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Ancient Monuments Laboratory
Report 4/92

SOIL REPORT ON CALCAREOUS FEATURES FROM THE EXCAVATIONS AT GODMANCHESTER, CAMBRIDGESHIRE

Matthew Canti

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Summary

Three types of calcareous features, found during the excavations at Godmanchester, have been analysed. These consisted of patches of calcareous subsoil, a ditch fill core and a single exposure of near-horizontal calcium carbonate layering. In each case, the matrix of the calcareous material was compared to that of adjacent normal soils using particle-size analysis and heavy mineral trends. The calcareous parts of the subsoils and layered area were found to have finer textures and associated mineralogical variations relative to their adjacent counterparts. It is suggested that the subsoil patches form naturally in areas of fine soil, while the layering was the result of an industrial process in which similar fine soil was used, probably in conjunction with imported lime. The ditch fill showed no systematic variation between calcareous and non-calcareous materials, but differed significantly from the surrounding soil. It is suggested that the core represents the last remnant of a larger body of carbonate-enriched material, perhaps originally filling the whole ditch.

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SOIL REPORT ON CALCAREOUS FEATURES FROM THE EXCAVATIONS AT GODMANCHESTER, CAMBRIDGESHIRE

1. Introduction

Excavations were carried out at Godmanchester during 1988-1990 by the Central Excavation unit, directed by Fachtna McAvoy. The work was necessitated by the extension of gravel-quarrying over a threatened area containing a previously excavated Roman farm (Frend 1968) and a wealth of varied crop-marks. The site emerged as a complex multi-period excavation with foci on a large Romano-British agricultural estate and Neolithic/Bronze-Age enclosures of considerable ritual significance. Throughout the different ages represented, unusual features were found containing concentrations of calcium carbonate. These could not easily be explained on a gravel-based site, and additional work was needed to elucidate their origin in an archaeological or natural context. This report deals only with the specific questions raised by these features.

2. Geological Background

The site geology consists of Pleistocene river gravels overlying Jurassic Oxford clay at around 3-5 metres depth (BGS Sheet 187). Locally, modern alluvium forms a significant part of the topsoil profiles.

The gravels are strongly bedded with marked textural variations observable in the gravel-pit sections to the East of the site. The underlying Oxford clay is highly calcareous (losing some 35% of it's mass on HCl dissolution - see Appendix 3) and thus represents a potential source for calcium carbonate accretion under suitable hydrological conditions. Evidence that such conditions may have existed can be found in the quarry-sections, where discontinuous $CaCO_3$ bands are occasionally found (see Plate 1). These appear to be associated with distinctly fine sediment layers, but the true source of the carbonate (either contemporary with deposition or a subsequent hydrological effect) is not known.

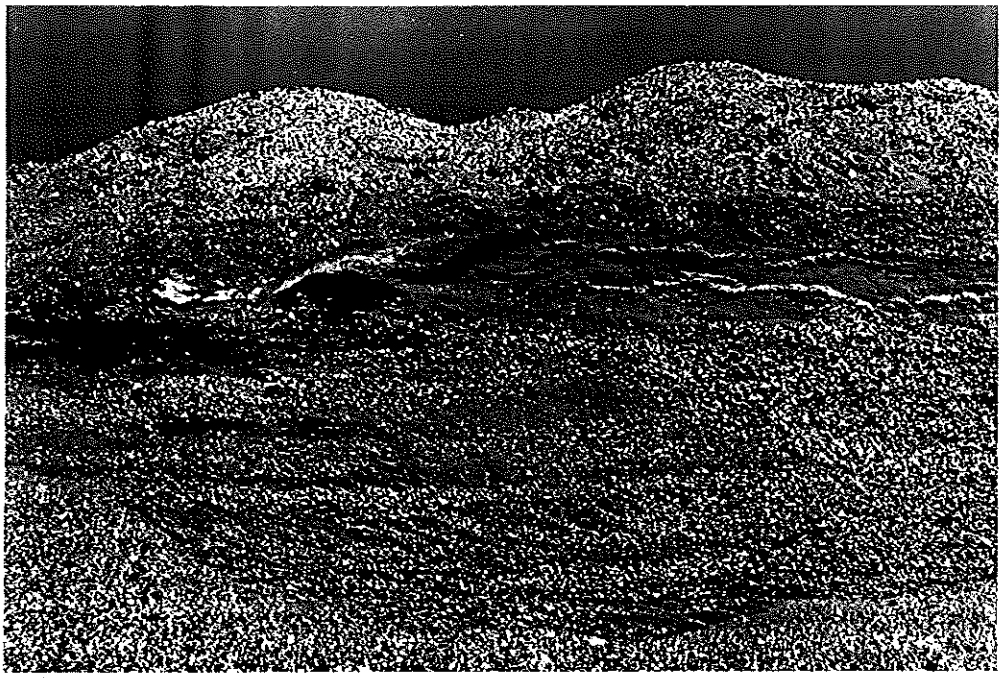

Plate 1
Calcareous bands associated with fine layers in the quarry East of the site.

3. The Calcareous Features

The calcareous features found during the excavation fall into three groups:-

1) Calcareous subsoils - these were patches of $CaCO_3$-enriched subsoil found randomly all over the site. They were discrete pockets, merging abruptly into normal coarse sandy soil at the edges. CS samples.

2) Calcareous Ditch Fill - this feature consisted of a $CaCO_3$ enrichment found in a roughly elliptical patch in the central bottom half of a ring ditch-fill. The feature was visible in all sections around approximately 1/2 of the ring-ditch. CF samples.

3) Calcareous Layering - this was a single exposure of a series of calcareous bands, intercalated down-profile with less calcareous material. CL samples.

Figure 1 shows the locations on a broad site plan. The questions raised by these three features have both individual and possibly whole-site implications that need to be considered. Initially, they are discussed here in turn as Sections 4, 5 and 6 with a broader discussion of the linkages in Section 7.

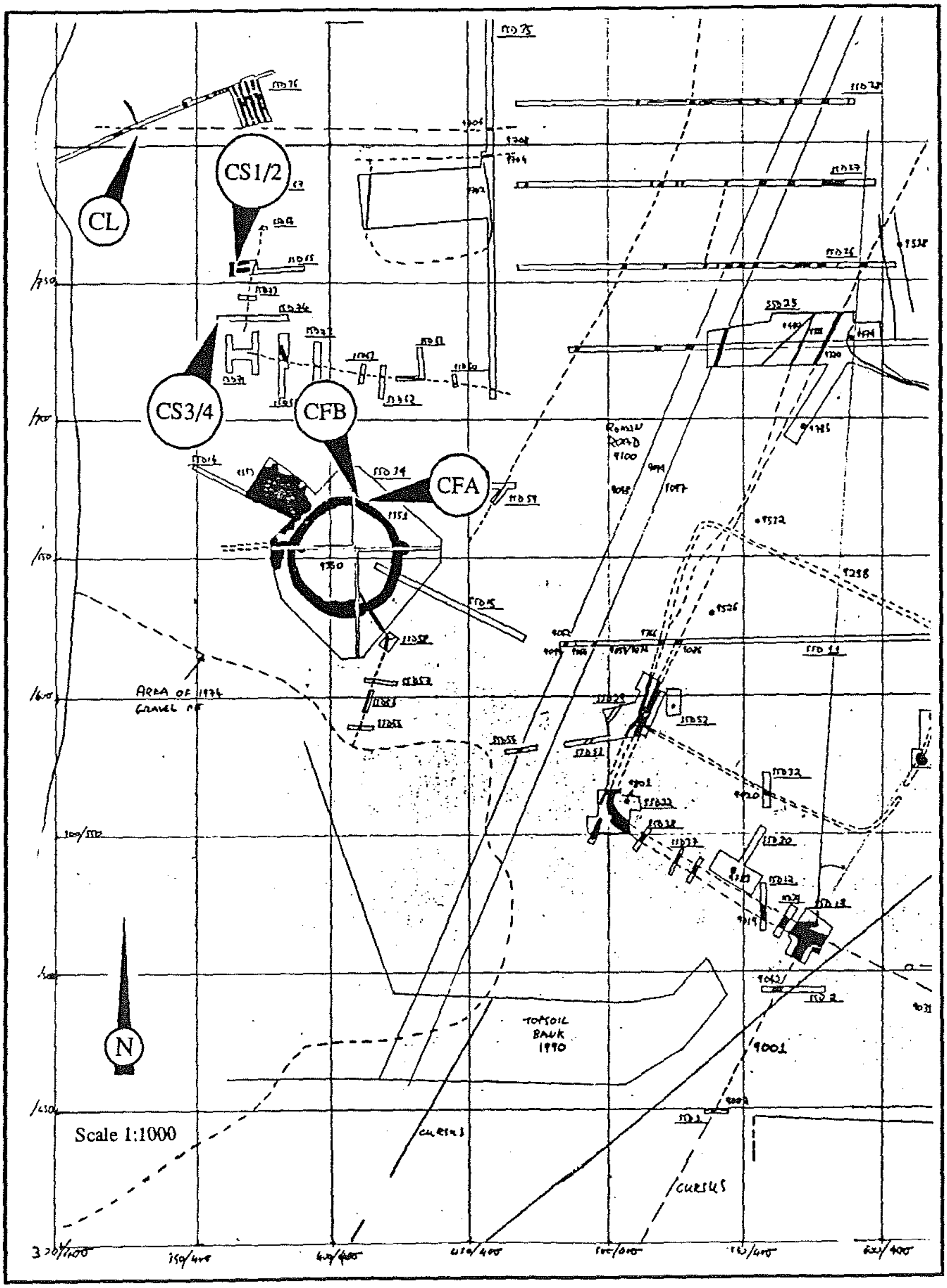

Figure 1
General locations of the three calcareous features.

4. The Calcareous Subsoils

4.1 Sampling Details

Two locations were chosen for sampling these features and in both cases, a sample was collected from the calcareous zone and the normal subsoil zone immediately adjacent. The samples were :-

CS1 - Calcareous subsoil at 369/753
CS2 - Normal subsoil from 0.5m along section Westwards.

CS3 - Calcareous subsoil at 363/736
CS4 - Normal subsoil from 0.5m along section Westwards.

Plate 2 shows a pre-sampling view of CS3/CS4, and highlights the abruptness of the change from calcareous to non-calcareous subsoil at either side of the feature.

Plate 2
A typical exposure of the calcareous subsoil patches. CS3/CS4.

4.2 Laboratory Analyses

The samples were split and one half was treated with HCl to remove the carbonates. These are referred to by a B suffix and the untreated soils by an A. Both were then subjected to particle-size analysis by sieves and Sedigraph. The A samples had their 125 - 63um fractions retained for heavy mineral analysis. Table 1 shows the percentages of material remaining after acid-treatment of the 4 samples. These figures are partly distorted, because the soils usually contained some chalk fragments which were lost along with the secondary carbonate enrichment.

CS1	(Calcareous)	- 83.5%
CS2	(Normal)	- 91.1%
CS3	(Calcareous)	- 79.6%
CS4	(Normal)	- 93.8%

Table 1
Percentages of material remaining after HCl treatment of the CS samples.

Figure 2 (overpage) shows the results of the particle-size analyses, with HCl - treated soils (B suffix) represented as dotted lines. These curves are a standard representation of the full range of mineral particle sizes found in each sample, and a discussion of of interpretation methods can be found in Canti (1991). By comparing the acid-treated (B) soils with their eqivalent A parent, it can be seen that the acid-treatment had suprisingly little effect on the particle size make up in most cases - presumably due to the presence of carbonate cemented pseudo-particles evenly spread along the size range. However, it is only with the acid-treated samples that we can be certain of examining a truly unbiased comparison between the texture of the $CaCO_3$ enriched and the normal samples of these soils.

Figure 3 shows the acidified curves only, and two distinct texture groupings are immediately apparent, corresponding to the two pairs of samples. Although there are some subtle variations along the curves, the chief difference is the considerably higher stone content in the soil surrounding the calcareous features (CS2B and CS4B).

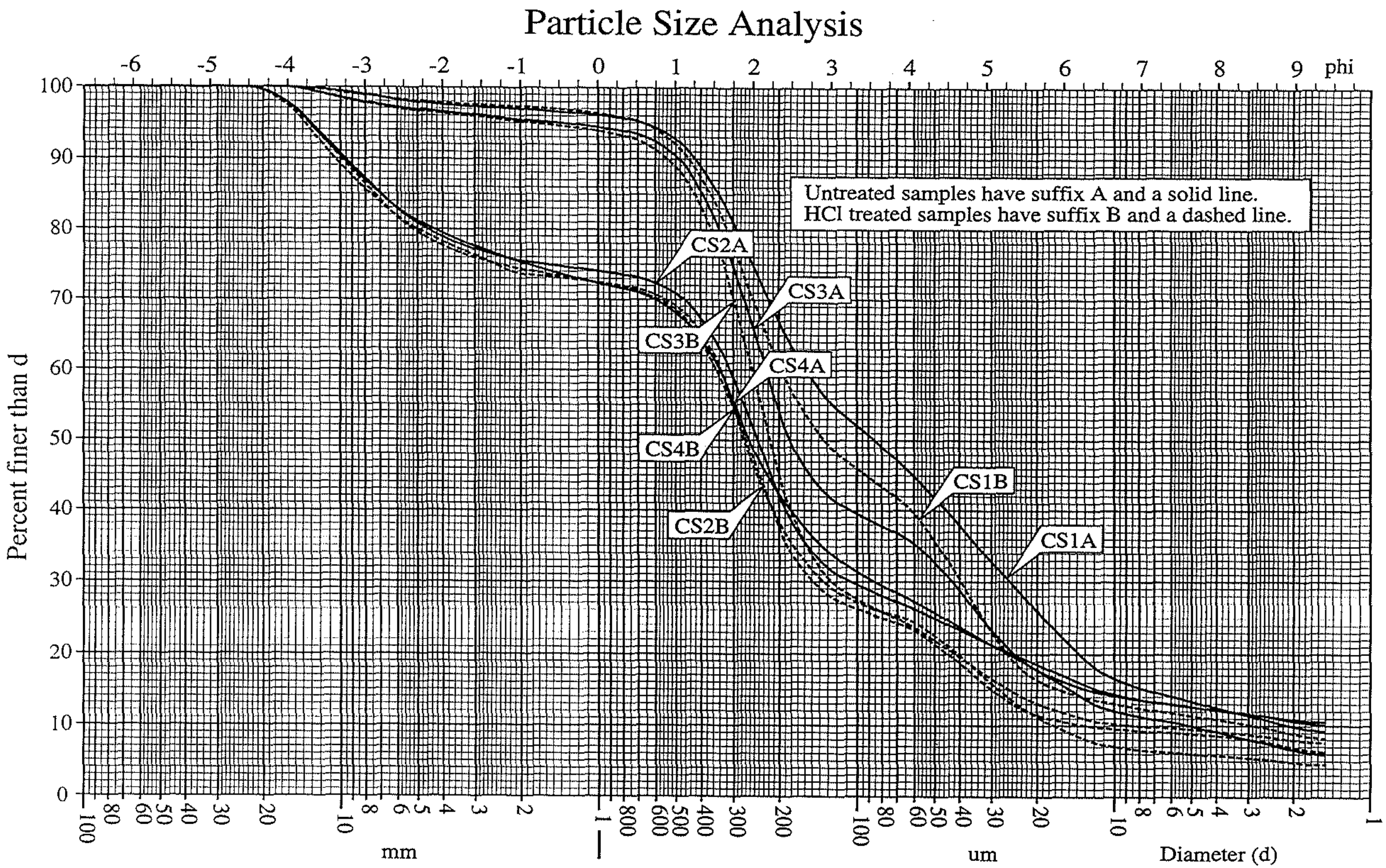

Figure 2.
All the samples from the calcareous subsoil sites.

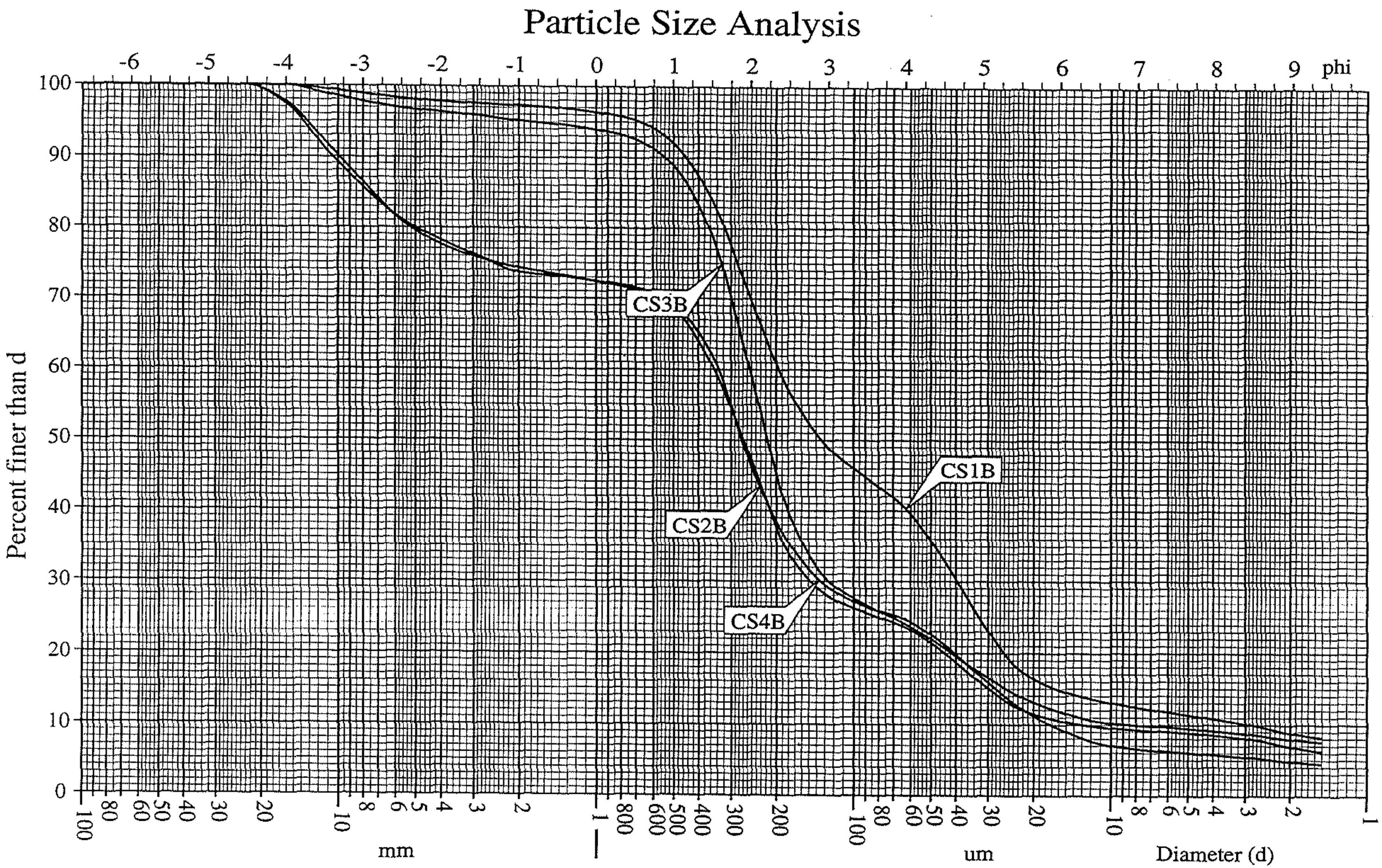

Figure 3.
All the HCl-treated soils from the calcareous subsoil sites.

Heavy mineral analysis provides a second sediment character - isation technique to act as an overlay for the information provided by particle size analysis. It involves extraction of the minerals heavier than Tetrabromoethane (S.G.= 2.95) by centrifugation, and their identification by optical microscopy. Around 20 groupings can be confidently identified and the percentages can then be compared to assess possible source variations.

Extractions were carried out from the 125-63um fraction of the untreated (A) samples. The full percentages are presented in Table 2 and summarised in histograms of the major minerals (those attaining >5% in any sample in this report) on Figure 4.

Mineral	CS1A	CS2A	CS3A	CS4A
Zircon	27.7	37.7	22.9	34.1
Rutile	4.1	5.2	9.8	10.8
Anatase	0.0	0.0	0.5	0.0
Titanite	1.4	0.9	1.9	2.2
Tourmaline	7.7	3.8	7.9	5.4
Apatite	5.0	5.2	2.3	5.8
Garnet	18.2	22.2	17.3	17.9
Staurolite	2.3	2.8	3.7	3.1
Kyanite	0.0	1.4	1.9	0.0
Orthopyroxenes	0.9	0.0	0.5	0.0
Clinopyroxenes	3.6	1.4	3.7	0.9
Clear Amphiboles	0.0	0.0	0.0	0.0
Green Amphiboles	15.5	8.5	12.2	7.6
Brown Amphiboles	0.0	0.5	0.9	0.9
Clinozoisite	4.5	1.9	4.2	3.1
Epidote	2.3	2.8	1.9	0.4
Chlorite	1.8	0.5	2.8	0.4
Unidentified	5.0	5.2	5.6	7.2

Table 2
Full heavy mineral percentages from the 125-63um fraction of the CS samples.

The heavy mineral percentages are similar but the slight observable differences are apparently systematic across the sample pairs. The calcareous subsoils (CS1A and CS3A) both have higher green amphibole content, while the surrounding soil tends to be richer in zircon and garnet. The differences are partly masked by between-pair variations notably in rutile content, but the calcareous soils' slightly higher chlorite content should be noted here as it appears to be more significant amongst the CL samples in section 6.

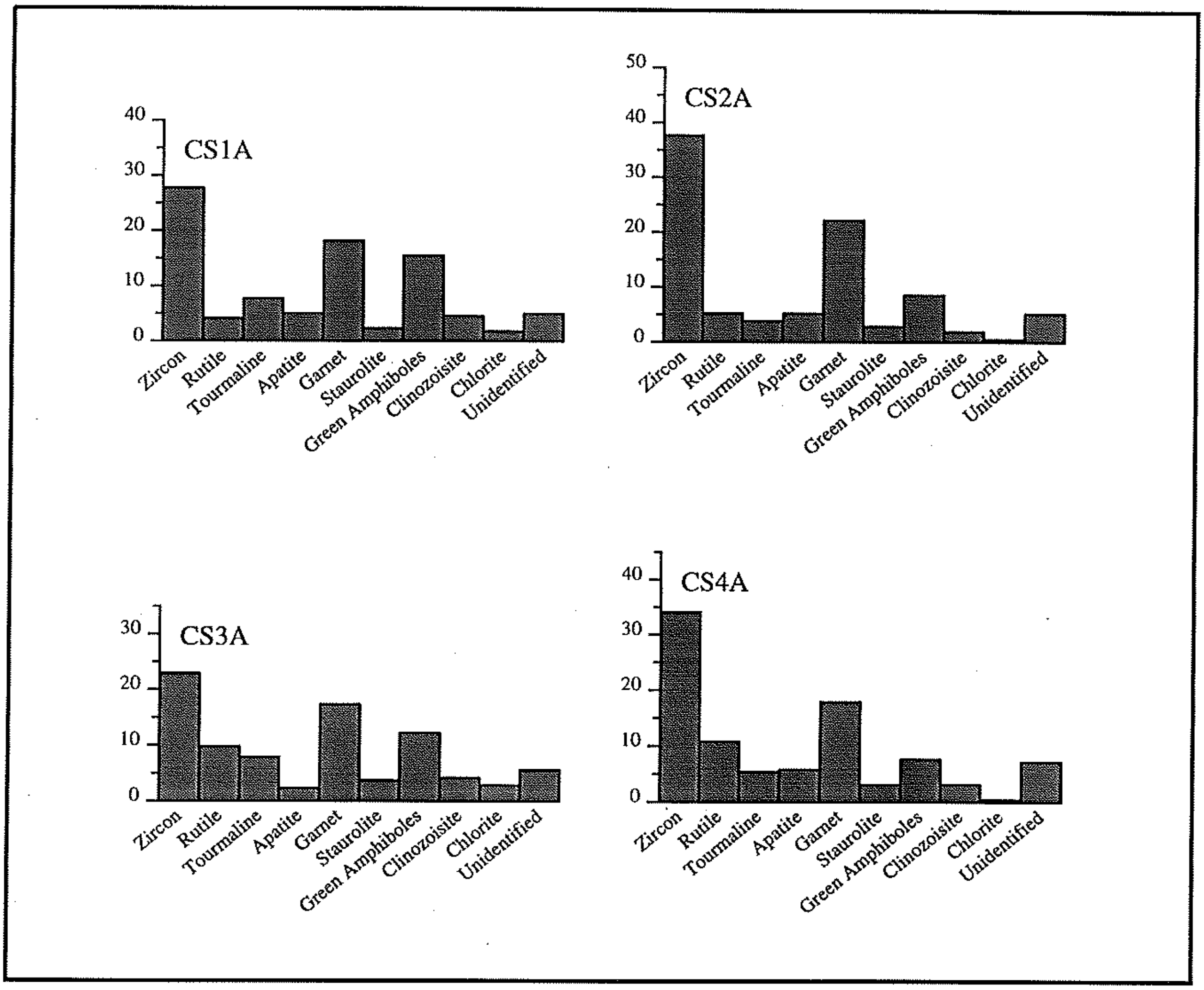

Figure 4
Percentages of the major minerals in the CS samples.

4.3 Discussion

The calcareous subsoil patches clearly have a significantly finer texture than the adjacent soil. With this change in texture there is a slightly modified mineralogy, involving increases in green amphibole and possibly chlorite content. However, in both tests, it was obvious that the bulk of the sediments were from one depositional system. Two possible broad hypotheses can be erected to explain these differences :-

1) The river-gravels have slightly varied mineralogies associated with different size-grades. Post-depositional effects (e.g ice-wedges) allowed a plug of fine sediment to penetrate the coarse surrounding gravel and this has subsequently acted as a channel for increased evaporation or some other hydrological effect perhaps bringing up calcium from the Oxford clay below.

2) The mineralogical and particle-size differences are the result of human activity, involving imported $CaCO_3$ (explaining their mineralogical variation) or imported sediment. In the latter case, the importation could only be from within a local context.

Neither hypothesis is simple. In the first case, the lack of a suitable explanation for the natural effect shown on Plate 1 hampers an understanding of the type of hydrological effect that might cause the carbonate accretion. If Plate 1 could be definitely ascribed to post-depositional calcification, then the only the fine sediment patches need to be explained, since it is apparent that they do effect a $CaCO_3$ concentration regardless of how. It does not seem to be necessary for the fine sediment to penetrate through to the Oxford clay. Perhaps the mechanism is to be found in a relationship between the water-table and the fine sediment?

In the second case, the sheer number of these features seems to weigh against a human cause. They were found in various parts of the site in some places more concentrated (as at the CS sites) and in others, more diffuse and taking up larger areas.

5. The Calcareous Ditch Fill

5.1 Sampling Details

Samples were collected from two sections of the ditch fill:-

At 414/668

CFA1 Non-calcareous outer parts of the fill.
CFA2 Calcareous central portion of the fill.
CFA3 Thin-section of the boundary between calcareous and non-calcareous fill.
CFA4 Thin section of the pure calcareous fill.
CFA5 Comparative soil material from outside the ditch-fill (i.e the subsoil into which the ditch was dug.)

At 411/670

CFB1 Non-calcareous ditch-fill.
CFB2 Calcareous central portion of the fill.

Plate 3 shows the section at 414/668 with sampling tins for CFA3 and CFA4 in position.

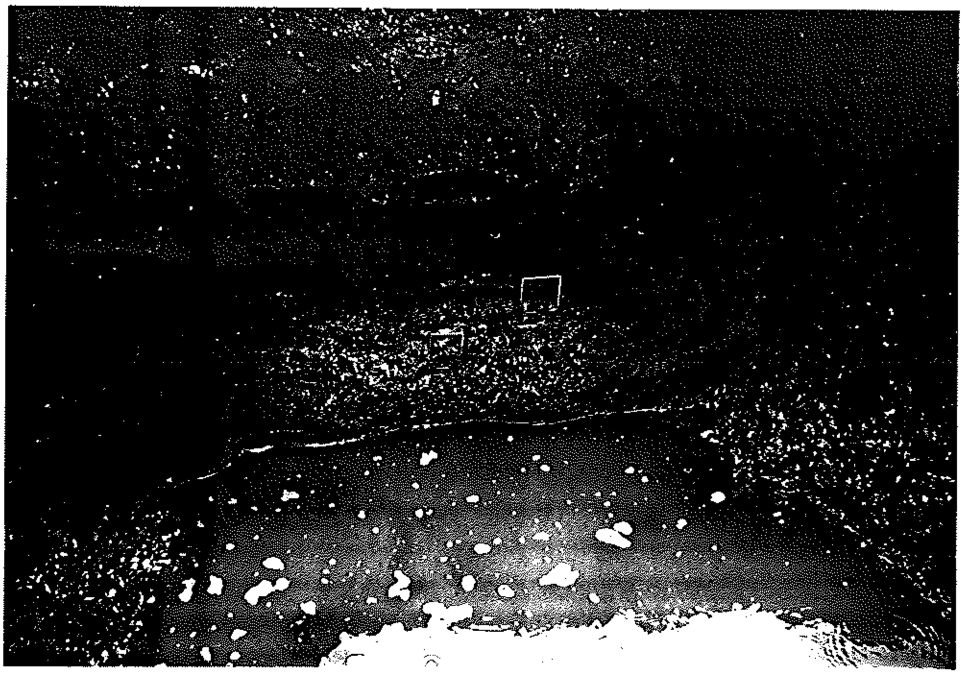

Plate 3
Sampling tins for CFA3 and CFA4 in position.

5.2 Laboratory Analyses

All laboratory methods were the same as for the subsoils (see 4.2). Table 3 shows the percentages of material remaining after acid treatment of the 4 ditch-fill bulk samples.

CFA1	(Non-calcareous)	98.1%
CFA2	(Calcareous)	53.7%
CFB1	(Non-calcareous)	98.3%
CFB2	(Calcareous)	65.8%

(CFA5 was not acid-treated as it was carbonate free).

Table 3
Percentages remaining after acid treatment of the CF samples.

The particle size analyses of this sample set are shown on Figure 5. The obvious disparities between these samples' curves are largely the result of carbonate cemented "pseudo-stones" that resisted normal disaggregation techniques. This leads to a wide variation between 500um and 3mm, particularly with CFA2A and CFB2A (i.e the untreated calcareous fills). The other main feature of note is the extreme difference between the ditch fill samples and the surrounding subsoil CFA5.

In order to simplify the assessment of the curves, the acid treated samples only are shown on Figure 6. With the aggregates now dissolved, the ditch fill curves are similar enough to be considered homogenetic, bearing in mind that fluvial deposition tends to produce localised variation in percentages within a fairly close sorting regime. Thus it is the similarities in the steep parts of the curves (400-200um) that provide the clue to a

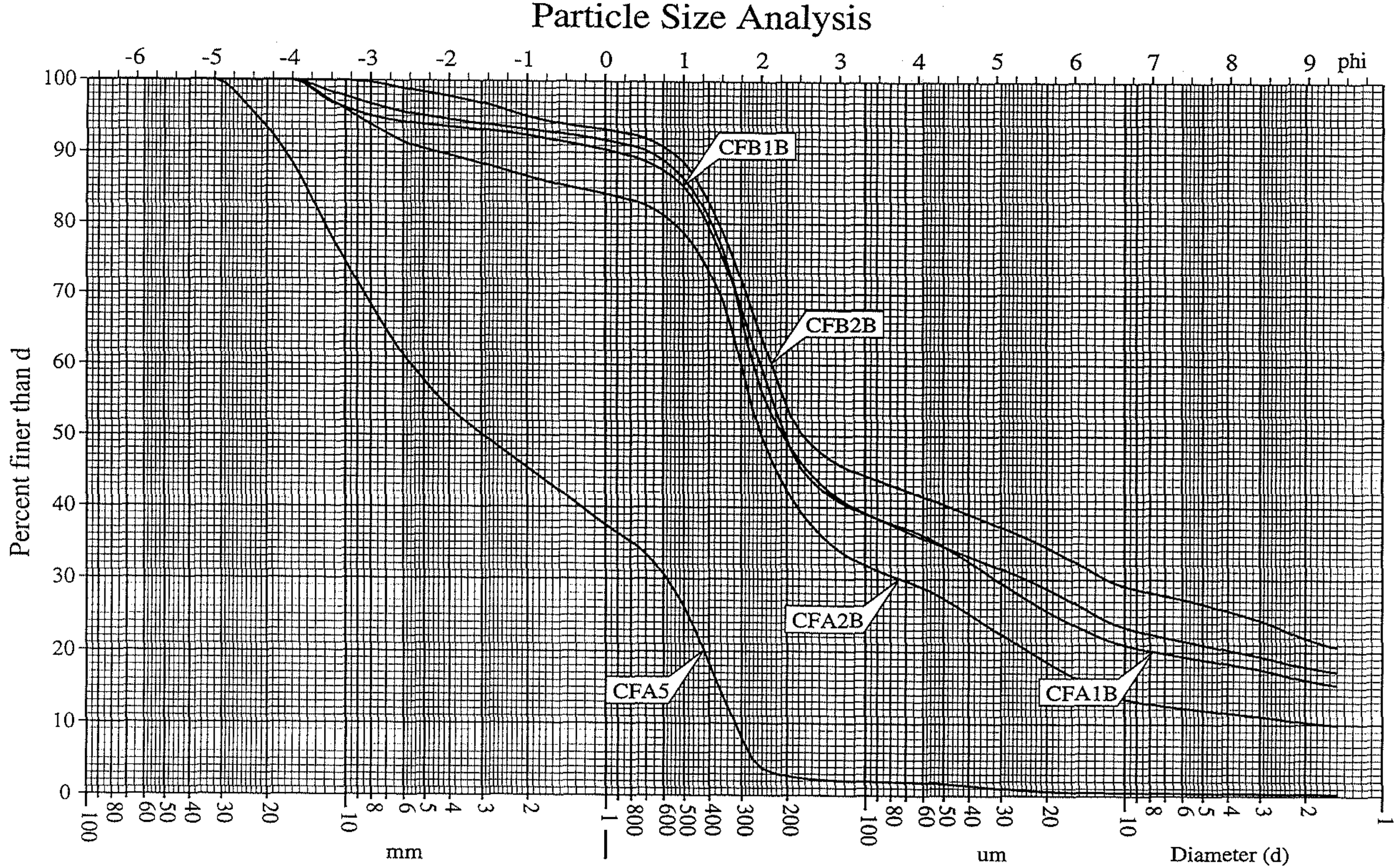

Figure 6.

Particle size analyses of all the HCl-treated ditch-fill samples and the surrounding soil.

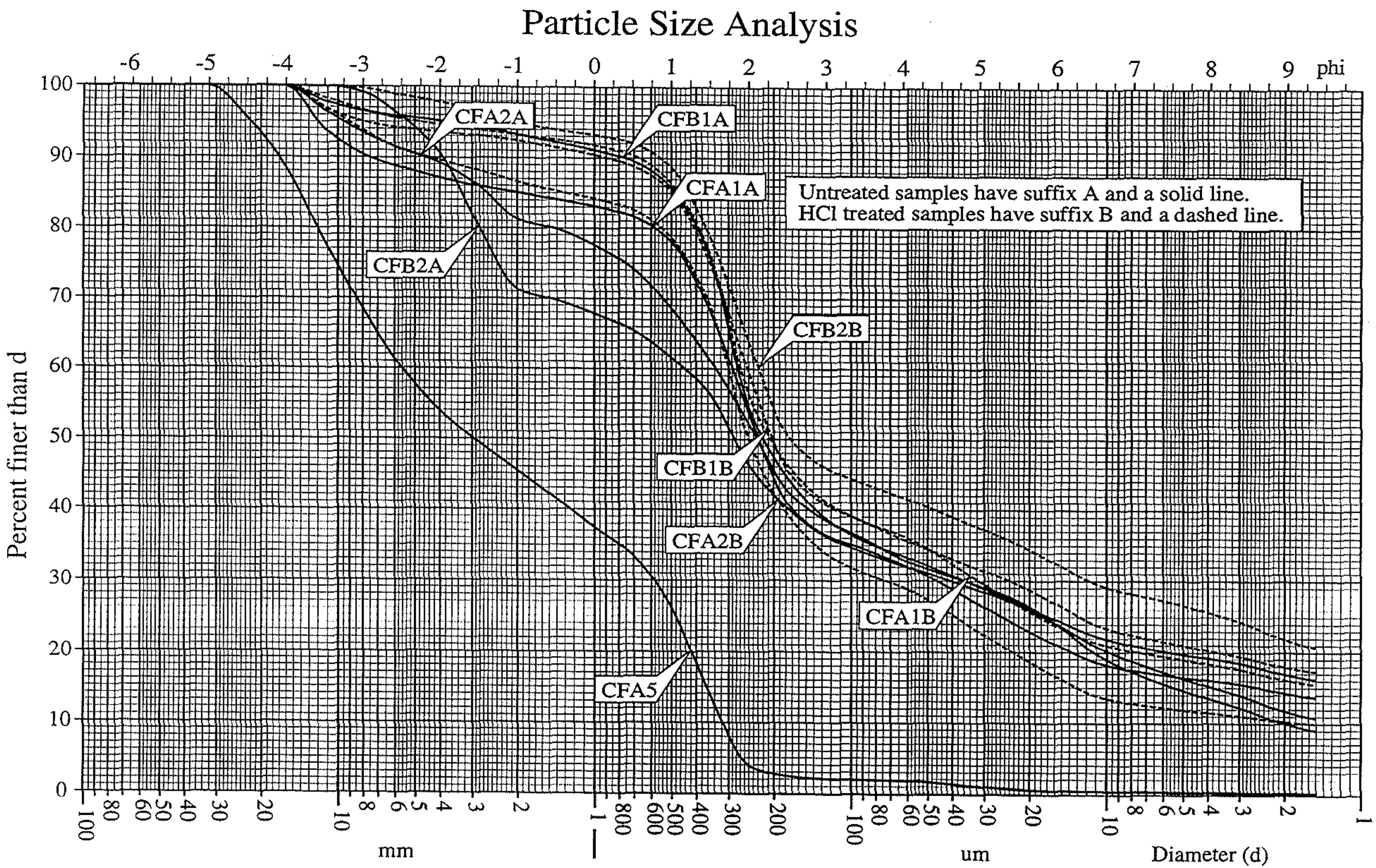

Figure 5.

Particle size curves for all the soils relating to the ditch-fills.

single source for the whole of the ditch fill. Even the radically different texture of the surrounding soil (CFA5) shows this same tendency towards sorting in the medium sand range.

Full heavy mineralogical analyses of all the CF samples are presented on Table 4 and summarised on Figure 7 as histograms of the major minerals.

The most noticeable difference is the higher garnet values in CFA2A (calcareous fill) and CFA5 (adjacent soil). There is clearly no systematic meaning here, since the ditch-fill is demonstrably different from the surrounding soil (see Figure 5). As with the particle-size analyses, their mineralogical diversity should be seen as part of the chance variation that occurs in a fluvial deposition sequence, due to changes in sorting as flowspeeds vary. In this context, it should be noted that the other calcareous fill sample (CFB2A) contains a mineralogy closely matched to the non - calcareous parts of the ditch exposure (CFA1A and CFB1A).

Mineral	CFA1A	CFA2A	CFA5	CFB1A	CFB2A
Zircon	25.9	17.4	16.4	30.2	24.8
Rutile	5.6	5.5	7.5	6.5	10.3
Anatase	0.0	0.0	0.0	0.4	0.0
Titanite	3.7	1.3	0.5	1.7	0.4
Tourmaline	5.1	9.3	6.1	5.2	9.9
Apatite	1.9	3.0	1.9	2.6	2.9
Garnet	28.2	39.4	43.9	22.8	26.4
Staurolite	8.3	3.4	4.2	2.6	6.2
Kyanite	2.3	0.8	1.9	2.6	2.5
Orthopyroxenes	0.0	0.0	0.9	0.4	0.0
Clinopyroxenes	3.7	3.0	2.8	3.4	1.7
Clear Amphiboles	0.0	0.0	0.5	0.0	0.0
Green Amphiboles	5.1	7.6	6.5	7.3	4.1
Brown Amphiboles	1.9	0.0	0.9	1.3	0.0
Clinozoisite	0.5	1.3	0.0	3.9	2.5
Epidote	2.3	2.1	0.9	2.6	1.2
Chlorite	0.0	0.0	0.0	0.0	0.4
Unidentified	5.6	5.9	5.1	6.5	6.6

Table 4
Full heavy mineral percentages from the 125-63um fraction of the CF samples.

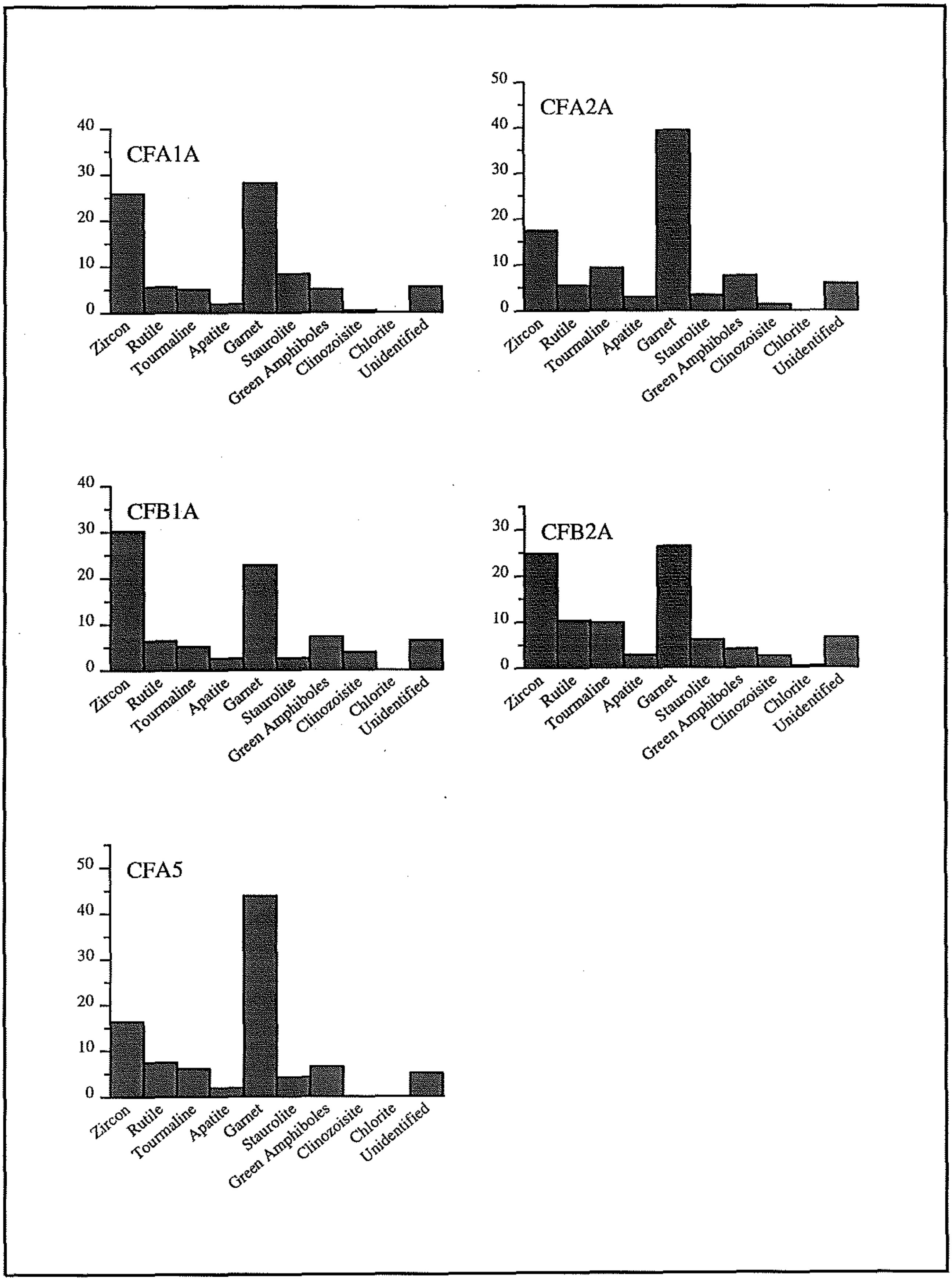

Figure 7
The main mineral percentages in the ditch-fill and adjacent soils.

Thin sections were produced from the two sample tins CFA3 and CFA4. These showed the calcareous zone to be a dense matrix infill, frequently showing amorphous calcium carbonate lining pores in the fabric. The transition from calcareous to non-calcareous matrix was very sharp, occurring over a distance of 1 - 2mm in sample CFA3 (see Plate 4).

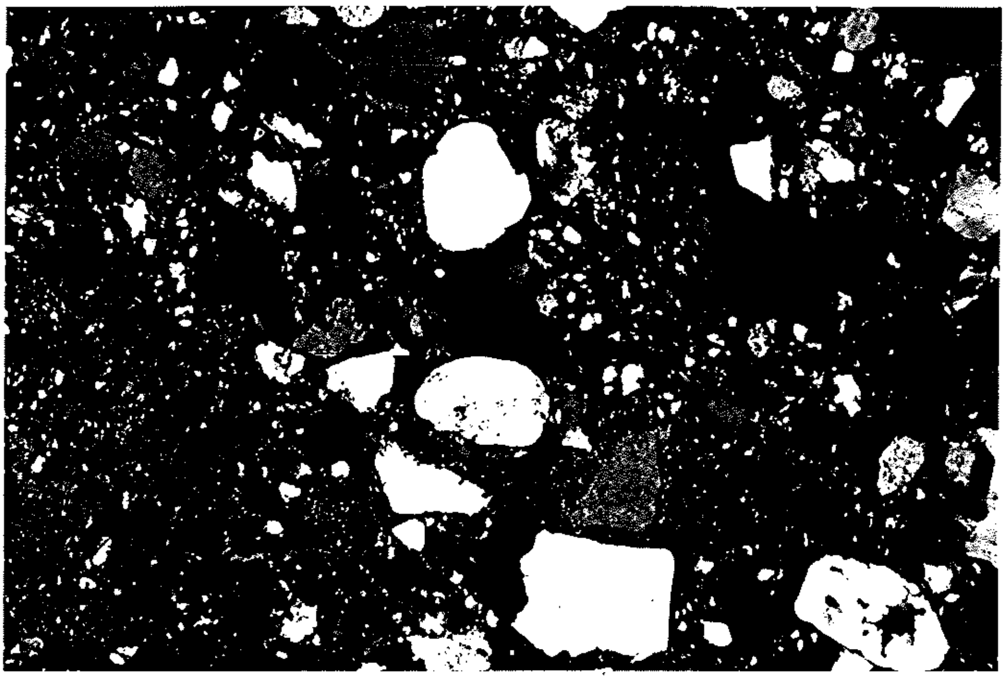

Plate 4

The calcareous/non-calcareous junction in CFA3 under cross-polarised light. Grey or white grains are quartz; black=voids. The calcareous infilling can be seen at the bottom left and red clay concentrations at the top left.

Outside the calcareous zone, the fabric had similar coarse components, but was characterised by fine layers of oriented clay lining channels and pores. This can be seen on Plate 4 towards the top left-hand corner. Since a slide of the subsoil outside the ring-ditch was not taken, it cannot be decided whether this was specific to the soils around calcareous features or not. However, reference to Plate 1 suggests that reddening is common in the fine fabric adjacent to calcareous zones. The relationship between red pedogenesis and calcareous environments is still the subject of much discussion (e.g Boero and Schwertmann 1989), but it is widely believed that red clays are the typical weathering product of limestone dissolution.

5.3 Discussion

Although there is significant variation in these samples, it is insufficient to support any hypothesis involving exotic inputs either to the ditch-fill (relative to the adjacent soil) or to the calcareous soil (relative to the rest of the ditch-fill). The calcareous and non-calcareous parts of this ditch-fill are clearly of one origin. They are different from the surrounding soil but only in the sense of having been transported a matter of metres from another river gravel stratum.

The reason for the calcareous material occupying only a central zone of the ditch fill is problematic. If the red-clay linings found in the slides represent the weathering product of the calcareous fabric, then it would be safe to assume that the current extent of the $CaCO_3$ infilling is less than at some time in the past. This could even imply that the whole ditch infill was at one time calcareous, and has been dissolving out ever since.

6. The Calcareous Layering

6.1 Sampling Details

At this site, the stratigraphy consisted of bands of calcareous material interleaved with non-calcareous layers. Plate 5 shows the Eastern face of the exposure and samples were collected from the uppermost and lowermost lime-bands. In each case, the non - calcareous soil directly beneath formed the comparative sample. Table 5 gives the sample details.

Plate 5
The Eastern face of the calcareous layering.

6.2 Laboratory Analyses

All laboratory methods were the same as for the subsoils (see 4.2). Table 5 shows the percentages of material remaining after acid treatment of the 4 banded pit samples. An anomaly that should be noted here is that the largest drop in weight was recorded in CL4 which was collected as a non-calcareous samples.

CL1 (Calcareous band)	78.6%
CL2 (Non - calcareous layer)	81.4%
CL3 (Calcareous band)	62.7%
CL4 (Non - calcareous layer)	46.6%

Table 5
Percentages remaining after HCl treatment of the CL samples.

The particle size analyses of these samples are shown on Figure 8. CL2 is a typical of the Godmanchester soils seen so far, but the others show anomalies. CL4A appears to have had a great deal of calcareous sand, which dissolved out to leave a much finer curve for CL4B. This may go some way to explaining the large drop in weight after acidification of this supposedly non-calcareous sample.

The other two unusual samples (CL 1 and 3) are best viewed on Figure 9 (acid-treated curves only). Here, it can be seen that they are considerably freer of stone and coarse sand than the typical soil represented by CL2B. In this respect, they tend to resemble the two calcareous subsoil samples on Figure 3. CL3B is especially anomalous, since it's major sorting is occurring in the 100 - 20um range. This makes it more typical of a modern river alluvium and it seems likely that the Pleistocene gravels have in some way been contaminated by the present river at this part of the site.

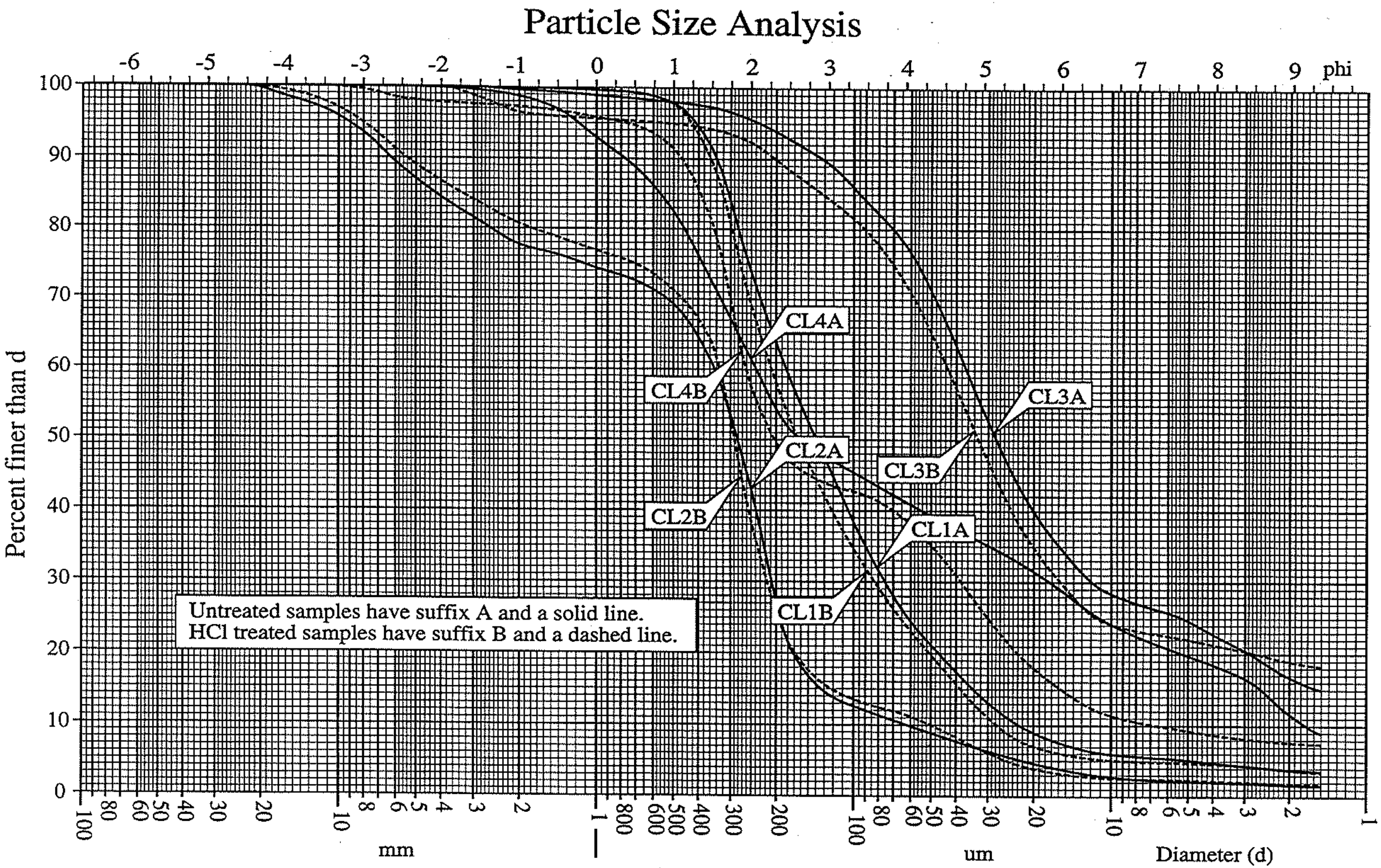

Figure 8.

Particle size analyses of all the samples from the layering.

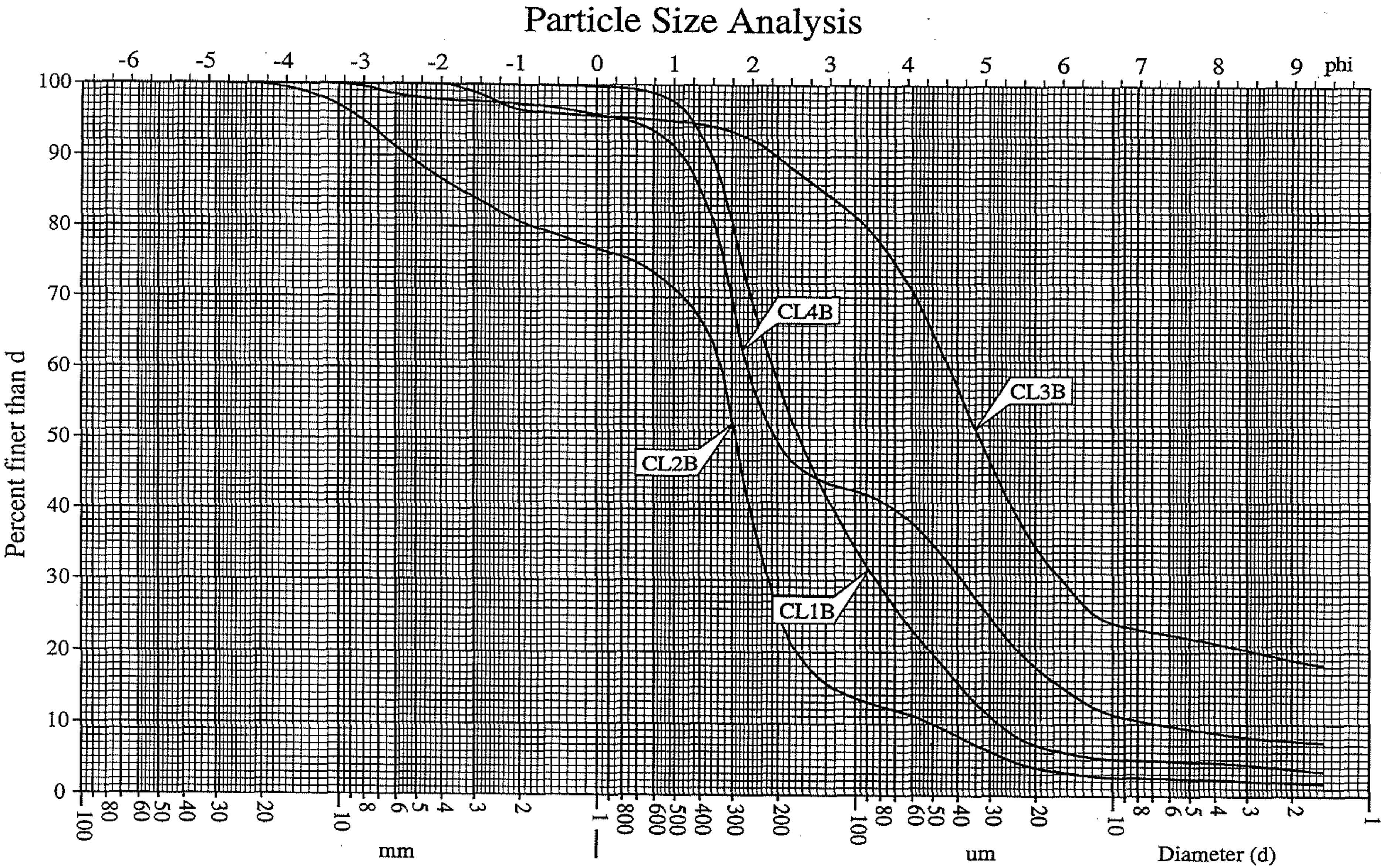

Figure 9.

Particle size analyses of all the HCl-treated CL samples.

Full heavy mineralogical analyses of all the CL samples are presented on Table 6 and summarised on Figure 10 as histograms of the major minerals.

Mineral	CL1A	CL2A	CL3A	CL4A
Zircon	19.7	36.4	17.0	41.9
Rutile	8.0	8.9	5.0	7.6
Anatase	0.0	0.0	0.0	0.0
Titanite	1.9	0.9	1.8	1.0
Tourmaline	11.7	2.8	6.9	4.3
Apatite	8.9	6.1	6.4	1.9
Garnet	8.5	23.4	12.8	19.5
Staurolite	4.2	3.3	1.8	2.4
Kyanite	0.9	0.9	1.4	1.4
Orthopyroxenes	0.5	0.0	0.0	1.0
Clinopyroxenes	3.8	1.9	4.1	2.4
Clear Amphiboles	0.5	0.5	0.5	0.0
Green Amphiboles	8.9	6.1	17.0	8.1
Brown Amphiboles	0.9	0.5	1.4	0.0
Clinozoisite	5.6	1.4	6.4	0.5
Epidote	0.5	0.5	2.3	0.0
Chlorite	9.4	0.9	9.2	2.4
Unidentified	6.1	5.6	6.0	5.7

Table 6
Full heavy mineral percentages from the 125-63um fraction of the CL samples.

The calcareous samples show a marked change from the typical distribution seen so far, and the trends detected in the CS samples appear to be developing further strength. The by now familiar high garnet/zircon "background" mineralogy is exemplified in the two non-calcareous samples (CL2A and CL4A) despite the anomalies of CL4A's $CaCO_3$ content and particle size. The calcareous bands, on the other hand, contain much higher values of chlorite, clino - zoisite, green amphiboles and tourmaline.

6.3 Discussion

A definite relationship has now emerged between the finer soil textures and the mineralogy. The better sorted and stone-free soils tend to contain more chlorite, green amphiboles, clinozoisite and tourmaline. Looking back to the CS samples, we can see that both tourmaline and clinozoisite were greater in the calcareous samples (although the amounts were smaller than the green amphiboles and chlorite relationship - see page 8).

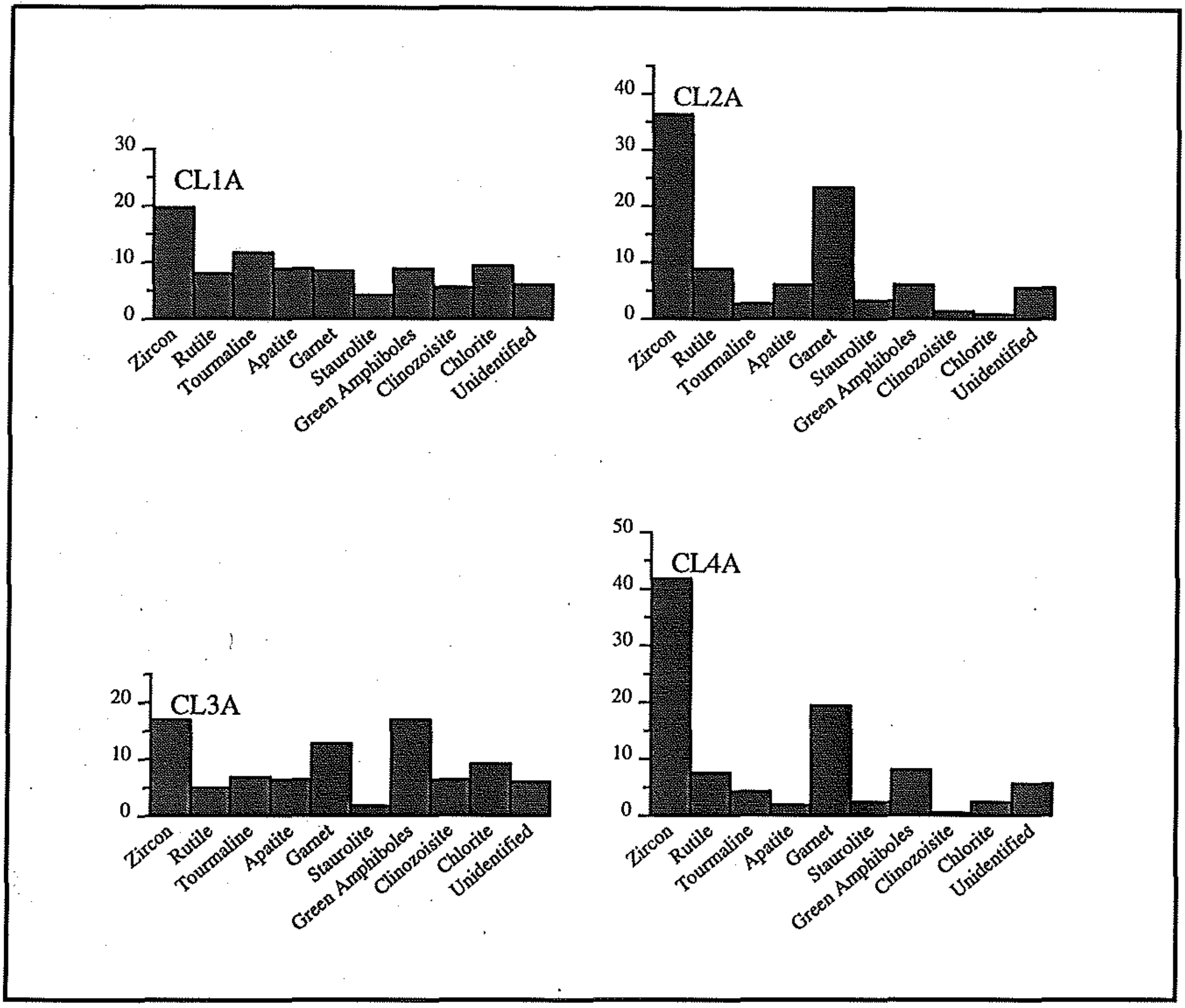

Figure 10
The main mineral percentages in the layers.

7. Overview

The experimental work has established the following points about the three types of calcareous features at Godmanchester :-

1) Two of the calcareous features (the subsoil patches and the layering) are formed of soil fabrics that are considerably finer than adjacent non-calcareous soil. The nature of this "fineness" varies, but is associated with a low stone content and often a greater silt content.

2) The fabric of the ditch-fill feature is not comparable with the other two types. It is similar to the adjacent non-calcareous soil.

3) The fine fabric soils are associated with a low garnet/zircon and high chlorite/green amphibole mineralogy in the 125-63um range. The coarser soils show the opposite tendency (see Fig 11).

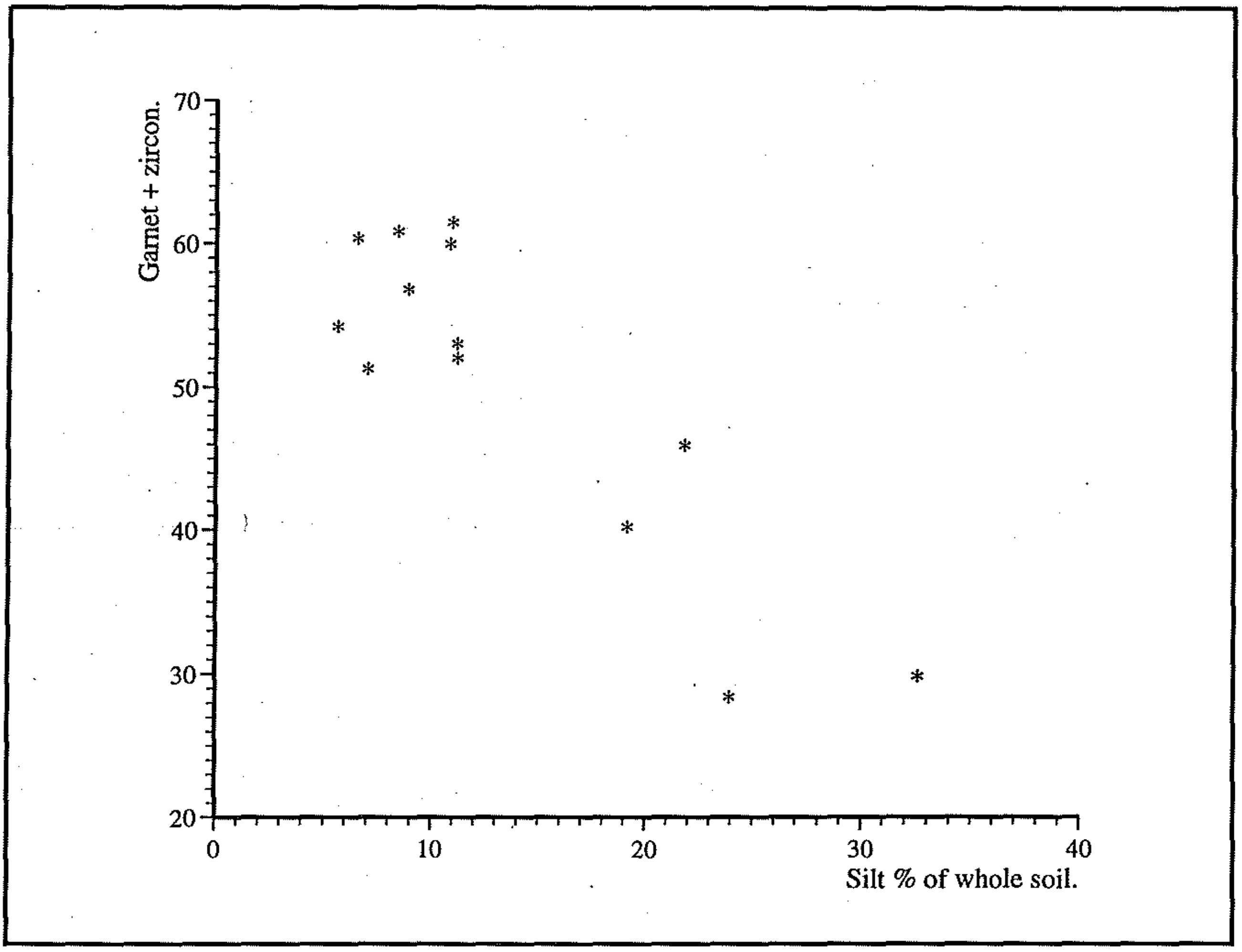

Figure 11
Silt % against zircon + garnet for all the Godmanchester samples.

The key question to be asked of the fine fabric soils is whether they are in part exotic to the site. This could involve explaining the lime as deliberately brought to Godmanchester for some manufacturing process. The layered area is clearly a man-made feature not only from its stratigraphy, but also from the numbers of buried baulks and pits that were found nearby. An industrial explanation would, therefore suit it well. However, if this rationale were applied to the subsoil features, the implication would be that vast areas of the site had been contaminated with the waste. It is impossible to reconcile this view with the richness of the archaeology and the obviously natural examples of $CaCO_3$ concentration that do exist.

An explanation for the mineral variations found in this study might be that the finer fractions of the river gravels sediment are richer in chlorite and green amphiboles. These minerals would then not have to be viewed as imported, but more as a species change that occurred when flowspeeds of deposition were slower perhaps sourcing a different parent rock catchment. Further counting is not proposed, but a cursory study of the 63-20um fraction of the CF samples has shown high chlorite and green amphibole concentrations, even in these coarse soils. These minerals are likely also to characterise the modern alluvial sedimentation; this would mean that whatever process was being carried out in the layered area, locally imported river water might be contributing to the amphibole/chlorite concentrations found.

Using these premises it is possible to explain the similar mineralogies of the calcareous subsoil patches and the layered area broadly as the result of local slow-water deposition. In the former case they are entirely natural, while the latter are partly the result of water imports or the deliberate use of fine sediment to manufacture the product. The $CaCO_3$ for the layering could therefore have been imported; but the subsoil features must have concentrated it from the groundwater (or preserved it from a pre-existing calcareous soil) by virtue of their finer texture. No mechanism for the concentration effect is proposed, but it would seem to be a rare phenomenon caused by the local occurrence of the calcareous Oxford clay under a thin deposit of variable gravels.

The calcareous ditch-fill is probably the most difficult of the three features. It shows no texture or mineralogy variations and yet is as clearly defined as both the fine-fabric examples. Its shape suggests the final remnant of a larger calcareous fill which has weathered down around much of the ring-ditch and now only remains as a small patch near the base in some places. The fill generally is from a different part of the site, suggesting deliberate emplacement. The calcium carbonate must surely be viewed as part of this process, since the fill's texture (unlike the subsoil patches) has no possible reason to act as a natural concentration focus.

There seem to be strong similarities between this ring-ditch fill, and one found at Haddenham in the 1984-1986 excavations by Chris Evans (not published). Soil work on site proved inconclusive (French - pers. comm.) but the geological stratigraphy (gravel over Oxford clay) appears to have been near-identical.

8. Conclusion

The preservation of the calcareous features at Godmanchester suggests an apparent underlying trend at the site. A combination of highly calcareous clay and overlying gravel seems to provide conditions that allow free carbonate to remain in the soil for longer periods than would normally be the case in a coarse-textured soil. Viewed geologically, the site is an enormous calcium well capped by a thin skim of gravel. Whenever evapotranspiration is in deficit, the soils must be suffused with $CaCO_3$-rich waters from below. In addition, the typical period of evapotranspiration surplus (i.e. winter) would be characterised by a high water table (see Plate 3) perched on the Oxford clay and enriched by it. Under these circumstances, $CaCO_3$ leaching proceeds very slowly, perhaps not happening at all in some years. It is suggested that special physical conditions produce the calcareous subsoil patches, but that both the other features described here are fundamentally man made, their persistence being due entirely to the extreme weakness of the soil leaching environment. The implication of this conclusion is that the calcareous nature of similar features, (whatever activities they imply) could well have disappeared on sites where the geology produces leached soil conditions.

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APPENDIX 1

Particle Size Analyses.
Values are weight% finer than diameter in left hand column.

Diameter	CS1A	CS1B	CS2A	CS2B
22.60mm	100.00	100.00	100.00	100.00
16.00mm	100.00	100.00	97.81	97.68
11.30mm	99.66	99.52	92.61	92.21
8.00mm	98.99	98.88	87.20	86.39
5.70mm	98.12	98.24	82.25	81.02
4.00mm	97.59	97.82	78.90	77.62
2.80mm	97.24	97.52	76.82	75.58
2.00mm	96.96	97.30	75.50	74.32
1.40mm	96.57	96.97	74.74	73.36
1.00mm	96.16	96.38	74.05	72.42
707.10um	95.31	95.37	73.20	71.27
500.00um	92.83	92.11	70.99	68.69
353.60um	86.06	84.04	64.48	60.51
250.00um	74.72	69.80	51.49	47.19
176.80um	63.15	56.66	38.03	33.54
125.00um	55.15	48.89	31.51	27.79
88.40um	50.55	44.61	28.74	25.54
62.50um	45.57	40.31	26.49	23.61
44.20um	39.74	32.90	24.09	19.99
31.30um	33.57	24.09	21.64	15.54
22.10um	27.61	17.33	19.24	12.01
15.60um	22.05	14.72	16.88	10.51
11.00um	17.25	13.34	14.74	9.69
7.80um	15.17	12.38	13.59	9.28
5.50um	13.80	11.60	12.82	8.96
3.90um	12.39	10.81	12.17	8.52
2.80um	11.17	9.99	11.53	7.96
2.00um	9.87	8.84	10.63	6.90
1.40um	9.14	8.14	10.09	6.20

Textural Details
These values are the normal weight percent in each of the class groups. See Appendix 2 class details.

	CS1A	CS1B	CS2A	CS2B
Coarse Sand	2.61	3.18	4.09	5.37
Medium Sand	28.38	34.42	40.26	44.28
Fine Sand	22.68	21.67	20.93	19.03
Total Sand (S)	53.67	59.27	65.28	68.67
Coarse Silt	19.47	23.99	10.11	15.94
Medium Silt	12.25	4.60	7.38	3.21
Fine Silt	4.43	3.05	3.15	2.90
Total Silt (Z)	36.15	31.64	20.64	22.05
Total Clay (C)	10.18	9.09	14.08	9.28
Texture	SL	SL	SL	SL

APPENDIX 1 contd.

Particle Size Analyses.
Values are weight% finer than diameter in left hand column.

Diameter	CS3A	CS3B	CS4A	CS4B
22.60mm	100.00	100.00	100.00	100.00
16.00mm	100.00	100.00	97.83	97.43
11.30mm	98.96	98.90	92.28	91.23
8.00mm	97.91	97.78	86.94	85.70
5.70mm	97.08	96.89	82.37	81.20
4.00mm	96.56	96.35	79.45	78.22
2.80mm	96.06	95.82	77.16	75.79
2.00mm	95.44	95.15	75.30	73.66
1.40mm	95.05	94.65	73.67	73.14
1.00mm	94.42	93.92	72.35	72.47
707.10um	93.50	92.67	71.11	71.64
500.00um	90.55	88.97	68.18	69.19
353.60um	81.64	78.95	61.48	62.07
250.00um	65.83	59.12	48.53	46.10
176.80um	49.00	39.07	39.58	35.11
125.00um	41.68	29.93	33.82	29.04
88.40um	38.59	26.58	30.29	26.36
62.50um	35.88	24.06	27.57	24.70
44.20um	30.65	20.67	24.66	21.13
31.30um	24.11	16.94	21.67	16.41
22.10um	18.71	13.78	18.66	12.13
15.60um	16.05	11.76	15.47	9.29
11.00um	14.44	10.41	12.47	7.28
7.80um	13.53	9.93	11.22	6.54
5.50um	12.85	9.61	10.29	6.13
3.90um	12.10	9.14	9.01	5.77
2.80um	11.47	8.63	7.83	5.39
2.00um	10.84	7.95	6.56	4.83
1.40um	10.50	7.53	5.84	4.49

Textural Details
These values are the normal weight percent in each of the class groups. See Appendix 2 class details.

	CS3A	CS3B	CS4A	CS4B
Coarse Sand	3.11	4.00	7.02	3.92
Medium Sand	40.46	48.83	36.78	44.05
Fine Sand	19.32	22.26	20.03	18.92
Total Sand (S)	62.89	75.08	63.83	66.88
Coarse Silt	18.51	11.13	12.51	17.89
Medium Silt	4.93	3.57	9.61	6.77
Fine Silt	2.30	1.86	5.33	1.90
Total Silt (Z)	25.75	16.56	27.45	26.56
Total Clay (C)	11.36	8.35	8.72	6.56
Texture	SL	SL	SL	SL

APPENDIX 1 contd.

Particle Size Analyses.
Values are weight% finer than diameter in left hand column.

Diameter	CFA1A	CFA1B	CFA2A	CFA2B	CFA5
22.60mm	100.00	100.00	100.00	100.00	95.50
16.00mm	100.00	100.00	100.00	100.00	88.47
11.30mm	93.97	94.05	96.61	97.07	77.98
8.00mm	90.38	91.20	93.51	93.86	68.45
5.70mm	88.58	90.07	91.18	91.13	60.23
4.00mm	87.10	89.25	89.22	89.63	53.90
2.80mm	85.91	88.51	85.88	88.11	49.31
2.00mm	85.09	87.89	81.28	86.63	45.45
1.40mm	84.09	87.25	79.89	85.27	41.40
1.00mm	83.17	86.52	77.62	84.24	37.48
707.10um	81.74	85.26	74.33	82.73	33.60
500.00um	78.17	81.51	68.67	78.74	26.20
353.60um	68.32	72.09	61.28	69.14	13.78
250.00um	53.83	54.19	52.26	49.90	3.82
176.80um	40.83	44.71	42.63	39.33	2.45
125.00um	36.46	39.82	38.52	33.88	2.08
88.40um	34.51	37.21	35.92	31.05	1.95
62.50um	32.37	35.40	33.10	29.13	1.87
44.20um	29.67	32.54	31.08	26.26	1.53
31.30um	26.71	29.11	29.31	22.88	1.08
22.10um	23.80	25.81	27.24	19.54	0.70
15.60um	21.04	23.07	23.98	16.50	0.53
11.00um	18.59	20.79	19.78	13.86	0.49
7.80um	17.42	19.57	17.11	12.75	0.44
5.50um	16.68	18.69	15.12	12.09	0.41
3.90um	16.07	17.82	13.45	11.51	0.38
2.80um	15.40	16.94	11.93	10.97	0.36
2.00um	14.31	15.73	10.05	10.31	0.32
1.40um	13.62	15.00	8.95	9.92	0.30

Textural Details
These values are the normal weight percent in each of the class groups. See Appendix 2 class details.

	CFA1A	CFA1B	CFA2A	CFA2B	CFA5
Coarse Sand	5.47	4.53	11.50	6.20	32.64
Medium Sand	42.52	41.59	32.65	44.98	61.36
Fine Sand	14.31	13.93	15.45	15.53	1.96
Total Sand (S)	62.30	60.05	59.61	66.71	95.95
Coarse Silt	10.64	11.52	7.76	11.73	2.66
Medium Silt	7.24	6.91	13.46	7.41	0.46
Fine Silt	3.00	3.64	6.81	2.25	0.21
Total Silt (Z)	20.89	22.06	28.03	21.39	3.33
Total Clay (C)	16.81	17.89	12.36	11.90	0.71
Texture	SL	SL	SL	SL	S

APPENDIX 1 contd.

Particle Size Analyses.

Values are weight% finer than diameter in left hand column.

Diameter	CL1A	CL1B	CL2A	CL2B
22.60mm	100.00	100.00	100.00	100.00
16.00mm	100.00	100.00	98.54	99.42
11.30mm	100.00	100.00	96.76	97.86
8.00mm	100.00	100.00	93.48	94.87
5.70mm	100.00	100.00	88.62	90.50
4.00mm	99.99	99.99	84.40	86.70
2.80mm	99.97	99.96	80.83	83.48
2.00mm	99.94	99.93	77.70	80.67
1.40mm	99.83	99.84	76.22	78.71
1.00mm	99.65	99.73	74.37	76.88
707.10um	99.33	99.39	72.63	75.04
500.00um	97.88	97.74	69.29	71.27
353.60um	91.52	89.68	60.92	63.76
250.00um	73.95	69.21	42.99	38.42
176.80um	58.80	52.86	20.73	21.07
125.00um	46.19	40.91	14.20	15.19
88.40um	34.52	31.56	11.92	12.91
62.50um	25.36	23.94	10.05	11.42
44.20um	19.10	17.56	8.27	9.10
31.30um	13.72	11.70	6.55	6.44
22.10um	9.76	7.66	5.04	4.31
15.60um	7.49	6.03	3.84	3.24
11.00um	6.12	5.22	2.91	2.63
7.80um	5.62	4.94	2.44	2.45
5.50um	5.28	4.80	2.18	2.39
3.90um	4.75	4.58	2.03	2.21
2.80um	4.28	4.29	1.89	2.04
2.00um	3.84	3.75	1.66	1.85
1.40um	3.60	3.39	1.52	1.73

Textural Details

These values are the normal weight percent in each of the class groups. See Appendix 2 class details.

	CL1A	CL1B	CL2A	CL2B
Coarse Sand	1.08	1.06	8.17	8.81
Medium Sand	35.01	40.78	57.52	59.57
Fine Sand	39.30	34.94	21.65	17.74
Total Sand (S)	75.39	76.78	87.34	86.13
Coarse Silt	15.62	16.18	6.65	9.01
Medium Silt	3.60	2.18	3.14	1.86
Fine Silt	1.56	1.10	0.73	0.72
Total Silt (Z)	20.77	19.47	10.52	11.59
Total Clay (C)	3.84	3.75	2.14	2.29
Texture	LS	LS	S	LS

APPENDIX 1 contd.

Particle Size Analyses.
Values are weight% finer than diameter in left hand column.

Diameter	CL3A	CL3B	CL4A	CL4B
22.60mm	100.00	100.00	100.00	100.00
16.00mm	100.00	100.00	100.00	100.00
11.30mm	100.00	100.00	100.00	100.00
8.00mm	100.00	100.00	100.00	99.59
5.70mm	100.00	100.00	100.00	98.35
4.00mm	100.00	100.00	99.91	97.82
2.80mm	99.97	98.48	99.57	97.55
2.00mm	99.63	96.44	98.79	97.29
1.40mm	99.36	95.90	96.88	96.70
1.00mm	98.93	95.60	92.96	95.82
707.10um	98.49	95.31	88.90	94.71
500.00um	97.98	94.92	82.52	91.47
353.60um	97.29	94.18	72.42	80.96
250.00um	95.55	92.35	61.53	57.58
176.80um	92.78	88.41	51.46	46.89
125.00um	89.43	84.39	47.37	43.63
88.40um	83.91	79.71	44.24	42.05
62.50um	77.77	72.14	41.19	38.71
44.20um	67.15	61.07	38.32	32.93
31.30um	54.15	48.38	35.51	25.80
22.10um	42.53	37.33	32.50	19.37
15.60um	34.70	29.87	28.88	15.02
11.00um	29.13	24.71	24.95	11.87
7.80um	27.01	23.21	22.36	10.44
5.50um	25.35	22.32	20.25	9.54
3.90um	22.58	21.22	18.34	8.70
2.80um	19.85	20.18	16.00	8.11
2.00um	16.73	18.93	11.62	7.65
1.40um	14.92	18.21	8.73	7.43

Textural Details
These values are the normal weight percent in each of the class groups. See Appendix 2 class details.

Coarse Sand	1.38	1.34	12.71	3.81
Medium Sand	4.42	5.43	32.35	45.39
Fine Sand	17.14	19.58	13.59	11.55
Total Sand (S)	22.95	26.35	58.66	60.76
Coarse Silt	36.87	37.39	9.38	20.76
Medium Silt	14.18	12.84	10.94	8.44
Fine Silt	9.21	3.78	9.27	2.18
Total Silt (Z)	60.26	54.02	29.58	31.38
Total Clay (C)	16.79	19.63	11.76	7.86
Texture	SZL	CL	SL	SL

APPENDIX 1 contd.

Particle Size Analyses.
Values are weight% finer than diameter in left hand column.

Diameter	OXA	OXB
22.60mm	100.00	100.00
16.00mm	100.00	100.00
11.30mm	100.00	100.00
8.00mm	100.00	100.00
5.70mm	100.00	100.00
4.00mm	100.00	100.00
2.80mm	100.00	100.01
2.00mm	100.00	99.90
1.40mm	99.96	99.80
1.00mm	99.92	99.69
707.10um	99.89	99.66
500.00um	99.85	99.63
353.60um	99.79	99.58
250.00um	99.68	99.51
176.80um	99.58	99.49
125.00um	99.42	99.46
88.40um	99.00	99.44
62.50um	98.52	99.42
44.20um	97.46	98.96
31.30um	95.83	98.11
22.10um	93.46	96.87
15.60um	87.60	94.12
11.00um	76.45	88.84
7.80um	68.37	84.11
5.50um	61.34	79.39
3.90um	54.69	74.96
2.80um	49.16	70.62
2.00um	43.50	64.99
1.40um	40.40	61.64

Textural Details
These values are the normal weight percent in each
of the class groups. See Appendix 2 class details.

Coarse Sand	0.13	0.25
Medium Sand	0.25	0.15
Fine Sand	1.20	0.11
Total Sand (S)	1.58	0.51
Coarse Silt	5.80	2.95
Medium Silt	29.56	15.92
Fine Silt	19.56	15.56
Total Silt (Z)	54.92	34.44
Total Clay (C)	43.50	65.05
Texture	ZC	C

APPENDIX 2

Particle size classes and textural assessment.

Size Classes :-

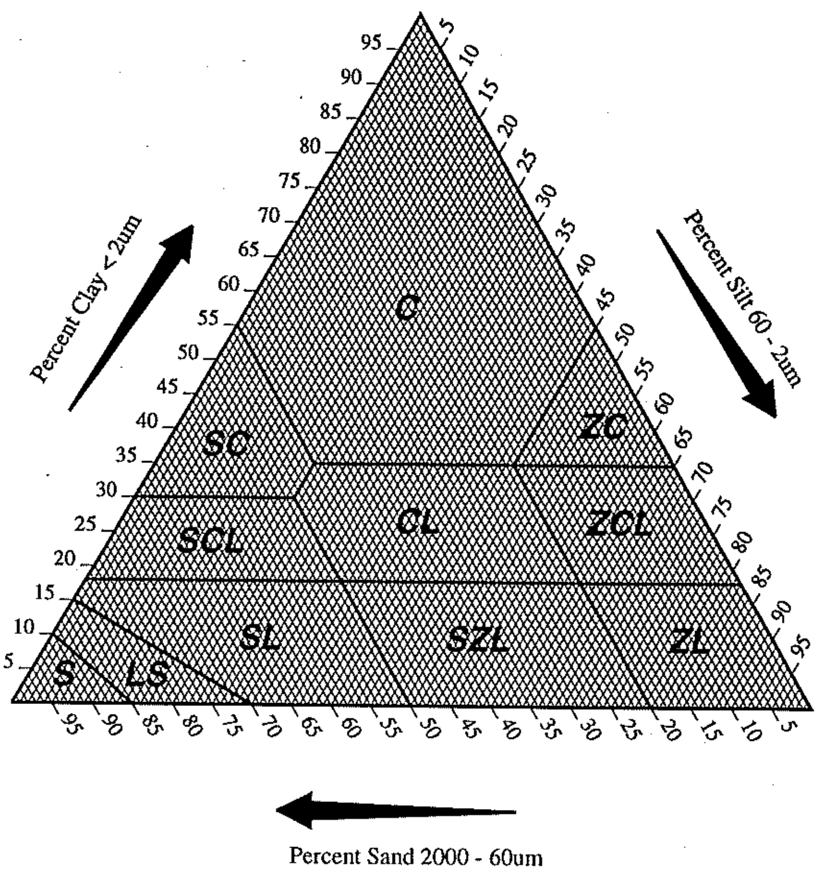
SAND (S) 2mm-60um
Coarse (CS) 2mm-600um
Medium (MS) 600um-200um
Fine (FS) 200um-60um

SILT (Z) 60um-2um
Coarse (CZ) 60um-20um
Medium (MZ) 20um-6um
Fine (FZ) 6um-2um

CLAY (C) <2um

Textural Assessment :-

Values for Sand, Silt and Clay are entered into the triangular diagram below.



APPENDIX 3

The Oxford clay was tested to determine if it could have played any part in the various particle size differences that were observed in the samples. The dissolution in HCl yielded 65.9% - approximately 35% weight loss. The particle size distributions of the treated and untreated samples are shown below, and it is clear that the fineness of this sediment precludes anything but trace quantities having been present in any of the samples.