Channel.

The association of Site 9 (Maydencroft) with the Ware Member is reinforced by a strong link with a sample at Lower Wilbury Farm, 7.5 km to the northeast. Here a single sample of till (LWF) lying above the Letchworth Gravel is considered also to represent the Ware Member. As with Frogmore Quarry, this site is shown to be associated with the upper till at Site 3, as well as samples at Sites 7 and 4 south of Hitchin. In addition a more distant link exists to Site 1 at Knebworth Park. North of the Chalk scarp at Upper Stondon a sample from Site 12 shares a similarity coefficient of 99.7% with that from Primrose Hill Quarry at a distance of 4.8 km.

Data from previous studies of samples from Primrose Hill Quarry (PHQU1 - 4 & PHQUS) relate to the uppermost till at this site (Section 5.2) which is believed also to be equivalent to the Ware Member (Brownsell, 1996). This unit provides the greatest number of links with samples in this study, 22 being with sites south of Hitchin. The strongest of these links are with Site 1 (Knebworth Park), lying 12 km to the south, and other links include four high similarities with the upper till of Site 2 at Norton Green. Only one link above 99.6% associates the upper tills at Primrose Hill Quarry with the middle till investigated in this study; this is a 99.7% similarity coefficient between sample PHQU4 and sample 35. However, all of the similarities between the upper and middle tills at this quarry lie above 98% as shown in Table 7.27 suggesting that both the upper and middle tills at this site are related to the Ware Member. They are separated by over 10 m of sands and gravels and current bedded sands (Lower Holwell Sands), which formed part of a braid plain of a southerly flowing river (Etienne, 2001). However, a similar sequence was noted to the south of the study area by Cheshire (1986), where the Holwell Sands (a different Holwell, near Welwyn Garden City) seen west of Hertford within the Vale of St Albans lie between two massive beds of the Ware Member till.

The remaining comparison sites representing the Ware Member are at Poles Lane Pit (PLPL), Eastend Green (EGJR7 & 8), Birch Green (BIGR1) Holwell Hyde (HH6) and Holwell Court (HC1) all forming links at more than 11.5 km distance. In general these support associations already mentioned with the upper tills at Sites 2 and 3, together with samples at Sites 1, 4, 5, 6, 7 and 9. Together they suggest very strongly that the Ware Till extends into the study area.

	Comparison Samples				
Sample No.	PHQU1	PHQU2	PHQU3	PHQU4	PHQUS
33	99.28	99.39	98.98	99.45	99.31
34	98.71	98.86	98.79	99.10	99.22
33	99.21	99.52	98.59	99.68	99.18
36	98.82	98.97	98.82	99.18	99.13

Table 7.27. Primrose Hill Quarry (Site 11) - Similarity coefficients between middle (this study) and upper (comparison) tills.

The Ware Member has been shown to have a well defined mode in the +2.0 to +3.0 phi range and a low acid-soluble content in the sand fraction (Cheshire, 1986). The average flint and quartz contents of the fraction between -0.5 to +1.0 phi are recorded as 8.2% and 70.7%, respectively. With the exception of samples from Site 7, tills linked to the Ware Member in Table 7.26 possess modes between +2.0 and +3.0 phi. However, their corresponding average flint content is 7.2% and the quartz content ranges between 50.3% and 61.6%, with an average of only 56%. Thus, both the flint and quartz contents of these tills are lower than those found in the Ware Member south and east of the study area. This may be due to higher amounts of aggregated grains in the -0.5

to +1.0 phi fraction, ranging between 10.2% and 19.6% and averaging 14.9%, compared to an average of 9.6% reported by Cheshire. It is possible that these differences result from lateral changes in the composition of the tills due to localised assimilation of material, e.g. quartz-rich sands from the pre-Anglian Thames deposits in Hertfordshire. It is possible that flint values may increase as the southwards moving ice passed over the Chalk outcrop. The acid-soluble content of the sand fraction is similar to that found by Cheshire, i.e. values of 3 - 4%.

7.5.2. Stortford Member

Cheshire (1986) found the Stortford Member to contain less medium and coarse sand than the Ware Member with a higher acid-soluble content in the sand fraction, ranging from 4.9 to 10.1 % (average 7.9%). The percentage of aggregated grains in the -0.5 to +1phi fraction is also less than in the Ware Member. A less well defined mode exists between +1.5 and +3.5 phi, and the average quartz and flint content in the -0.5 to +1.0 phi range are 60.1% and 7.3% respectively.

Five links exist between tills in this study and two comparison sites representing the Stortford member (Table 7.28). Samples from Cottered are linked to samples from the upper till at Site 3 at Cannocks Wood, Site 5 at St Ibbs and Site 6 at Little Wymondley. A further sample from the upper till at Site 3 is associated with a single sample from Hyde Hall Farm (HHF).

Site	Location	Number of links	Number of comparison sites
3(U)	Cannocks Wood	2	2
5	St Ibbs	1	1
6	Little Wymondley	2	1

Table 7.28. Comparison data links (Stortford Member) from Table 7.25.

All the samples in Table 7.28 are seen in Chapter 5 to possess broad modes at around 2.5 phi. Quartz values in the -0.5 to +1.0 phi range in these samples are lower than those of the Stortford Member, averaging only 53.3%. Quantities of flint are slightly lower, averaging 6.8%, and the acid-soluble content of the sand fraction is much lower averaging 3.77% and reaching a maximum of only 6% in a sample from Site 5 (St Ibbs).

The upper till from Site 3 together with tills from Sites 5 and 6 appear to possess somewhat similar characteristics to all of the Cottered comparison samples (Table 7.29), with approximately half of the similarity coefficients being over 99%. However, only four links reach the threshold coefficient of 99.6% out of a possible 98. In view of the latter and the number of samples linked with the Ware Member with higher similarity coefficients over similar distances, i.e. Frogmore, Lower Wilbury Farm and Primrose Hill Quarry, it is not considered that representatives of the Stortford Member are to be found in the Hitchin region. However, these results might reflect a greater similarity between these two tills within the study area than was found by Cheshire in central and southeast Hertfordshire.

	Sample number	**COT 1**	**COT 2**	**COT3**	**COT4**	**COT5**	**COT6**	**COT7**
Site 3(U)	6	99.49	99.02	99.44	99.33	99.26	99.17	98.79
	7	99.22	98.71	99.12	99.03	99.08	99.04	98.85
	8	99.24	99.01	99.40	99.19	99.14	99.28	99.33
	9	96.62	97.26	97.52	96.79	97.15	97.57	97.89
	10	98.98	98.15	98.97	98.72	98.57	98.53	98.32
	11	99.21	98.06	98.77	98.83	98.95	98.62	98.31
	12	99.08	98.52	98.88	98.71	98.89	98.81	98.69
	13	99.70	98.90	99.55	99.58	99.47	99.47	99.47
	14	99.09	98.19	99.27	99.19	98.76	99.02	98.93
	15	98.21	97.61	98.15	97.71	98.06	97.94	97.75
Site 5	19	99.34	99.02	99.69	99.50	99.30	99.47	99.58
Site 6	20	99.41	98.54	99.39	99.31	99.49	99.47	99.46
	21	97.02	96.77	97.24	97.59	97.44	97.86	98.31
	22	99.49	99.13	99.69	99.48	99.60	99.58	99.35

Table 7.29. Similarity coefficients between samples from this study and comparison samples COT1 – COT7 from Cottered.

7.5.3. Wadesmill Member

The only links showing greater than 99.6% similarity with samples of the Wadesmill Member exceed the 20 km maximum geographic distance between samples imposed during this study (Section 4.6.4).

The geographically closest of Cheshire's sites representing this Member to the present study area is that within the lower Beane Valley at Watton by-Pass (WBP) which lies 6.8 km from Site 1. The strongest links shown with this site are for samples from Baldock at 99.0%, i.e., below the threshold similarity coefficient.

7.5.4. Summary

Results from this section show that tills at many sites investigated as part of this study share similarities with tills assigned to the Ware Member by Cheshire (1986). Cheshire considered the Ware Member ice to be the first to enter the Vale of St Albans and Lea Valley south and east of the study area, and to be the most widespread. Far fewer links were shown with examples of the Stortford and Wadesmill Members; this may be partly due to the geographic distance at which these lie, but may also be because these successive ice advances of the main Lowestoft Ice did not encroach into the study area. An alternative explanation is that the textural and lithological characteristics found by Cheshire in these tills lose their identity up-glacier. If these variations only developed as the ice moved south of the chalk escarpment where the various ice lobes diverged, it might not be possible to identify tills from the separate advances within the study area.