

THE PLEISTOCENE GEOLOGY  
AND GEOMORPHOLOGY OF  
WESTERN LEICESTERSHIRE

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THE GLACIAL GEOLOGY AND GEOMORPHOLOGY OF WESTERN LEICESTERSHIRE

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Abstract

The Pleistocene stratigraphy of an area of  $116 \text{ km}^2$  in western Leicestershire was mapped largely by means of a hand-auger. The investigations revealed the following sequence:

Flinty Gravel  
Chalky Till  
Pennine Till  
Cadeby Sand and Gravel  
Bosworth Clay  
Basal Till

The vicinity of the sand and gravel workings at Cadeby was selected as the type site.

The sub-drift surface of the area is dominated by the Hinckley valley, a major left bank tributary of the proto Soar. The Basal Till contains erratics of a predominantly, but not exclusively, northern provenance and betokens an ice advance prior to the accumulation of the Bosworth Clay, an extensive glacio-lacustrine formation. This proglacial lake is regarded as part of Lake Harrison which was initiated on the retreat and stagnation of ice following the deposition of the Basal Till. A subsequent readvance of the ice led to the deposition of a large sandur over the lake deposits and subsequently a till sequence comprising both Pennine and Chalky Till varieties. Till macrofabric analysis supports an interpretation of much of the Pennine Till as a lodgement till but overlying 'banded tills' indicate the contemporaneous deposition of chalky material, possibly through melt-out from a compound ice sheet.

This sequence of deposits is readily correlated with that described by Shotton in the Avon valley and has been matched with Rice's succession in the Leicester area. The entire sequence is regarded as the product of one Wolstonian stadial. Sands in the cores of Devensian involutions are probably the remnants of a once extensive sheet of aeolian material.



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# Preface

In presenting this research it seemed logical to separate the description of the Pleistocene geology derived from field mapping from the interpretation and environmental reconstruction which follows from it. Thus the first part of the work represents the factual basis on which the interpretation rests.

Following a discussion of previous research, the outline of the present research and its methodology (chapter 1), Part 1 consists of the reconstruction of the sub-drift surface (chapter 2) and then a chapter for each of the major drift divisions (chapters 3, 4 and 5). Acting as a link between Parts 1 and 2, chapter 6 begins by reinforcing the rock-stratigraphic division of Part 1 by considering the type site at Cadeby where the full succession is developed. This leads to the bulk of the interpretation and correlation which extends the scope beyond west Leicestershire in a review of events within the Lake Harrison basin. The Postscript (chapter 9) briefly deals with related topics such as the dissection of the drift, periglaciation and the present geomorphology of the area.

A point system of chapter numbering has been used, thus each chapter has been broken down into a number of sections. The first digit of each point number refers to the chapter, the second to the section. For ease of cross-referencing, each page is headed (top left) with the appropriate point number. The text figures are similarly numbered according to the chapter and the order of figures within each chapter.

All the maps and diagrams have been drawn by the author.



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In particular, a great debt is due to Dr. John Rice whose teaching awakened in the writer an interest in things Pleistocene and whose spirited guidance, willing counsel and ready help in the field are all gratefully acknowledged.

Thanks are due for technical help and cartographic advice provided within the Department of Geography and also for the forbearance of my research colleagues who put up with a geomorphologist in their midst. Professor J.T. Andrews and Dr. D.M. Mark kindly supplied listings of computer programs.

The help of numerous landowners and the operators of the Cadeby quarry who granted access to their land is acknowledged as is the assistance of my mother who has carefully typed the final draft of this thesis.

The Natural Environment Research Council awarded the Research Studentship without which this study could not have been undertaken.



# Part 1

"Let us pitch our tents, even here in  
Bosworth Field".

William Shakespeare, Richard III



# 1

## Introduction



Although the gravels at Hinckley received mention by Buckland (1823), in his treatise on 'Geological Phenomena attesting the action of an Universal Deluge', the first geologist to attempt a systematic description of the Pleistocene succession was Deeley (1886) whose work on the Trent basin made reference to "aqueous boulder clays" at Market Bosworth and in the surrounding area (Fig.1.1). By this time the glacial hypothesis had been largely accepted: Crosskey had made several reports to the British Association recording erratic blocks at Hugglescote (1873), Market Bosworth and Carlton (1880) and Plant (1882) had documented the 'Vestiges of the Ice Age in Leicestershire'.

The area was mapped for the Geological Survey by Fox-Strangways, the memoir for the Atherstone sheet (155) being published in 1900, and that of the Leicestershire and South Derbyshire coalfield in 1907. Near Leicester, Fox-Strangways recorded three distinct boulder clays, the oldest of which contained "quartzite and pre-Carboniferous pebbles", a later boulder clay with Eastern material and the newest clay occurring along the valleys. This pattern of an older boulder clay or clays reflecting a northern or northwestern provenance and a stratigraphically higher deposit demonstrating an eastern provenance is a recurrent theme in all the major works on the geology of the East Midlands at the turn of the century (Table 1.1, Deeley, 1886; Harrison, 1898; Fox-Strangways 1900, 1907). In western Leicestershire Fox-Strangways recognized that the thickest mass of boulder clay was in the neighbourhood of Market Bosworth where a borehole has indicated up to 30m (100ft) of drift. Intercalated with the clays he mapped several beds of sand and gravel differentiating between pebbly (i.e. Bunter pebbles) and chalky gravel in the memoir. The Coventry Sheet



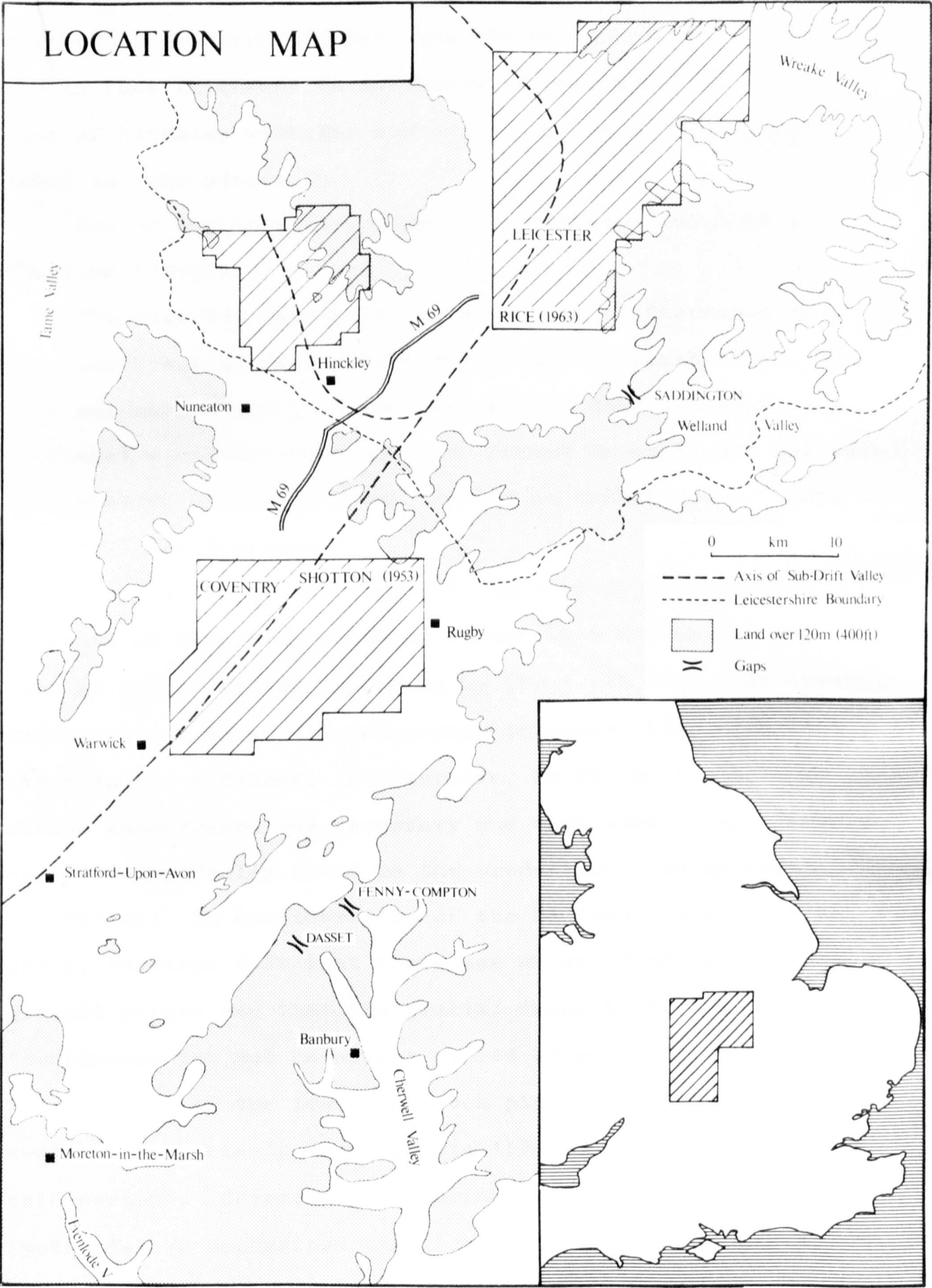


FIG 1.1



(169) was mapped by Eastwood et al. (1923) and showed that the plug of drift around Market Bosworth was continued southwards and in fact thickened to a maximum of over 61m (200ft) south-east of Hinckley with the sub-drift surface well below stream level in many places.

One of the more visionary pieces of work was that of Harrison (1898):

"The district mainly to the southwest of Charnwood in northwest Leicestershire and north Warwickshire.... was surrounded in such a way by ice dams and high land, that a considerable lake was formed in northwest Leicestershire extending from Hinckley to Market Bosworth and Ashby-de-la-Zouch."

Harrison pointed to the loams of Hinckley as being direct evidence of this lake which he termed Lake Bosworth. The lake as he saw it was impounded by three glaciers, the Arenig, Irish Sea and North Sea which were in competition with each other in the Midlands. Furthermore, he recognised that no marine submergence was necessary and that some of the gravels described by Deeley could be the product of fluvioglacial deposition. In consideration of the Midland counties as a whole, Harrison felt that there was no proof of any interglacial period and that the glacial deposits fell into one "continuous but not unvarying period of cold, during which fluctuations of the ice front took place." This is in sharp contrast to Deeley's views (Table 1.1) which indicated three cold periods. Nevertheless Harrison did not attempt any synthesis and emphasised the lack of continuity of the glacial beds.

Harmer's map of 1928 which categorizes the erratics for the entire country rather underestimates the western edge of



the chalky boulder clay which has been defined by Clayton (1953) as extending almost to Uttoxeter and well up the Middle Trent. Wills (1937), working in the West Midlands discriminated between a 'Pennine' spread of drift and a subsequent 'Eastern' one, but he noted that "near Hinckley and perhaps also at Bedworth, part of the older series consists of well-bedded, probably lacustrine deposits." Much of these earlier workers' thinking can now be seen as false as a result of their failure to recognise that the Avon/Trent watershed has been radically displaced. The most significant development in the study of the Pleistocene of this region was Shotton's 1953 paper which demonstrated that the sub-drift surface of much of the Midlands pointed to a very different topography than the present one. The major element of this sub-drift surface is the proto Soar valley, a gently sloping broad vale heading near Bredon Hill and greatly increasing the area of the ancestral Trent catchment when compared with its present basin. The main England watershed between Avon and Trent passes across the middle reaches of this buried valley and thus a considerable thickness of drifts has been preserved in the south Leicestershire and Warwickshire region.

Apart from the published drift maps of the Geological Survey, few detailed local mapping programmes had been undertaken until Shotton's work on the Pleistocene sequence exposed in the Avon valley (Shotton, 1953). Shotton identified considerable thicknesses of lake deposits which he established as being deposited in a vast proglacial lake part of which (the Market Bosworth arm) contained the brickearths of Harrison's Lake Bosworth. Such is the clarity of the geological record in the Avon valley that the section at Wolston was adopted as the type site for the Wolstonian stage of the British Quater-



nary (Shotton and West, 1969). To the northeast where the Soar has dissected the drifts of central Leicestershire (Fig 1.1), Rice (1963, 1968) has mapped the sequence which shows only scant evidence of glacio-lacustrine material and correspondingly more indication of direct glacial deposition in the form of substantial thicknesses of tills. The tills were shown to display "a transition from materials of predominantly northwestern origin to those of northeast derivation." Rice was able to match the Leicester succession with that in the Avon and contended that it was the product of one glacial stage, namely the Wolstonian. This opinion is at variance with the findings of West and Donner (1956) who ascribed the two tills discriminated by their macrofabrics to two glacial stages. Similarly Posnansky (1960) in reviewing the Pleistocene succession of the Middle Trent valley specified two major glaciations represented by the Pennine and Eastern drifts.

The Pleistocene deposits of Charnwood Forest received attention by Bridger (1971), who reported a complex picture. Bridger found it difficult to correlate sections from one part of the Forest to another and the rapid lateral changes in lithology and the patchy nature of the drifts made mapping very difficult. Sections opened in Charnwood Forest when the M1 was being constructed were recorded by Poole (1964, 1968) and although the two prominent till lithologies were present (i.e. Pennine and Eastern types), they were regarded as the deposits of one major glacial stage.



From the foregoing section, it will be clear that most of the published work has been either rather general in nature or has considered limited areas where local successions have been based on intensive field mapping and have permitted a reconstruction of events during the Pleistocene. Examples of the latter approach include the works by Shotton (1953) and Rice (1963), both of which present maps of the drift successions which demonstrate a moderately high degree of lateral persistence of the beds. Once widespread evidence of lacustrine deposition has been established, the height relationships of the beds can assume regional importance (Shotton, 1953; Bishop, 1958). No work has focussed on western Leicestershire although it was Harrison's recognition of brickearths here that led him to advocate a glacial Lake Bosworth.

Although the Leicester and Coventry successions have been correlated (Rice, 1963), the lithologies represented in the two areas are rather different. Between Leicester and Coventry there is clearly a transition between the lacustrine beds and the tills, and because Lake Harrison would only have been watertight with an ice block across the proto-Soar valley near Leicester, the oscillations of such an ice front at the northern edge of the proglacial lake may well have led to a rather complex distribution of sediments. In western Leicestershire, however, the Market Bosworth arm of Shotton's Lake Harrison (Shotton, 1953) was ponded in a left bank tributary of the proto Soar, the Hinckley valley, and although in its later stages the lake here may have been held up by ice to the north, its initial accumulation would have been against the rising slopes of the valley. The succession thus contained within the basin of the Market Bosworth arm was regarded as an appropriate study area in the decipherment of the Pleistocene



of western Leicestershire and in the reconstruction of the events which controlled the northern part of Lake Harrison.

One of the principal aims of this thesis has been to present the Pleistocene stratigraphy of an area which has an undoubted glacio-lacustrine element but which is sufficiently close to the central Leicestershire study area of Rice to permit direct correlation. In this fashion it is hoped that the correlations between the Lake Harrison sequence and those areas which were outside the northern bounds of that lake will be strengthened and that a significant gap in the regional Pleistocene stratigraphy of the Midlands will be filled.

Any such study can only be complete if it is based on an accurate description of the drift sequence in rock-stratigraphic terms. As has been suggested above, the Geological Survey mapping, even at the six-inch scale, is inadequate and a further outcome of this research has been the production of a more reliable geological map. Finally, the scope of this research is extended to a consideration of the geomorphology of western Leicestershire where most of the present landforms have been developed on the glacial beds.

### 1.3

The study area (Fig 1.2) was selected after an initial period of reconnaissance survey which was able to delimit roughly the extent of the lacustrine material and to establish the major drift lithologies which would form the rock-stratigraphic basis for the detailed mapping programme. The area is centred on Market Bosworth and includes the greater part of the Market Bosworth arm of Lake Harrison as outlined by Shotton (1953). To the west it is bounded by the relatively drift free plain of the Anker valley; to the north by the Leicestershire coal-



Table 1.1

Pleistocene Stratigraphy of the Middle Trent

R.M. Deeley (1886)

## Newer Pleistocene Epoch:

Later Pennine Boulder Clay

Interglacial River Gravel

## Middle Pleistocene Epoch:

Chalky Gravel

Great Chalky Boulder Clay

Melton Sand

## Older Pleistocene Epoch:

Middle Pennine Boulder Clay

Quartzose Sand

Early Pennine Boulder Clay

Pleistocene Stratigraphy of Leicester (Sheet 156)

C. Fox-Strangways (1903)

Valley Drift

Great Chalky Boulder Clay (with  
intercalated beds of sand and gravel)

Older Boulder Clay (upper part)

Quartzose Sand

Older Boulder Clay (lower part)

Older Sand and Gravel (?)



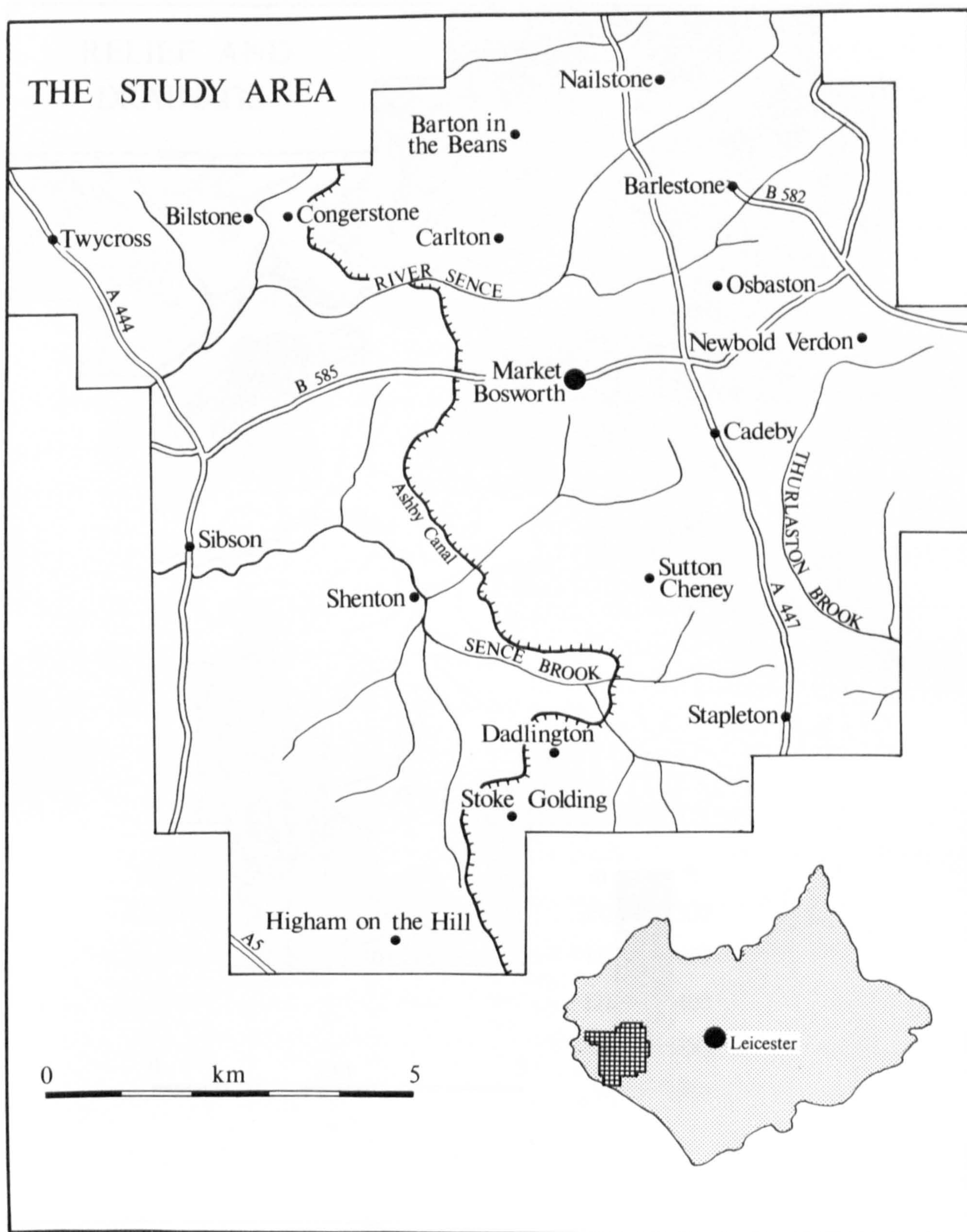


FIG 1.2



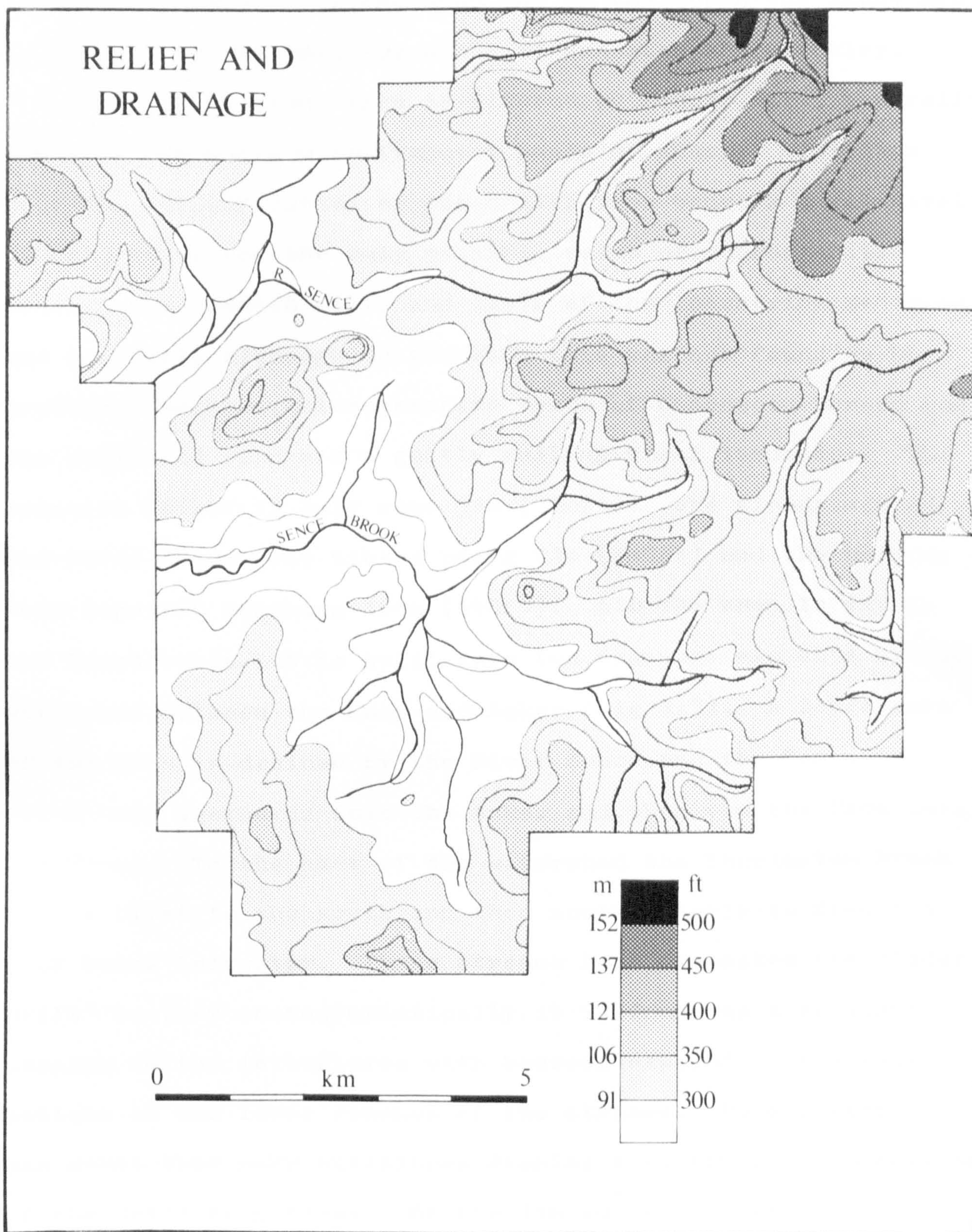


FIG 1.3



field and the rather patchy drifts of that area; to the east the higher ground of the Soar/Anker interfluvium with a non-lacustrine sequence is included and to the south the study area is defined by the built-up areas of Nuneaton and Hinckley.

The entire study area is floored by Keuper Marl, typically the soft red marls with frequent bands of skerry. This has made the identification of the drifts from bedrock a relatively simple matter for the only possible point of confusion is between the reddish silts and clays of the lacustrine sequence and the marl, although in practice this was not found to be a problem. Western Leicestershire south of Charnwood Forest and the coalfield presents a gently rolling rural landscape. The relative relief is only some 91m (300ft): the floodplain of the River Sence near Sibson being 73m (240ft) and the uplands near Bagworth reaching 164m (540ft). All the area is within the Trent basin but is split into two drainage elements by the watershed between the Soar and Anker (Fig 1.3). A large part of the area is drained by the River Sence and the Sence Brook which head westwards into the Anker and thus via the Tame into the Trent. To the east of the watershed the Thurlaston Brook trends first to the south and then southeasterly to feed the Soar below Leicester. These streams have dissected the 'Older Drift' so that characteristically it is found as a substantial capping on the interfluvies with bedrock exposed in the valley bottoms of the lower reaches of the streams. This pattern has meant that many hillslopes display a fairly full succession of the drift formations. Of the 116 km<sup>2</sup> of the study area, 66 km<sup>2</sup> (57%) were mapped as Pleistocene drift.

In such a predominantly rural area with few major construction projects, sections are scarce and subsurface investigations are almost wholly dependent on the hand auger. The



major exception to this is at Cadeby where Tilcon have for the past few years been extracting sand and gravel from a pit and some good sections have been opened (Douglas, 1974). For the most part however this research has been based on the information yielded by field mapping with a 1.25m Dutch hand auger and where deeper auger holes have been necessary, a similar extending auger has been used which has permitted depths up to 5m below ground surface to be reached. The diameter of the corer is 6cm and enables samples of up to 0.5kg to be collected. The auger samples are considerably disturbed and delicate bedding can rarely be detected as a result, nevertheless the tool proved efficient to use in the field and a total of well over one thousand auger holes were drilled giving a mean density of more than  $20/\text{km}^2$ . The field mapping made use of what temporary sections were available, the most useful being field drainage ditches. The borehole cover of the district is also scanty but several of the boreholes put down in connection with the exploration of the southern edge of the concealed coalfield at the end of the nineteenth century have provided some data of interest, although the logs have not been preserved and the drifts were often undifferentiated. The geological map (at the end of this volume) is the product of the field mapping initially at a scale of 1:10,260. The mapping undertook to provide the data for a rock-stratigraphic classification and so the divisions have distinctive lithological characteristics. It is felt that the boundaries between these types have been fixed fairly accurately, in most instances to within  $\pm 50\text{m}$ .

Selected samples collected in the field either from sections or by auger were subjected to analysis in the laboratory. Particle size analyses were performed to DS:1477 using the pipette method and a mechanical sieve shaker. Carbonate



determinations made use of a Collins calcimeter. Till macro-fabric was studied at the Cadeby site. Individual pebbles were marked in the field using a template and reorientated in the laboratory to determine the attitude of the a-axes. The three-dimensional statistics were obtained using the eigenvalue method. (Refer to the Appendix for a full discussion of the statistical techniques used and the computer program employed for the till fabric analysis.)

The data used for this research are largely those obtained during field mapping in 1973/4 and any explanations advanced depend on the reliability of that data. As many of the early workers on the Pleistocene recognized, the sequence of deposits is a very complex one and attempts to put these into a regionally applicable chronology can now be seen to be at variance with the facts. (e.g. Deeley, 1886). Horton (1974) in describing the Pleistocene of north Birmingham based on motorway boreholes has pointed out that the beds are rarely persistent for any great length laterally, that lithological diversity is the norm and that no simplistic explanations can be offered. In western Leicestershire, as in the Coventry region, the widespread development of the glacio-lacustrine beds has provided an important stratigraphic datum and has given a meaningful altitudinal relationship to much of the drift succession. This is not to say that the boundaries of the drift formations are isochronous but in the terms of the rock-stratigraphic classification they are real and remarkably persistent. Harrison (1898) in a consideration of the glaciation of the Midlands Counties noted that, "No exact divisions of the drift beds can be made out; indeed it is probable that no two sections which are more than a few yards apart ever reveal exactly the same sequence." It is the purpose of what follows in this



thesis to establish that in western Leicestershire at least,  
that is not the case.



2

The Sub-drift Surface



A reconstruction of the sub-drift surface is an essential preliminary to the meaningful description and analysis of the drift succession. In geological terms it represents an unconformity which does not necessarily reflect the pre-glacial relief. However, apart from an important exception noted in 2.2, the sub-drift surface may be regarded as a fair approximation of the land surface at the start of the cold period during which the drifts were deposited, and that deposition onto that surface, rather than erosive modification of it, was the norm. This conclusion is reached via the following line of argument, namely that the gross morphology of the sub-drift surface describes an integrated system of drainage which fits with the evidence from outside the area (Shotton, 1953; Rice, 1963).

The bedrock surface is a combination of the sub-drift surface and the present day topography in those areas where the drift cover has been removed. The boundary between these two components is the outcrop of the sub-drift surface. It is this datum which has provided the majority of information used in the reconstruction of the surface (Fig 2.1). Many of the hillslope auger traverses passed into bedrock and the interface with the drifts was fixed. Other subsurface information was obtained from borehole and well records. Where post-glacial stream incision has resulted in valleys with a narrow strip of bedrock exposed on the valley floor (e.g. the headwaters of the River Sence and Thurlaston Brook), it is a relatively simple matter to interpolate the sub-drift surface. However, where stripping of the drift cover has been more extensive, as in the western part of the study area, and the amount of bedrock surface lowering is unknown, such reconstructions are much more tentative although there is sufficient



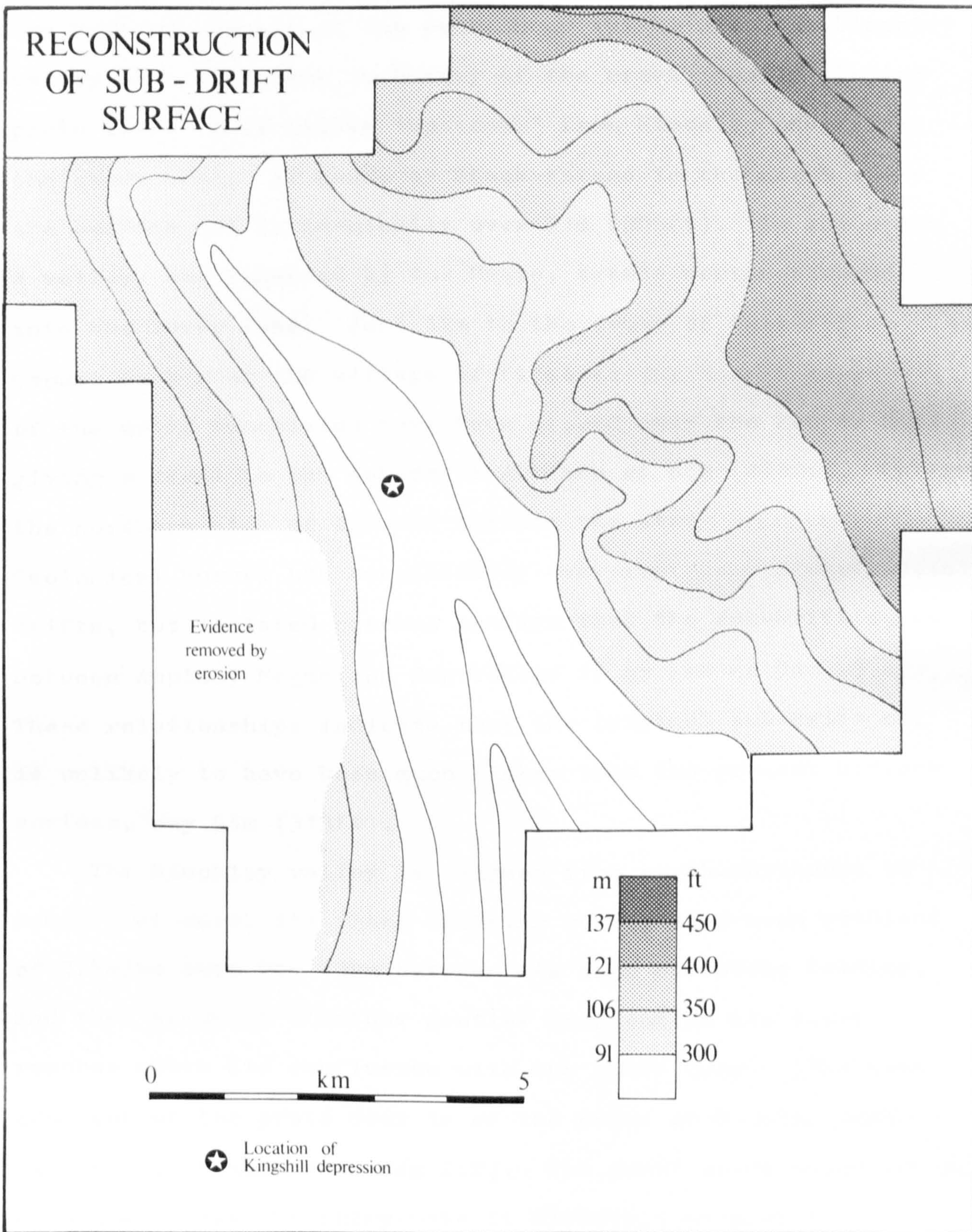


FIG 2.1



information to establish the general pattern of the surface.

Shotton (1953, Fig 11) presented a regional map showing the bedrock surface of the proto Soar system with the Hinckley valley as a left bank tributary of the broad, gently sloping proto Soar. This valley 'upstream' from Hinckley underlies the study area. It heads at Shackerstone in the north where the bedrock col is marginally over 91m (300ft). To the north a valley, now occupied by the Mease, trends northwestwards into the lower Tame. Just 1km to the south of this col in Gopsal Park near the village of Bilstone the lowest members of the drift succession have been proved over the Keuper Marl giving a level to the sub-drift surface of 88m (290ft). On the northern side of the col outside the study area, the Geological Survey has considerably over-represented the glacial drifts, but isolated patches confirm that the sub-drift surface between Appleby Magna and Snarestone is as low as 91m (300ft). These relationships indicate that the original sub-drift col is unlikely to have been much higher than the present bedrock surface, say 95m (313ft).

The Hinckley valley is aligned from north-northwest to south-southeast, its floor shelving gently at a mean gradient of 2.4m/km over the 13km between its head and Stoke Golding, and then assuming a rather gentler gradient in its lower reaches above its confluence with the proto Soar. (The mean gradient of the proto Soar is of the order of 0.3m/km between Warwick and Leicester: Fig 2.2). The great drift thicknesses encountered near Hinckley make it difficult to plot its exact course, but the two valleys probably merge in the vicinity of Sharnford where the height of the proto Soar is estimated at 64m (210ft). A boring at Compass Fields Farm, Stoke Golding records 41m (135ft) of drift and places the rock head at 66m



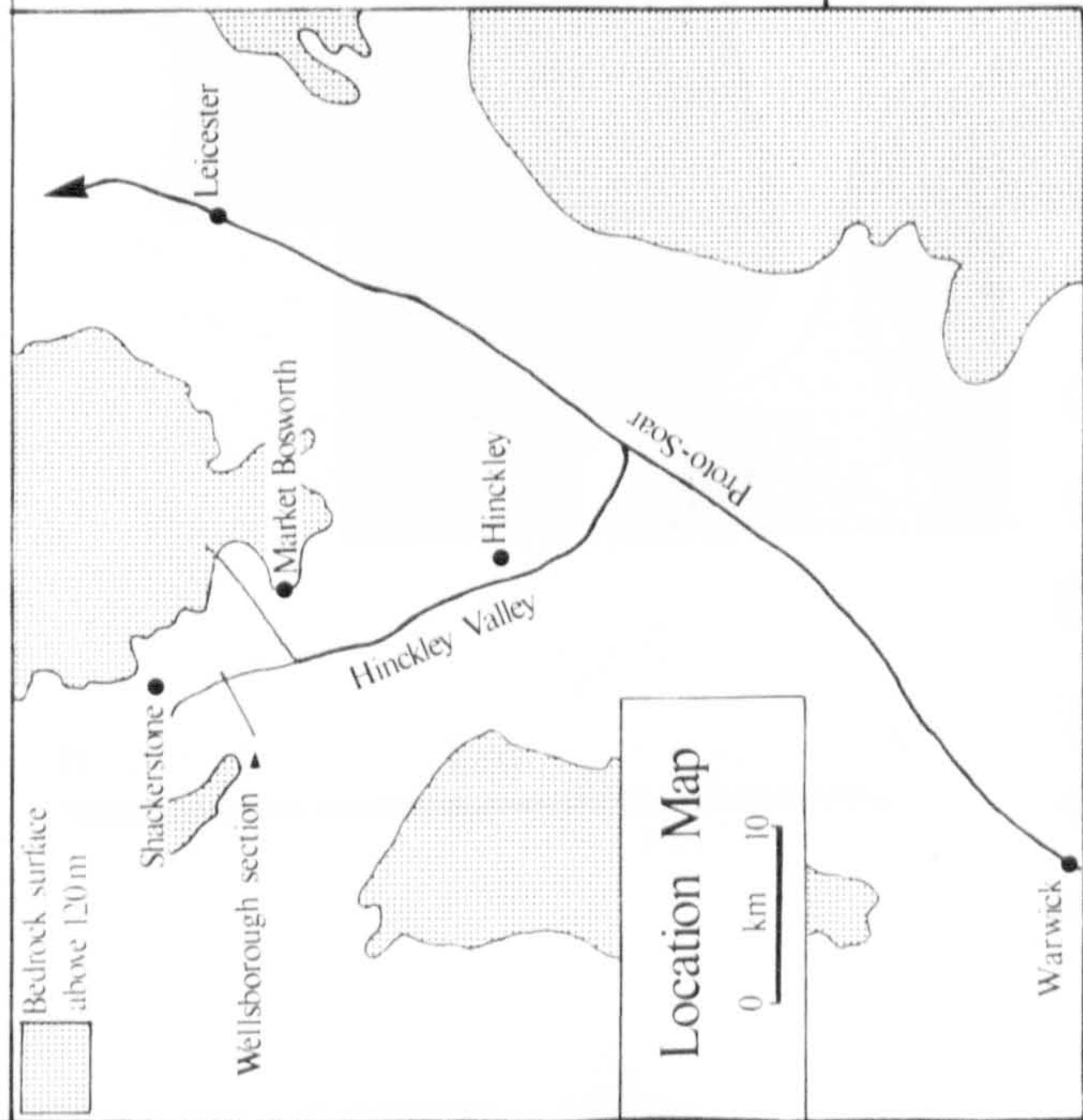
(215ft). Many of the well records and boreholes at Hinckley show similar thicknesses of drift, with the sub-drift surface below 76m (250ft) in most cases (Pickering, 1916).

With such a sparse cover of deep borings it has been impossible to pinpoint the axis of the lower part of the Hinckley valley. The sides of the valley are more readily reconstructed as surface observations have been able to establish the edge of the drift in many places where the contemporary drainage has cut across the trend of the preglacial relief. Fig 2.1 shows the generalised contours of the sub-drift surface. The eastern side of the Hinckley valley is punctuated by short tributaries whose gradient is considerably steeper than that of the main valley. The bedrock valley which parallels the upper part of the River Sence has a mean gradient in excess of 8m/km.

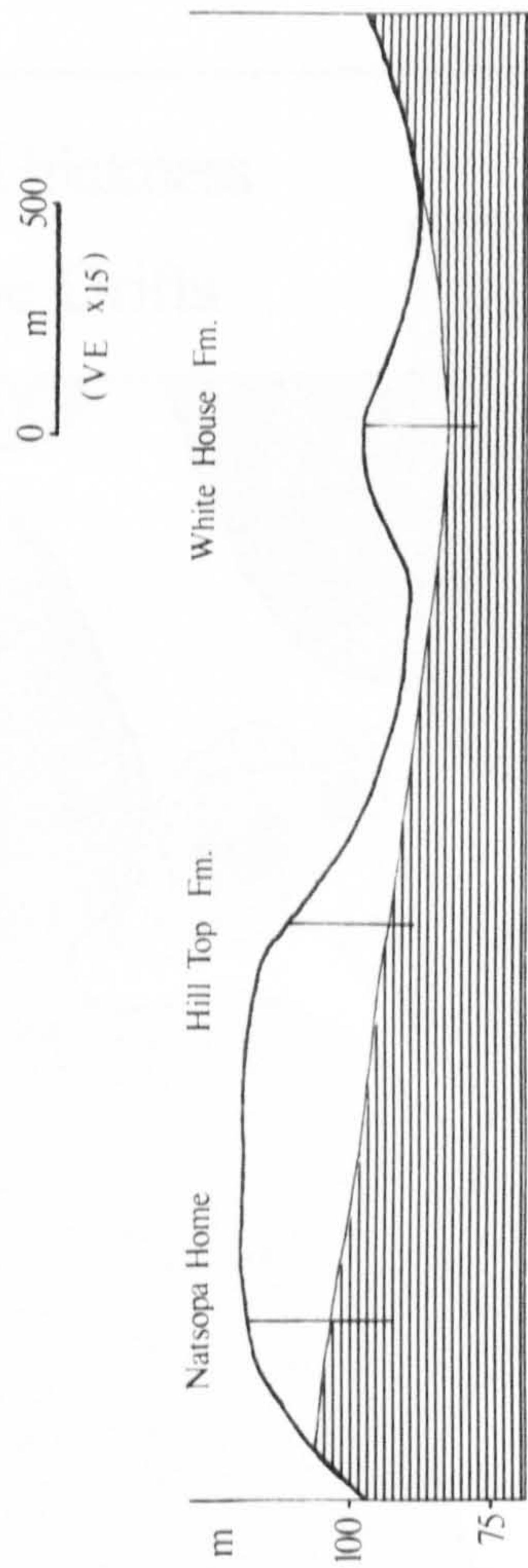
A comparison of Figs 1.4 and 2.1 shows that not only is the contemporary drainage of the study area radically different from that defined by the sub-drift surface, but also that present slopes developed on the drift are often steeper than the preglacial surface of Keuper Marl. Figs 1.4 and 2.1 have been used to construct Fig 2.3 which indicates the thickness of the Pleistocene sequence now preserved. There is a continuous infill of drift along the length of the Hinckley valley with thicknesses exceeding 38m (125ft) in the plug of drift at the southern margin of the study area near Dadlington. Elsewhere, the interfluves are picked out by greater drift thicknesses, and to the northwest the 'outlier' of Twycross and Wellsborough Hill stand out. At Wellsborough there is sufficient subsurface information to establish the gradient of the western slopes of the sub-drift valley. (Fig 2.2). Over a stretch of 2 km normal to the central axis of



# PROFILES ON THE SUB DRIFT SURFACE



## SECTION AT WELLSBOROUGH



## HINCKLEY VALLEY & PROTO-SOAR

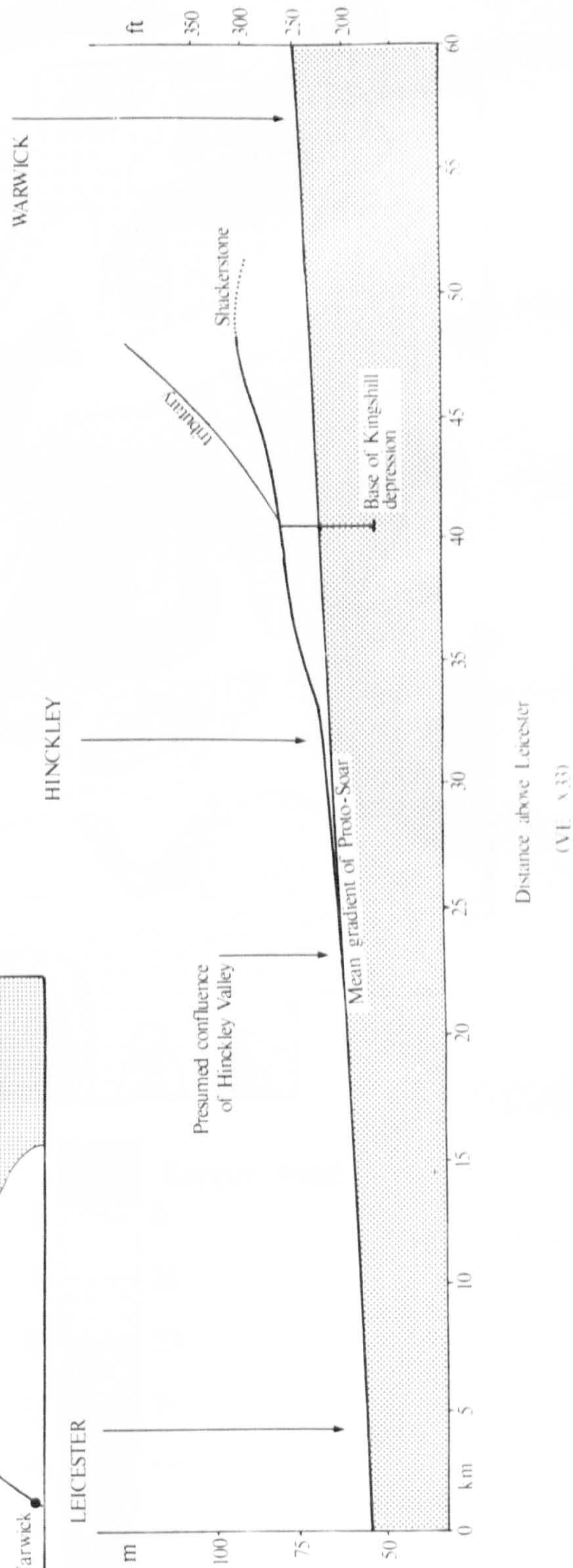


FIG 2.2



# Estimated Thickness of Pleistocene Drifts

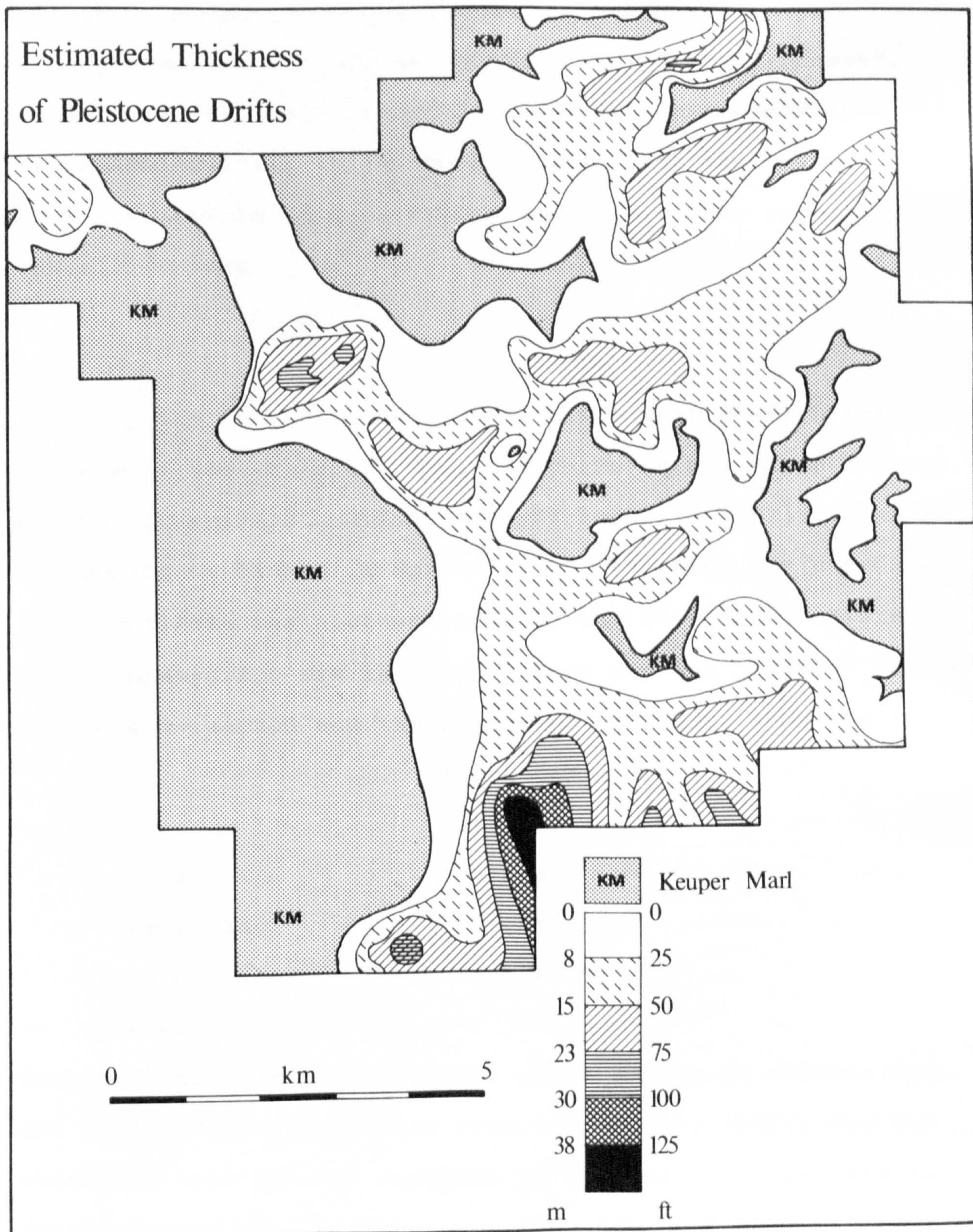


FIG 2.3



the valley, a fall of 22m (72ft) is recorded (11m/km).

Fox-Strangways (1900) recognised that the drift occupied a valley or depression in the Keuper Marl, and that "from Market Bosworth southwards it sinks below the present level of drainage and appears to attain its maximum thickness". Inasmuch as the reconstructed sub-drift surface reflects the preglacial relief, it may be concluded that the present land-forms of western Leicestershire owe much to the effects of the Pleistocene.

## 2.2

Although the foregoing presents a relatively straightforward picture of the sub-drift surface, there is one major anomaly worthy of separate mention. Fox-Strangways (1907) quotes an old boring at Kingshill Spinney (383016) which was put down to investigate the southern edge of the concealed coalfield. On the manuscript six inch geological map the position of the borehole is marked and the following record is annotated:

	thickness	
	ft	(m)
soil	4	1
brickclay	93	28
sand	7	2
red marl		

Elsewhere however the record is given simply as boulder clay and sands 126ft (38m) thick (Fox-Strangways, 1907), but the thickness here is only regarded as approximate. The log no longer exists, and without repeating the boring there seems little chance of verifying its authenticity. The boring was put down before 1884 whilst Fox-Strangways was mapping the sheet for the Geological Survey; it would seem likely



therefore that his record on the manuscript map would be an accurate one. Furthermore, other records of a similar date at Cowpasture, Market Bosworth and Bosworth Wharf are reliable in their description of the drift.

The problem arises in reconciling the level of rock head recorded by this boring, about 53m (176ft), with any sub-drift surface which could be regarded as supporting an integrated drainage system (Figs 2.1, 2.2). The bedrock floor of this channel or depression is 24m (80ft) below the minimum level of the surface at this point. The depression must be a localised phenomenon with very steep bedrock sides. Only 500m from the site of the boring, field mapping has revealed bedrock at the surface: this means that the depression would have a minimum slope of 50m/km, far steeper than would be expected for slopes developed on Keuper Marl.

An extending auger was used to investigate the deposits nearer the surface in the vicinity of the borehole. A depth of 3.75m (12ft) was reached before slumping of the material beneath the water table made further progress impossible. The entire auger hole was in stoneless, bedded clays and silts which Fox-Strangways had described as brickearths. There were no possible grounds for confusion with the Keuper Marl. The borehole record indicates a bed of sand resting on the Keuper Marl; as sand could similarly not be confused with the red marls, it must be concluded that rock head here is abnormally low and that a depression of undefined shape, but clearly limited by bedrock outcropping immediately to the west, truncates the sub-drift surface. Further consideration of this problem is provided below (Chapter 6).



3

Basal Till  
and Bosworth Clay



The lowest member of the drift succession in the study area is a till. Although very thin in places, the bed is remarkably persistent and occurs over large areas as a mask on the sub-drift surface of Keuper Marl (Fig 3.1). This contact is not always a sharp one since a variable layer of reworked and weathered marl may interpose between the in situ marl and the Basal Till. Although the weathered layer may include fragments of skerry, few if any erratics are present and the contact between bedrock and till can therefore be identified fairly precisely even with an auger.

Stone counts on the erratic pebbles contained within the till reveal that they have been derived from several sources. Carboniferous rocks figure prominently together with Bunter pebbles. Many samples of the till contain several fragments of coal; sandstones and grits are also represented in large numbers together with Keuper siltstones. Apart from three localities mentioned below, no 'eastern' (Jurassic or Cretaceous) erratics have been found, and the Basal Till is characteristically a till of the 'northern drift' type of Harrison (1877) or of 'Pennine Boulder Clay' type (Deeley, 1886).

No good sections are known to show the till within the study area, but some drainage ditches show its contact with the bedrock and enable its thickness to be measured. Where the till is thin, as is frequently the case, auger-holes have to be very closely spaced to detect it: indeed it was only after several months of field mapping that its widespread nature was appreciated. The following sites best illustrate the nature of the formation:



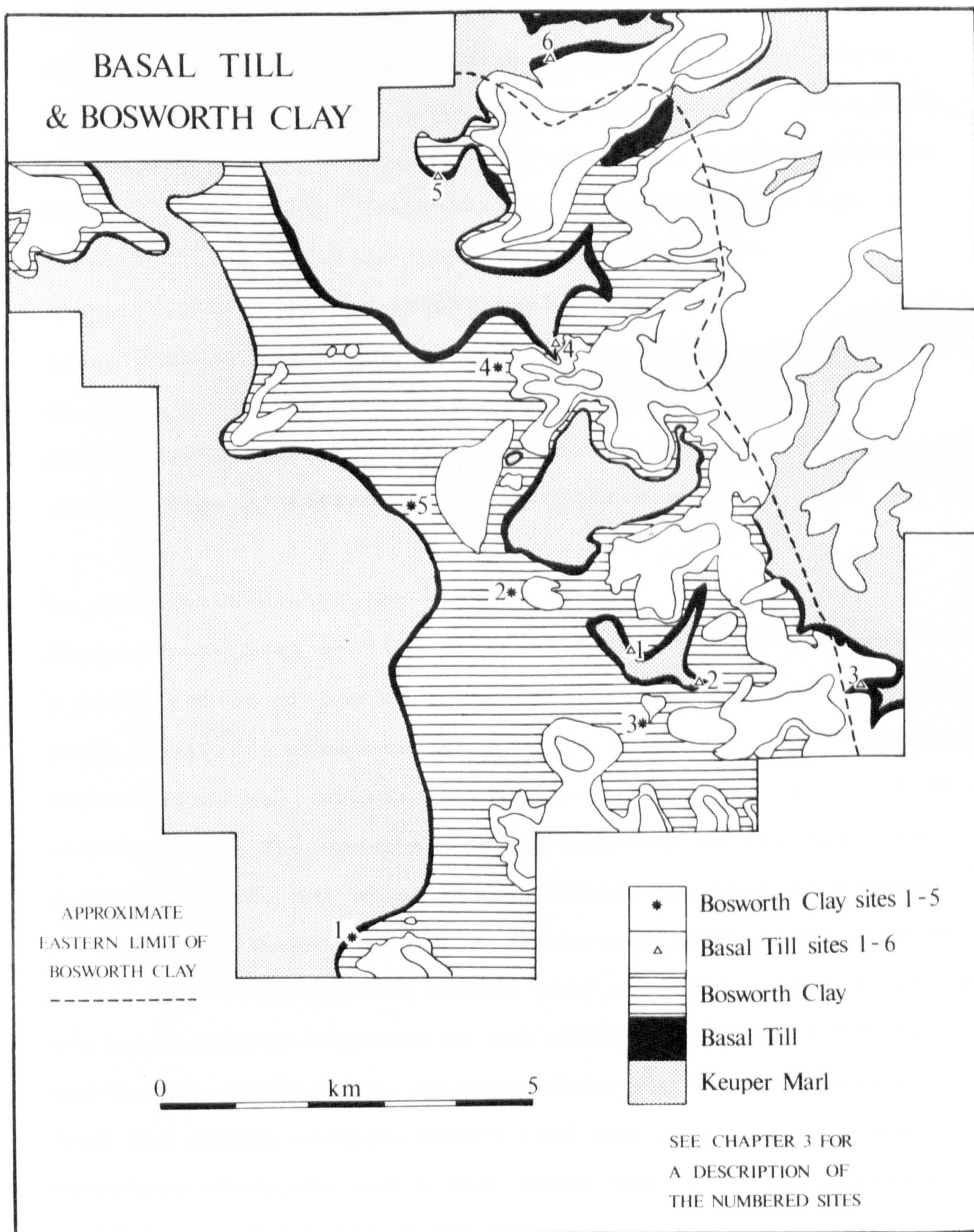


FIG 3.1



### 1. Sutton Wharf (SP 413994)

A drainage ditch cut at the edge of a field to a depth of about 1.50m exposed the junction between drift and bedrock. The ditch sloped gently from 102m (335ft) towards the Ashby-de-la-Zouch canal at 91m (300ft), which was built on Keuper Marl at this point. The sides of the ditch showed that the Basal Till was about 2m thick and rested on a fairly sharp contact of undisturbed Keuper Marl. Some few metres downslope, beds of skerry in the red marls showed no disturbance at all. Above the till were brown stoneless clays. The reddish colouring of the till matrix indicated that it incorporated a large proportion of reconstituted marl.

### 2. Stapleton Fields (SP 424991)

Arguably the best section of Basal Till in the study area is a bank section of one of the streams of the Sence Brook which heads westwards from Stapleton. The till here is relatively thick (about 4m), and is intermittently exposed along 50m of stream bank. The upper and lower contacts of the unit are poorly exposed, but as at Sutton Wharf, the till is floored by Keuper Marl and overlain by stoneless clays. The till is completely unbedded, and packed with erratics. Coal fragments are particularly numerous as are Bunter pebbles, Carboniferous and Keuper sandstones. An auger-hole sunk to 2.25m upslope from the stream section showed that the junction with the stoneless clays was not a very sharp one, clasts increasing in frequency through a depth of one metre between the completely stoneless clay and the fully developed till.



### 3. Barwell Fields Farm (SP 447989)

East of Stapleton the streams drain eastwards towards the Sbar. A few metres to the north of Barwell Fields Farm a spring issues from a sand horizon and flows over Basal Till before reaching Keuper Marl. Augering on the surrounding slopes has detected at least 5m of till between the outcrop of the overlying sand and bedrock. The matrix of the till is commonly rather darker (10YR 3/2) than that described above, and although the erratic suite is very similar, isolated flints and a piece of chalk have been recovered from samples. The till can be traced as a continuous bed into the valley of the Thurlaston Brook, and northwestwards beyond Stapleton Brockey. It is consistently overlain by sands with a sharp, clean interface (see below 6.3).

### 4. Market Bosworth (SK 404035)

To the northwest of the town a prominent sand and gravel scarp overlooks gently sloping land. A re-entrant into the scarp is drained by a small stream which has been channelled in a ditch. Recutting of this drainage ditch exposed Basal Till in a similar situation to that at Sutton Wharf. At 108m (355ft) a thin layer of till, calculated at no more than 1.25m thick, forms the lowest member of the drift succession. The erratic suite comprises numerous Carboniferous sandstones and shales and Hunter pebbles as well as a substantial local component of Keuper Marl inclusions and skerry. The fragments of marl can be detected by their red colouring as opposed to the characteristic reddish-brown matrix of the till. There is some evidence at this site of a limited reworking of the underlying marl; there being no trace of bedding immediately below the till contact, indeed the thin beds of grey clay and silt-



stone seem to be mixed with the red marl. This zone of disturbance is excluded from the mapped Basal Till unit as no erratics are present.

#### 5. Barton in the Beans (SK 386059)

At 110m (360ft) near Larch Spinney, 1km west of the village of Barton in the Beans, stoneless clays mask a very thin band of till, no more than 1m thick, yet traceable over considerable distances in the same stratigraphic position. The till has the usual reddish-brown matrix (7.5YR 4/2) and contains large amounts of coal although individual fragments rarely exceed 1cm in length.

#### 6. Nailstone Gorse (SK 403074)

The headwater of the River Sence draining west from Nailstone has cut through the drift exposing Keuper Marl in the valley bottom. Along the north-facing slopes of the valley an outcrop of pebbly sands and gravels forms a gentle scarp. Augering through the edge of this bed, a till has been proved which can be followed along the valley sides and on the southern side of the interfluvium between Nailstone and Osbaston Hollow (Fig 3.1). This till rests on bedrock although one auger-hole encountered 20cm of sand at the interface. Unlike the other sites described here, the till contains large amounts of flint and chalk, and in many ways is typical Chalky Boulder Clay. The matrix is variable in colour, from a grey-brown to a reddish-brown more consistent with the Basal Till elsewhere. 'Non-Eastern' erratics are present and in some samples dominate where they are usually associated with a reddish-brown matrix. No exposures are known in the area, so whereas the relationship of the till unit to other beds is



clear, the internal structure of the till types is far from certain for augering has shown that the pattern of matrix colouration and erratic content is a very complex one. (For evidence of correlation see below 4.2 and 6.2).

Apart from these restricted occurrences where chalky material is evident, the Basal Till lithology is quite consistent. Particle size analyses were performed on samples of the matrix from four sites and the results are presented in Table 3.1 and Fig 3.2. The Trask sorting coefficients of about 4 confirm the ill-sorted nature to be expected with a till, and differentiate the Basal Till from the well-sorted lacustrine material which frequently overlies it. Confirmatory evidence of the till is provided by logs of boreholes at Stoke Golding and Hinckley which figure red stony clays immediately above bedrock. Near Hinckley records indicate the till to be 1-10m (3-33ft) thick (Whitehead et al., 1923).

### 3.2

In the Geological Survey memoir of the Atherstone Sheet, Fox-Strangways (1900, p38) noted: "At Bosworth Wharf, Shenton, Stoke Golding, and further south a great part of the clay is free from stones, and is more of a character of a brickearth, containing sandy and loamy bands and a great profusion of the small calcareous lumps known as 'race'." Fox-Strangways' manuscript six inch maps describe several sections in brick-yards which are no longer open. His mapping of the brickearths grossly underestimates their distribution and much of that which is shown as boulder clay is in fact stoneless. It is probably no coincidence that those areas in which brickearths were recognised follow the railway line where exposures in cuttings would have provided subsurface information.



TABLE 3.1

Particle size analysis: Basal Till and Bosworth Clay

Sample Location	Sieved Fractions							(mm)	Pipette Analysis			Trask Sorting Co-ef
	1.18	.600	.300	.212	.150	.075	.020		.006	.002	.002	
	2.00	1.18	.600	.300	.212	.150	.075	.020	.006	.002		
<hr/>												
Barton in the Beans	0.7	1.2	4.2	3.7	3.9	9.3	17.8	13.5	10.8	34.9		4.96
Sutton Wharf	0.1	1.4	3.2	2.6	2.7	6.6	30.1	15.2	9.1	29.1		3.93
Stapleton	0.1	0.4	1.0	0.7	0.7	1.4	15.4	15.5	14.8	50.1		4.15
Mailstone Gorse	0.3	0.5	3.1	3.8	3.8	6.4	15.7	15.6	11.9	38.9		4.67
<hr/>												
-----												
Wellsborough						0.6	3.0	4.8	16.7	74.8		2.00
Kingshill Spinney						0.3	2.6	6.8	19.8	70.5		1.93
Temple Farm						1.6	3.2	13.6	16.8	64.8		2.81
<hr/>												

Basal Till

Bosworth Clay







Similarly, Eastwood et al. (1923) report brown laminated silts and clays in the Hinckley and Dedworth areas, but map them (Sheet 169) as boulder clays.

The mapping unit of Bosworth Clay has been rigorously defined in terms of lithology for the purpose of this research. The unit is clearly glacio-lacustrine in origin; rafts of foreign material and dropstones might be expected to occur within it, but in order to avoid all possible confusion with glacial till, the Bosworth Clay mapped by augering can be regarded as an almost totally stoneless deposit (Fig 3.1). The name of Bosworth Clay was adopted as a suitable local one which also recalls the Lake Bosworth of Harrison, subsequently refined by Shotton (1953) and renamed Lake Harrison. It was Harrison (1898) who originally recognised 'loams' in the area, and was the first geologist to attribute a lacustrine origin to them.

During the course of this survey, the Bosworth Clays were not exposed other than in restricted, temporary sections, consequently the mapping evidence derives largely from augering and is supplemented by a few borehole records. The following sites give the best description of the formation:

1. Higham on the Hill (SP 377957)

The cutting of the abandoned railway line to the west of Higham on the Hill station exposes the lower edge of the Bosworth Clay resting on the Basal Till which in turn overlies Keuper Marl. (Fig 3.3A) The section is overgrown, but shallow augering into the face adequately revealed the sequence. The bedrock rises gently to the west and intersects the upper edge of the cutting. This slope represents the western side of the Hinckley sub-drift valley and is masked



with a band of till of variable thickness, but averaging 2-3m. The clays above the till are smooth and plastic with no obvious signs of bedding. They are dark red-brown (7.5YR 4/2) and show little indication of weathering below soil level.

## 2. Shenton (SK 397000)

To the south of the disused station at Shenton, where the railway cuts through the western slopes of Ambion Hill, the east wall of the cutting displays up to 10m of brown plastic clay. Isolated silty bands indicate that the bedding is approximately horizontal and undisturbed, but cleaned sections in the chocolate clays have failed to exhibit any lamination. No dropstones or any other inclusions were found and this exposure strikingly demonstrates the consistent texture and undoubted lacustrine origin of the deposit.

## 3. Harper's Hill (SP 420984)

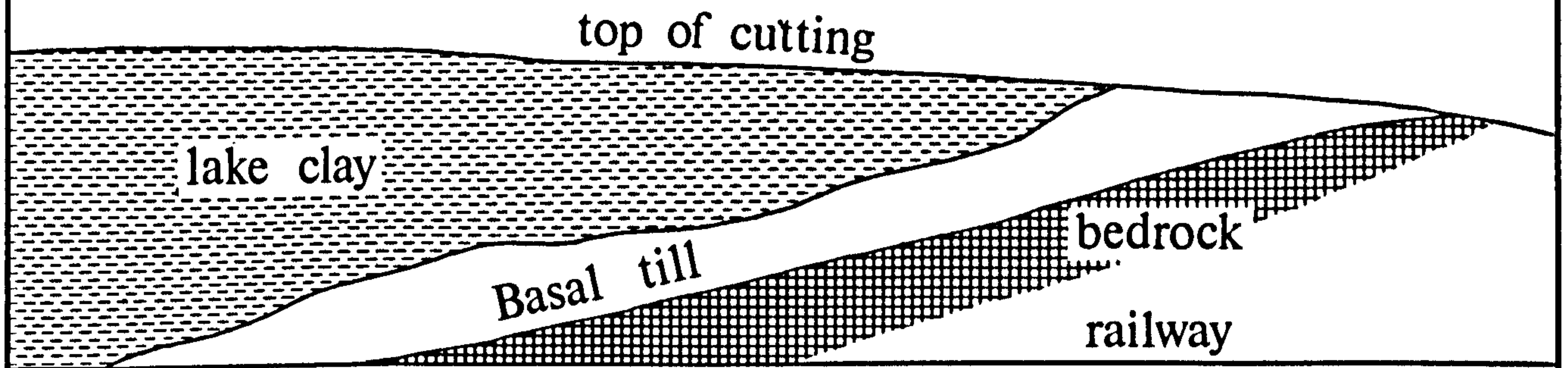
The interfluvium between the stream which rises at Stapleton and the Tweed River displays a minimum of 13m of chocolate clays with a small capping of sand. (Fig 3.3E) Outcropping parallel to the contours of the ridge two beds of sand no more than 2m thick are interstratified with the clays. The sands are non-calcareous, orange in colour and well-sorted comprising grains up to the coarse sand size. These beds are laterally persistent and can be traced for at least 1km. They are also present on the slopes south of the Tweed River at similar heights.

## 4. Bosworth Wharf (SK 392031)

Fox-Strangways on the six inch manuscript map describes the section (now closed) in the brickyard at Bosworth Wharf as

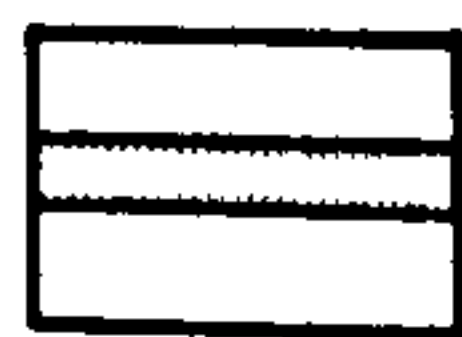
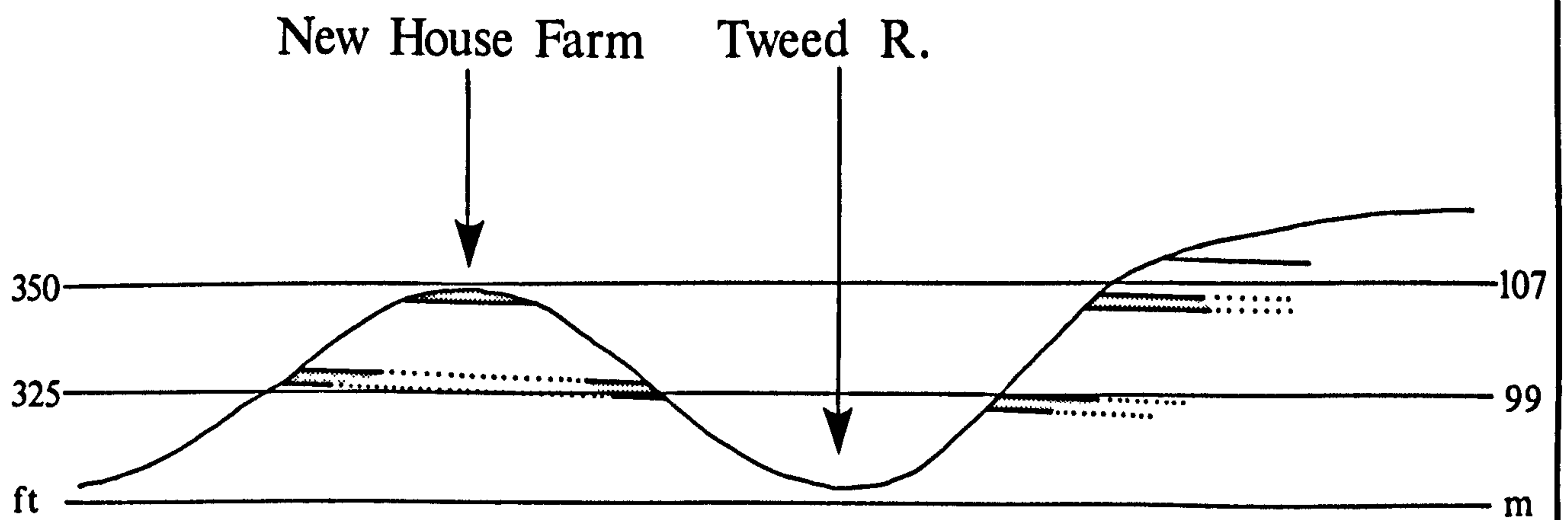


# A HIGHAM ON THE HILL



not to scale

# B HARPER'S HILL.



bands of sand in lake clays

not to scale

FIG 3.3



"brickclay with patches of sand, concretions and a few pebbles." The height of section was 5m. The concretions would almost certainly have been calcareous (race), and are frequently found to be associated with the darker grey and brown upper parts of the Bosworth Clay where carbonate levels are high. The nearby Bosworth Wharf boring records 8.5m (27ft) of drift; the log showing 2m of clay, sand and pebbles above 6.5m of brown clay on top of gypsiferous marls.

### 5. Kingshill Spinney (SK 383016)

Evidence for the greatest thickness of Bosworth Clay is provided by the boring at Kingshill Spinney discussed in 2.2, which records brickclay to 29m (97ft) below the surface (i.e. 56m (183ft) O.D.) Augering at this site with an extending bucket auger yielded the following:

cm	
0	Soil with surface Bunter pebbles, flints and Carboniferous and Triassic sandstones.
55	red-brown smooth clay
75	red-brown clay with grey staining
110	red-brown silts with bands of brown clay
150	grey-brown clay with partings of red-brown silt and fine sand
190	largely silt with some clay, water level below 200cm.
375	

These deposits are similar to those recorded elsewhere and mapped as Bosworth Clay, but whereas laminations have been difficult to detect in most auger samples, (micro-) varve-like bedding is well shown below 1m50 in the Kingshill auger-hole. Couplets of grey-brown and brown clay alternate with coarse silt bands; the average frequency of a couplet being of the order of 5/cm. Inspection of the silty layers under a binocular microscope shows delicate current bedding.



Laminations elsewhere in the Bosworth Clays are indicated both by varve-like changes in grain size and by partings between individual clay laminae which are commonly destroyed in a disturbed auger sample.

The upper surface of the Bosworth Clay is fully discussed below (6.3), but it is frequently a transitional one as the fine grained clays and silts grade into the overlying current bedded sands. Consequently, the boundary is difficult to fix precisely, but in general the transition zone from clay to sand is no more than 1-2m thick. The highest recorded occurrences of Bosworth Clay within the study area are near Barton in the Beans, 114m(375ft); Twycross, 119m (390ft); and Osbaston Hollow, 117m (385ft) which give an upper limit of lacustrine sedimentation in the Hinckley valley. The lowest point reached by the Bosworth Clay is in the Kingshill depression, 56m (183ft), giving a range of heights for the deposit of over 60m (200ft), whilst the thickest record of Bosworth Clay penetrated by any of the boreholes is 35m (114ft) south of Stoke Golding, and the 29m (97ft) at Kingshill Spinney (Fig 2.3). At Basin Bridge Farm (SP 395961), the following is recorded:

	thickness (ft)	depth
soil	1	
red clay	6	7
dark red clay	5	12
sand and gravel	6	18
blue clay	8 $\frac{1}{2}$	26 $\frac{1}{2}$
dark red clay	8	34 $\frac{1}{2}$
sand and gravel	7 $\frac{1}{2}$	42
red clay	4 $\frac{1}{4}$	46 $\frac{1}{4}$
red sand	7 $\frac{1}{4}$	53 $\frac{1}{2}$
soft red clay	21 $\frac{1}{2}$	75
soft blue clay	32	107
soft brown clay	8	115
stiff red clay	10	125
Keuper Marl		

Height of borehole: 106m (350ft) approximately.  
 Height of bedrock: 69m (225ft)



Although minor beds of sand and gravel are recorded this is not regarded as being inconsistent with the interpretation of the top 35m (115ft) as Bosworth Clay, in view of the inter-stratified sands and gravels encountered in the formation at other locations. The 'stiff red clay' immediately above bed-rock may be the Basal Till.

Prominent beds of sand within the Bosworth Clay have been recorded above (Site 3, Harper's Hill). Other patches of sand giving much lighter soils have been mapped at Lodge Farm (SP 398989), Greenhill Farm (SP 407992) where the sands cap a gentle knoll, and less than 0.5km away sands are exposed in a canal cutting near The Poplars (SP 412987) at the same height. In the northern part of the study area, similar sandy knolls surrounded by stoneless clays and silts occur at Hill Farm Bilstone (SK 362053) and Sibson Wolds (SK 369038).

A comparison of Figs 2.1 and 3.1 demonstrates that the Bosworth Clay is banked up against the higher ground of the sub-drift surface which is frequently masked with a veneer of Basal Till. The clay thins towards the east and the north but the feather edge is rarely seen, having been removed by erosion or buried by later deposits. The limit drawn on Fig 3.1 has been compiled from a consideration of the mapped extent of the clay, borehole evidence and interpolation between fixed points in sympathy with the sub-drift surface. It marks the eastern edge of the basin in which the Bosworth Clays accumulated. To the west, the formation can be seen to thin away from the axis of the Hinckley valley where it rests on rising Basal Till slopes at Twycross, Wellsborough and Higham on the Hill. Between these more elevated sites erosion along the lines of the Anker and Sence Brook has degraded the western flank of the basin below the level of the sub-drift surface.



The Basal Till floors much of the basin and is seen as a rim encircling the inliers of bedrock which have been exposed south of Market Bosworth and Sutton Cheney. The Basal Till is not confined to the Bosworth Clay basin, and outside these limits it is directly overlain by sands as at Barwell Fields Farm and Nailstone. Thus the Basal Till occupies a greater height range than the Bosworth Clay.

Particle size analyses performed on samples of Bosworth Clay show high levels of sorting associated with a bedded glacio-lacustrine sediment and confirm that there is a clear distinction in this regard from the underlying till (Table 3.1, Fig 3.2). Silt and sand bands within the sequence are similarly well-sorted although clay is by far the dominant lithology.



4

Cadeby Sand and Gravel



This formation which is widely developed in western Leicestershire has provided a ready source of sand and gravel. Many small sand pits can still be recognized, although even when Fox-Strangways was mapping the drift towards the end of the nineteenth century most of them had been closed. Over the last few years a major pit operated by Tilcon has been working the deposit at Cadeby and has thus provided the best sections in the region and the obvious local type site for the formation, (Fig 4.1). At the time of writing, a large site at Kirkby Lodge linked to the pit at Cadeby is beginning to be worked.

Previous authors have distinguished several beds of gravels and have differentiated them along with the remainder of the drifts on the basis of the provenance of the constituent clasts. The division has usually been drawn between drifts containing erratics of Jurassic and Cretaceous rocks, and those in which only pre-Jurassic rocks are prominent. On this basis it is possible to identify the gravel facies as either 'flinty' or 'pebbly' (Quartzose), the latter referring to Bunter pebbles. There are clear difficulties in applying these terms quantitatively, for those beds which have often been described as 'flinty' gravels may reveal a dominance of Bunter pebbles; the diagnostic feature being whether flints occur in significant numbers. As the classification adopted here is a rock stratigraphic one, the Cadeby Sand and Gravel formation is defined as a nearly continuous horizon of sands and gravels; their composition is variable but in most cases it is the 'pebbly' gravels of other workers.

The working sand and gravel pit at Cadeby has been described by Douglas (1974). It is located near the watershed between the Soar and Anker basins and although the adjacent valleys are floored by Keuper Marl, a considerable



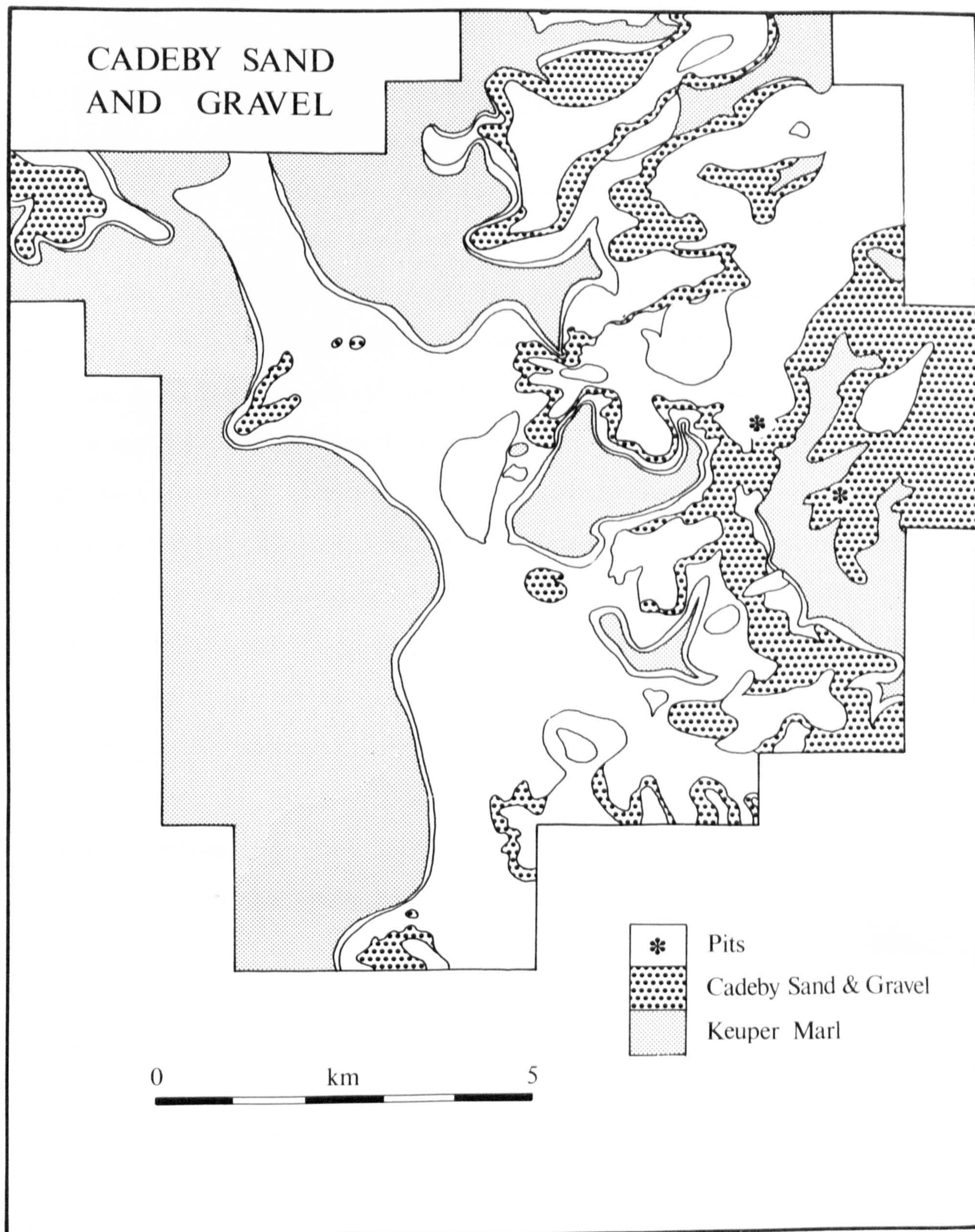


FIG 4.1



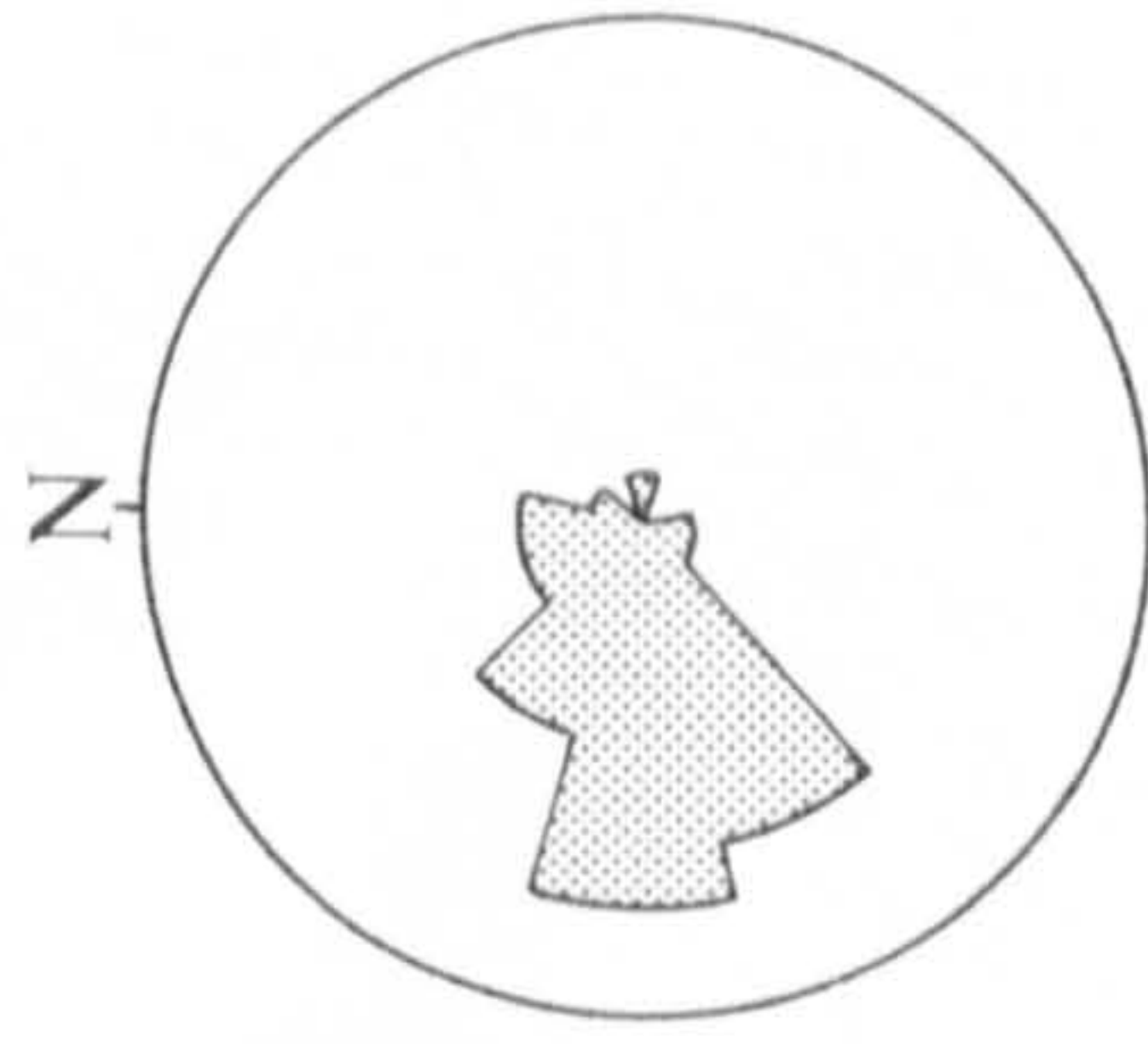
thickness of drift has been preserved on the interfluves. The ribbon diagram (Fig 4.2) illustrates the main elements of the succession as they were exposed in the working face of the pit during the summer of 1974. The floor of the pit is at approximately 120m (395ft) at the foot of this face. The deposit was worked dry and pumps were used temporarily to lower the water table which is otherwise just above the floor of the pit, near the base of the sands.

The lowest beds exposed are brown silts and fine sands. Layers of coal fragments pick out level-bedding. In some of the sandy layers minute cross stratification can be seen. These silts are followed by a well marked series of sands, each bed showing laminar cross stratification. The sands average 3m thick, are completely free from any inclusions of till or other heterogeneous materials and grade upwards into gravels which show cross bedding but are in places poorly bedded and ill-sorted. The Cadeby sands are not bounded by any erosional discontinuities, but are so consistently overlain by gravels that there is a strong case for sub-dividing the formation into two parts.

Measurements made on the direction of dip of foreset laminae in beds of sand at Cadeby indicate that the palaeocurrents responsible for their deposition came from an easterly direction. This is consonant with the local slope of the eastern limb of the Hinckley valley which probably controlled the flow direction of the outwash streams responsible for the deposition of the Cadeby Sand, (Fig 4.2, inset). Sand samples from individual foreset wedges may have different mean grain sizes, but are generally well-sorted with Trask sorting coefficients below 0.5. Isolated lenses of gravel appear within the sand sequence, particularly near the top which is

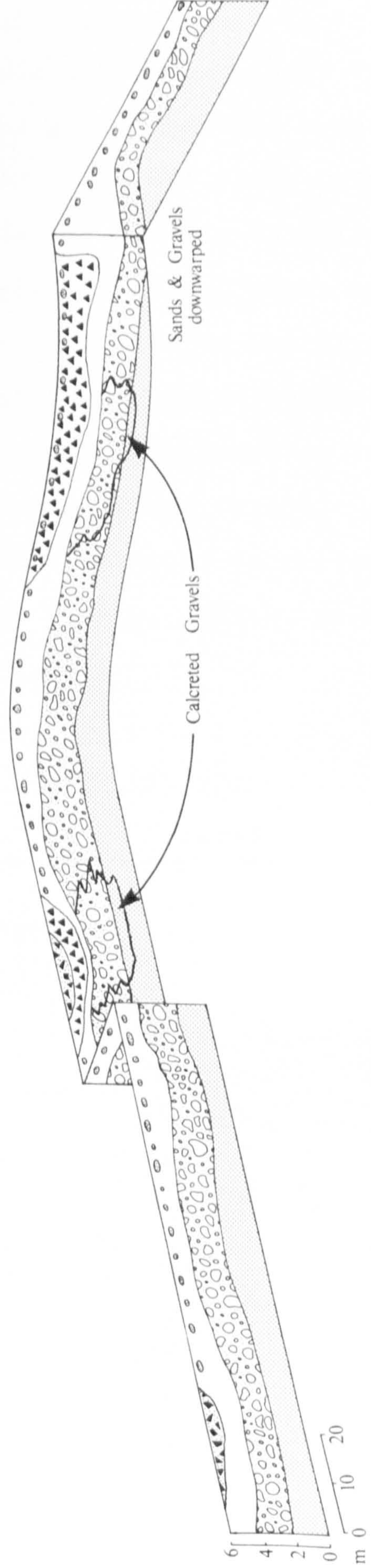


# RIBBON DIAGRAM



DIRECTION OF DIP  
OF 25 FORESET BEDS  
(CADEBY SAND)

- |  |                        |
|--|------------------------|
|  | Periglacial structures |
|  | Flinty gravel          |
|  | Chalky Till            |
|  | Pennine Till           |
|  | Cadeby gravel          |
|  | Cadeby sand            |



TILCON PIT CADEBY, SUMMER 1974



characterised by an increase in mean grain size and a corresponding decrease in sorting.

The Cadeby Gravel is 2-4m thick throughout the pit and is overlain by till where the gravel has not been truncated by the present ground surface. The pit faces afforded an excellent opportunity to sample the gravels at different horizons to detect any change in composition which might in turn be linked with the supply characteristics of the fluvioglacial environment. No such consistent change was observed. The aggregate of these stone counts is presented in Table 4.1, which shows that the Bunter pebbles and Triassic sandstone components dominate. 'Eastern' material is present in small amounts and is represented by flints, oolite, ironstone and Liassic limestones.

TABLE 4.1

Stone Count, Cadeby Gravels

<u>Rock Type</u>	<u>Percentage</u>
Carboniferous limestone and sandstone	6
Bunter Pebbles	52
Triassic Sandstone	34
Jurassic and Cretaceous	7
Others	1

Total count = 1082 stones

In certain places within the pit the gravels have been cemented into a conglomerate with a calcareous cement. The distribution of the calcrete shows a close relationship with overlying outcrops of Chalky Till through which water would have percolated redepositing the calcium carbonate in the interstices of the subjacent beds of the Cadeby Gravel (Plate 3, Fig 4.2). The cemented blocks can be very large,



up to 4m thick and several tens of m<sup>2</sup> in surface area. Apart from the hazard they represent to quarrying operations, they may exert an important morphological control being much more resistant than the unconsolidated sands and gravels.

As displayed in the pit faces the sands and gravels are largely horizontal and the bedding is undisturbed apart from one major structure in the northwest corner of the pit (Fig 4.2). The gravels here have been downwarped towards the north. The northern limb of the structure plunges towards the floor of the pit and a considerable thickness of till is preserved above it. The downwarped limb makes an angle of at least 25° with the horizontal. Surprisingly little disturbance has taken place at the 'hinge' of the structure which is quite sharp. It is clear that the deformation is post-depositional from the angles of the crossbeds preserved on the downturned limb.

The mechanical aspects of this example of glacio-tectonics cannot be identified properly without fuller exposure of the structure. Simple collapse of the overlying deposits as a result of the melting of buried ice may have been expected to have produced a more complex and chaotic structure. The axis of the downwarping trends west-east and might relate to folding as the result of pressure exerted by ice moving from a northerly direction; a situation which obtains in south Leicestershire (see below, 8.1).

By the summer of 1975 most of the sand and gravel immediately north and south of Naneby Farm (SK 434026) had been worked out and the bulk of the extracting operations were removed to Kirkby Lodge. Lengthy conveyor belts linked this site to the plant at Cadeby. Between Kirkby Lodge and The Becks an extensive flat at 125m (410ft) is edged by the steeper slopes of the Cadeby Sand and Gravel scarp. The sequence as



displayed in the first sections opened, closely parallels that at Cadeby but a thin band of till, no more than 1m thick, appears near the base of the sands. It would be difficult to interpret this as Basal Till for although there would be no objections on lithological grounds, in those areas outside the limits of the Bosworth Clays a break in sedimentation occurred between the deposition of the Basal Till and the Cadeby Sand and Gravel (see below, 7.1). This is the only observed occurrence within the study area of a till lens in the fluvio-glacial sequence. The erratics in the till are of similar provenance to those in the sands and gravels which in turn are closely comparable with those recorded in Table 4.1.

There is enough evidence to support the view that the edge of the sands is warped downslope near Fox Covert (SK 441016). The till layer parallels the bedding in the sands and is similarly warped. It is estimated that this 'cambering' may bring the base of the sands as much as 5m (16ft) below the undisturbed level of this horizon.

#### 4.2

The pits near Cadeby being the only operative ones in the study area, most of the mapping of the Cadeby Sand and Gravel has relied on augering. Several old sandpits can be detected in the landscape. On the six inch geology map of Market Bosworth (1901) no fewer than 15 old pits are recorded (a density in excess of  $1/\text{km}^2$ ). Most of them were shallow workings which supplied the needs of individual farms. In many such pits it is still possible to assess the facies of the gravel as 'flinty' or 'pebbly'.

In similar fashion to other formations higher in the drift sequence, the Cadeby Sand and Gravel frequently out-



crops on the upper slopes of the valleys which have dissected the drift. Characteristically too, the formation is underlain and capped by clays, and its greater resistance to erosion has resulted in steeper slopes along many of the valleys in the northern and eastern part of the study area. The River Sence between Osbaston Hollow and Bagworth shows such a 'scarp' well, its development being more pronounced on the north-facing slopes than those facing south. The ridge on which Market Bosworth stands is flanked by outcrops of the Cadeby Sand and Gravel which form the steeper slopes above 110m (360ft) (Plate 4). Whitehead et al. (1923) recognized this relationship further south: "Around Hinckley the junction of the red sands, loams and clays of the Upper Boulder Clay Series with the brown silt of the Lower Boulder Clay is frequently marked by a sharp rise in the ground, as well as by a total change in the character and colour of the soil." (p.110).

The contact between the sands and the Bosworth Clay is commonly associated with a spring line often picked out on aerial photographs as vegetational flushes which are useful in corroborating the augering evidence. The spring at Richard's Well on the site of the Battle of Bosworth is one such example. Ambion Hill (SK 403002) is set aside from the main outcrop of sand and gravel at Sutton Cheney as a small outlier. The slopes on its northern side are quite steep ( $8^{\circ}$ ) and there are signs of slumping of the sands over the stoneless clays. A considerable veneer of sandy 'wash' often masks the clays downslope from the sand and gravel outcrops. On numerous occasions it was necessary to use an extending auger to reach deposits unaffected by this 'wash'.

At Sutton Cheney there is evidence to suspect that the



Cadeby Sand and Gravel may be downwarped towards the valley and that its mapped lower limit may be below its corresponding position near the centre of the interfluve. A borehole near the centre of the village records the base of the sand and gravel at 108m (355ft), whereas its outcrop on the adjacent slopes is rather lower: 104m (340ft) to the southeast at SK 420001.

Field mapping then, has been supplemented with a certain amount of morphological evidence to reconstruct the Cadeby Sand and Gravel outcrop. Apart from those areas, extensive in the west and restricted to valley floors in the east, where the underlying Bosworth Clay, Basal Till or bedrock has been exposed, the sand and gravel horizon describes a sheet of material which at one stage covered virtually all the study area. One diagnostic feature of the formation is the 'coarse-up' arrangement, with fine sands overlying the Bosworth Clays and coarse gravels at the top of the sequence.

At Nailstone Gorse there is a thick spread of gravels edged to the north by steeper slopes and capped with till which is exposed on the crest of the interfluve. Following the edge of the sands westwards into the small re-entrant at The Fish Pond (SK 401070), the junction with the Keuper Marl (there is no Basal Till at this point) is marked by a spring at 117m (385ft). The sand is reddish-brown in colour and is well sorted. The overlying gravel is flinty with flints comprising rather more than 15% of the clasts and is very difficult to auger into. The same outcrop can be traced to Barton in the Beans where it oversteps the edge of the Bosworth Clays and forms a bold but rounded hillock immediately to the west of that village. The point of establishing the continuity of this section of the Cadeby Sand and Gravel



between Nailstone and Barton in the Beans is to show that facies changes can be identified on a local scale for the gravels capping the hillock at Barton in the Beans show very few flints and are more consistent with the composition of the Cadeby Sand and Gravel at the Cadeby pit (Table 4.1). The lower limit of the sand and gravel along this outcrop shows no sharp discontinuities, rather a gentle decline in elevation in a westerly direction.

Further west, away from the ridge of higher ground along the Soar/Anker watershed, there are important outliers of Cadeby Sand and Gravel at Twycross, Wellsborough, Ambion Hill and Higham on the Hill, (Fig 4.1). At Wellsborough the capping of fluvioglacial material is no more than 5m (16ft) thick, thus the Cadeby Sand is exposed at the surface and the gravels have been largely removed. The nearby Hoo Hills have similar small cappings of sand, although here, nearer the centre of the Bosworth Clay basin, the horizon is much lower at 104m (340ft) than at the western edge of the Wellsborough outcrop where it reaches 114m (375ft). The full implications of this height variability of the Cadeby Sand/Bosworth Clay interface are discussed below (6.4).

The area between Newbold Verdon and Kirkby Mallory is a flat-topped plateau over 122m (400ft) in height. A patch of till covers the sands at Brascote, but elsewhere the soils are very sandy with numerous Bunter pebbles and augering has confirmed the continuation of the Cadeby Sand and Gravel into the Soar basin. At several locations on the flanks of the upper Thurlaston Brook valley, the sands can be observed resting directly on a surface of Keuper Marl, and at only one point was Basal Till suspected. At Kirkby Noats (SK 452017) the gravels were worked until fairly recently, but the pit has



been flooded and tipped leaving no good sections. The facies of the gravel in this eastern area is certainly pebbly, flints being very scarce.

From the evidence presented above, it is contended that the Cadeby Sand and Gravel represents part of a once almost continuous sheet of fluvioglacial material interstratified with the other drifts. The continuity of the formation within the study area and its demonstrable continuation outside it (see below, 7.1), make it a particularly valuable marker horizon as a plane of reference to which other drifts may be referred as either inferior or superior; thus its identification is the key to regional correlation.



5

Pennine and Chalky Tills



The previous chapters have described the lower members of the Pleistocene succession in western Leicestershire, distinguishing a Basal Till and Bosworth Clays which are followed by the extensive Cadeby Sand and Gravel horizon. Above the gravels the sequence reverts once more to clays: the Pennine and Chalky Tills. Although the two till lithologies are readily differentiated in the field, mapping them as separate formations was found to be problematic as the relationship between them is often a very complex and intricate one. However, Fig 5.1 indicates those areas where each type is dominant and includes the Flinty Gravels described at the end of this chapter.

Fox Strangways (1900) recognised several spreads of boulder clay. Much of this material has been interpreted here as Bosworth Clay, but undoubted tills cap the higher ground of the watershed area between the Soar and Anker. He observed that: "the clay principally consists of local materials mixed with well-rounded quartzite and other pebbles; and generally contains, but not always, some fragments derived from the Jurassic rocks and Chalk, the latter being in many places so numerous as to form a regular Chalky Boulder Clay." Whitehead et al. (1923) demonstrate that the major sand and gravel beds in the vicinity of Hinckley are followed by a brown boulder clay with flints, fragments of chalk, pebbles of Jurassic limestone and derived fossils, but made no mention of a 'non-Eastern' till in the upper part of the succession.

The study area lies near the western edge of the Chalky Boulder Clay outcrop as outlined by most workers (Harmer, 1928; Clayton, 1953; Perrin et al. 1973), yet it is once again this disparity between Eastern and non-Eastern drifts which is the most meaningful one in any attempted subdivision of the tills which postdate the Cadeby Sand and Gravel, even though, as will



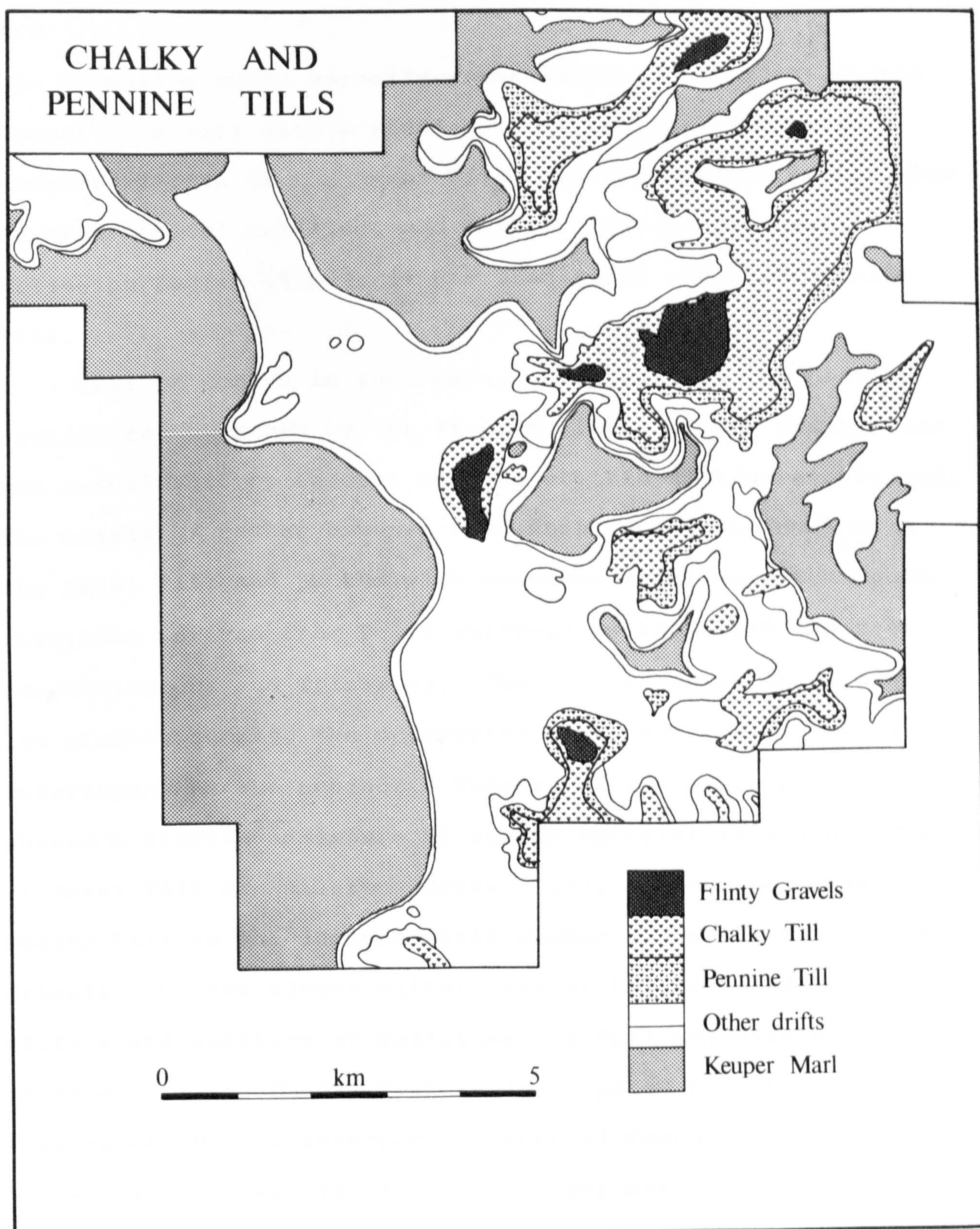


FIG 5.1



be argued later, the distinction has led to some misinterpretations of the glacial history.

## 5.2

The formation which normally rests conformably on the Cadeby Gravel is a till with a reddish-brown matrix, similar in characteristics to the Basal Till, but occupying a much higher stratigraphical position, and better exposed by dissection. Following Deeley (1886), it has been given the name Pennine Till.

East of Barton in the Beans, augering into the plateau defined to the north by the steeper slopes of the Cadeby Sand and Gravel outcrop several samples of this till were obtained. The matrix is rather browner than that sometimes found with the Basal Till and packed with numerous erratics which could have been derived from solid outcrops in the north and west (Carboniferous and Triassic). The till is quite thick near the plateau summit, the underlying sands and gravels rarely outcropping at the surface. Patches of the till capping showed a similar admixture of chalky material to the outcrop of Basal Till at Nailstone Gorse (3.1), and further east, Chalky Till is the dominant till member above the top of the gravels. On the slopes either side of the road joining the village and colliery of Nailstone the full sequence of gravel, Pennine Till and Chalky Till is developed. The Chalky Till is very extensive and incorporates several fragments of oolite, marlstone and Lias limestones in a grey matrix which varies in hue from a blue-grey to brown-grey. South of Nailstone colliery the Chalky Till reaches a level of 150m. (493ft), but thins eastwards against the rising bedrock surface (Fig 2.1).

On the B582 1km southeast of Barlastone a well record



showed 12m (40ft) of Chalky Till. The boring was at 139m (456ft) and was entirely in Chalky Till. This represents part of a large sheet of till which stretches from near Bagworth to Osbaston, Cadeby and Market Bosworth. Characteristically, the upper parts of this till sheet comprise Chalky Till and the lower Pennine Till. This pattern has resulted in the Chalky Till appearing at the surface over most of the area where its presence is indicated by plentiful flints in the topsoil and can be confirmed by augering. Pennine Till outcrops to the east of Garland Lane Farm (SK443065), but is overlapped westwards by Chalky Till and Flinty Gravel. At Cow Pastures (SK 414038), an old boring recorded 12m (40ft) of boulder clay, the uppermost part of which is Chalky Till. The same outcrop of Chalky Till can be traced around the slopes at Market Bosworth, but Pennine Till was recorded to a depth of 3m in an auger hole in Bosworth Park only 5m away from a similar hole in good Chalky Till.

To the south of Market Bosworth the postglacial stream incision has totally removed the drift cover over a wide area but a fairly full succession is exposed as the ground rises towards Sutton Cheney. Opposite the Greyhound Inn (SK 419008) deeper auger holes frequently showed the interdigitation of both Pennine and Chalky Till with little mixing or reworking of the till types as the matrix colourings were quite distinct with sharp junctions between the two types. Bands of Chalky Till no more than 10cm thick were interleaved with the Pennine Till which had been mapped on the lower slopes to the south and north. On the lane between Sutton Cheney and Sutton Wharf the sand and gravel outcrop below the Pennine Till appears to be missing. At this point and near the vicarage at Sutton Cheney the tills extend well below the level of the Cadeby Sand and



rest unconformably on the Bosworth Clays. A similar tongue of till cuts across the sands at SK 412009. It is entirely composed of Chalky Till, the red Pennine Till being locally absent.

Local unconformities exist elsewhere at this point in the succession. At Stoke Golding, the Cadeby Gravel is followed by the Pennine and Chalky Tills, but near Dadlington the tills are found to rest on Bosworth Clays at relatively lower heights. Closely spaced augering around Dadlington has revealed the pattern of this apparent 'overstep' of the tills onto successively younger beds. The plane at the base of the Pennine Till truncates the Cadeby Sand immediately to the south of Dadlington village at a height of 104m (340ft). From the point at which the Ashby Canal is carried over the Tweed river (SP 411985) to the Manor House (SP 405980), the shortened sequence with the sands and gravels missing is displayed. On the valley floor alluvium overlies both clays and silts of the Bosworth Clay. The stoneless clays are followed at 91m (300ft) by Pennine Till with bands of chalky material within it and the Chalky Till becomes dominant near the crest of the hill which is capped by flinty sands and gravels. Thus not only is an unexpected thickness of till preserved here, but its lowest point is at least 15m (50ft) below the height at which the horizon is found immediately to the south where it rests conformably on the Cadeby Sand and Gravel. To the east at Stapleton, Chalky Till is found on the highest point of the interfluvium (SE 436987) where augering has shown that it rests on gravels. The same till sheet is found much lower down the slopes near Elms Farm (SP 429989) and the Bradshaws (SP 427981) where it appears to lie in a shallow trench which has been cut through the sands and stoneless clays. Isolated patches of till at Stapleton Wood (SK 430002) and Hangmans Hall



(SP 427981) provide further examples of the till resting on formations older than the Cadeby Gravel. A deep drainage ditch at Island Lane Farm (SK 429000) showed Chalky Till truncating both Cadeby Sands and the underlying Bosworth Clay. There is no evidence of the Pennine Till here.

The most significant area where low-lying till is found which cannot be associated with the Basal Till is between Coton and Shenton. The cuttings along the line of the abandoned railway have provided some sections and reveal that the till is almost exclusively chalky. Its relationship to the Bosworth Clays is difficult to assess for sand horizons have been noted both above and below the till here and the whole zone of low-lying drift seems to be incised into the surrounding lacustrine sequence. The picture is further confused by extensive sand horizons within the Bosworth Clays. The cutting adjacent to Near Coton (SK 391023) shows alternating bands of sand and stoneless clays. One of the more substantial sand horizons gives rise to a small scarp running to the north of Near Coton and has been worked in shallow pits between Coton canal bridge and the railway. Chalky Till undoubtedly overlies this sand to the south where the till exceeds 4m in thickness. Above the Chalky Till patches of sand with lenses of pebbly and flinty gravel can be detected. It is tempting to recognise this entire sequence as the normal one with few, if any, breaks in sedimentation but merely invoking some sort of vertical displacement to explain the occurrence of Chalky Till as low as 90m (295ft). There is no observable continuity, however, between these beds and the 'normal' sequence at Market Bosworth. Bosworth Clays outcrop to the east at higher levels than the low Chalky Till. Furthermore, the Cadeby Gravel is not represented at Coton, nor, more significantly,



is the Pennine Till. The overlying sands and gravels which contain eastern material are related to the Chalky Till.

The problem of these limited areas of till which do not fit with an otherwise orderly sequence of drifts is more fully analysed in Chapter 7 where an attempt is made to reconstruct the events associated with this ice advance.

### 5.3

With certain exceptions noted above, it has been established that the pattern of tills which followed the Cadeby Sands and Gravels is for the reddish-brown Pennine Till to be overlain by the Chalky Till. A similar relationship has been described by Rice for the Oadby Till of central Leicestershire. In distinguishing Lower and Upper Oadby Tills Rice (1968) observed that: "The Oadby Till normally has a matrix derived from the Lias Clay, but very locally near the base a Keuper Marl matrix has been noted." This differentiation is in close parallel to the Pennine and Chalky Tills of western Leicestershire. At the Tilcon pit, Cadeby the sections cut through the tills have enabled a much closer study to be made.

Table 5.1 gives the stone counts of pebbles taken from samples of Pennine and Chalky Till at Cadeby. The count from the underlying Cadeby Gravel is appended for reference. The Pennine Till erratic suite is closely comparable to that of the subjacent Cadeby Gravel but shows a small absolute increase in the percentage of eastern material. These stone counts have been based on pebbles with a long axis of at least 1cm and have thus tended to omit the coal fraction which due to its highly friable nature introduces counting problems. It is however present in both till types, often scattered as small flocks within the matrix.



Table 5.1

Stone Counts - Tills, Cadeby

	Pennine Till	Chalky Till	(Cadeby Gravel)
Rock Type	Percentages		
Carboniferous	5	0	6
Bunter pebbles	53	13	52
Triassic sst.	26	5	34
Jurassic and Cretaceous	15	81*	7
Others	1	2	1

\* This total can be subdivided:

Chalk	38
Flint	12
Jurassic (mainly oolite, ironstone and Lias 1st.)	31

The matrix types of the two tills are immediately separable in terms of colour. The Chalky Till is essentially grey or grey-brown when unweathered, being largely derived from the Jurassic clays to the east and contrasts with the much redder Pennine Till matrix which is the product of ice movement over the extensive Triassic outcrops to the north and west. The distinction extends to the mechanical composition of the tills. Perrin et al. (1973) present the results of particle size analysis on 246 samples of Chalky Boulder Clay taken from eleven counties including Leicestershire. They reported no systematic differences and demonstrated the remarkably uniform nature of the mechanical composition. The mean value of their results from South Lincolnshire and Leicestershire accords well with the results from west Leicestershire obtained during the course of this research and has been plotted on the texture



# PARTICLE SIZE ANALYSIS

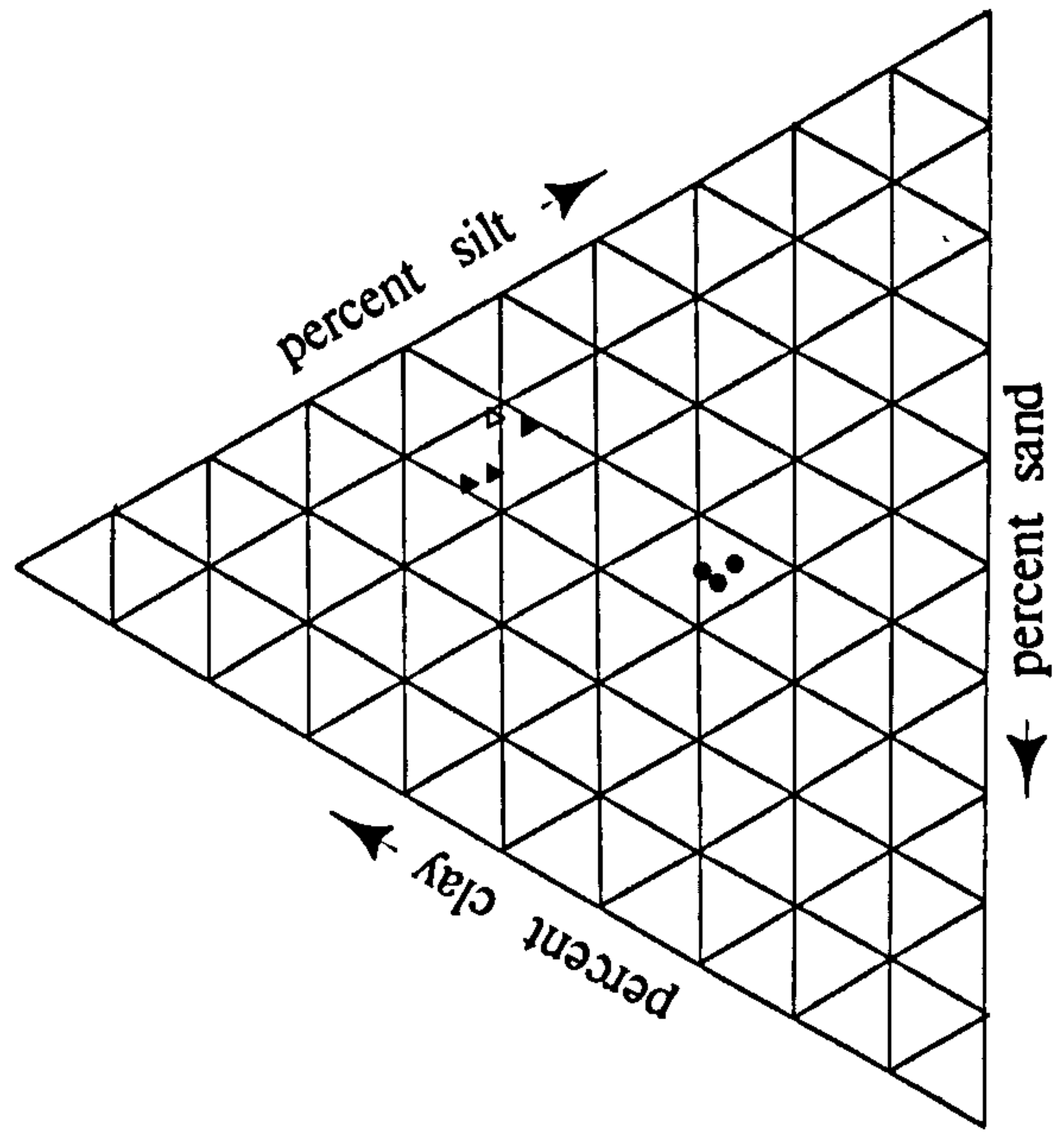
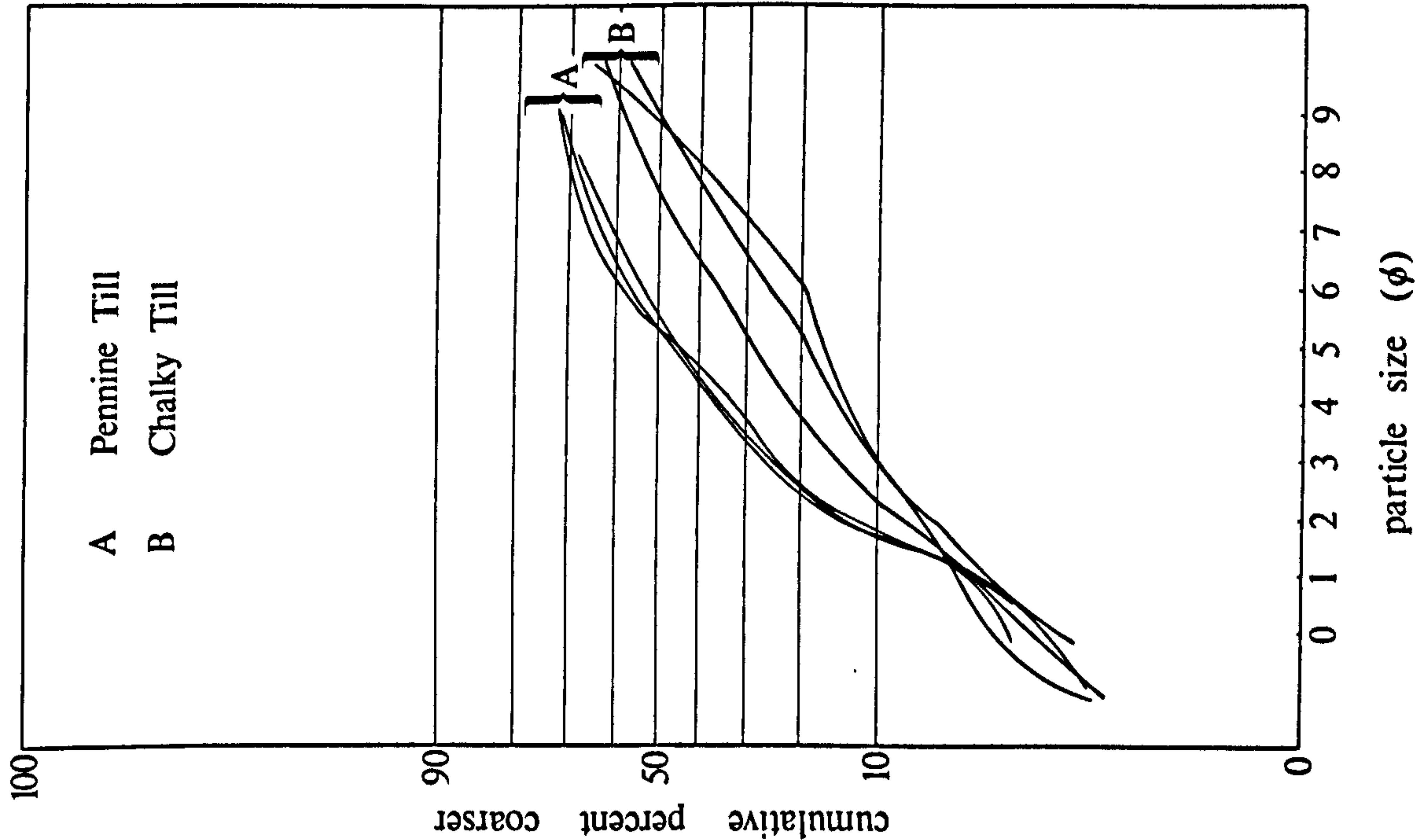


FIG 5.2



TABLE 5.2

Particle size analysis: Pennine, Banded and Chalky Tills

Sample Location	1.18	.600	.300	.212	.150	.075	(mm)	Pipette Analysis	Trask Sorting Co-ef
	2.00	1.18	.600	.300	.212	.150	.075	.020 .006 .002	
Cadeby	0.8	2.0	2.3	2.6	2.6	3.4	4.2	15.2 19.8 48.0	4.67
Sutton Cheney	2.4	1.4	1.8	1.7	1.8	13.1	6.2	14.4 20.1 47.1	3.26
Dunton Bassett	0.9	1.8	4.3	2.8	3.5	6.9	13.7	13.5 10.4 42.2	5.78
Cadeby 5	0.8	1.5	1.8	2.5	2.5	4.3	9.1	12.3 13.8 51.0	4.58
Cadeby 4	0.3	0.3	1.4	2.5	1.2	2.7	6.9	11.1 15.7 57.9	3.63
Cadeby 3	0.9	1.0	4.8	4.9	4.7	7.4	18.1	11.5 11.9 34.8	4.81
Cadeby 2	0.8	1.1	2.4	2.7	2.5	3.4	7.8	14.1 11.0 54.2	5.11
Cadeby 1	1.0	1.7	7.5	8.0	6.1	9.3	15.1	14.6 8.9 27.8	4.81
Cadeby	0.1	0.2	2.4	2.9	3.2	12.1	23.3	12.3 19.4 24.0	3.56
Cadeby	0.1	0.9	6.6	7.2	6.1	8.1	24.4	10.5 5.3 28.8	5.41
Cadeby	1.4	1.3	8.2	8.0	6.4	8.8	19.5	11.1 9.3 26.0	4.81

Chalky Till

Banded Tills

Pennine Till



diagram (Fig 5.2). The Pennine Till matrix (less than 2mm effective spherical diameter) is considerably coarser than that of the Chalky Till. This is shown on the particle size summation curves and in the way which samples cluster in different areas of the ternary diagram revealing their discrete textural identities (Fig 5.2, Table 5.2). About 50 per cent of the Chalky Till matrix is clay compared with only about 30 per cent for the Pennine Till which comprises a correspondingly greater total of sand-sized particles probably derived from the disaggregation of Carboniferous and Triassic sandstones.

The precise relationship between the two till types as exposed at Cadeby is a very intricate one. The scale of Fig 4.2 is too small to permit anything but the gross relationship of the two beds to be shown, and it is clear as elsewhere in the study area, that the Chalky Till follows the Pennine Till. In the northwest corner of the pit a thick wedge of till has been exposed above the gravels which have been downwarped at this point. The lowest layer of Pennine Till is entirely compatible with that recorded elsewhere and rests with a sharp, conformable junction on the Cadeby Gravel which in its upper layers has been calcreted. Above this in a zone extending for 1-2m the tills appear to be stratified with alternating thin bands of predominantly Chalky and predominantly red Pennine Till. Fig 5.3 shows a measured column of the sequence and depicts fifteen alternations between the two till lithologies. Some of these bands of till can be traced over 20m along the face of the pit and show a surprising degree of persistence. At the northern end of the exposure the bands wrap around a steeply inclined nose of Chalky Till. One or two of the narrower bands thin out until they become an almost imperceptible streak. The banding is picked out by the alternating



colours of the matrices and on inspection, the clasts contained within the till bands are consistent with that which would be expected from the two till types, very little chalk or flint being found in the red bands.

The banded tills strongly support the interpretation of this ice advance as a compound one with the contemporaneous existence of two parent ice masses. The published literature contains very few descriptions of tills showing similar banding. However, near Aberdeen red and grey Devensian drifts associated with different ice masses are interbedded (Murdoch, 1975); near Sileby Rice (pers. comm.) has reported the chalky and red tills to be interdigitated and at Derby Jones (pers. comm.) has recorded similar alternations of northern and eastern drift types. At Clava, Inverness; Peacock (1975) described thin tills which he suggested had been deposited as flows-till. The closely spaced variation in the lithology of these tills suggested that "these flows were derived from dirt bands containing debris derived from several sources". (p.36) The author has seen this interbedding displayed at the junction of the red and chalky till types at Huncote (SP 514983), near Leicester and many auger holes in the study area have enabled this interbedding to be detected.

Particle size analyses of samples from the column of till are shown in Fig 5.4 (Table 5.2). The sample from the Pennine Till at the base of the sequence showed the characteristically low clay content (less than 30 per cent) associated with this member of the succession. Samples from thin red bands of till which were interstratified with the Chalky Till showed a much larger and more variable clay content, so that in terms of mechanical composition differentiation between the bands was not possible, although as has been established above, the



# BANDED TILLS, CADEBY

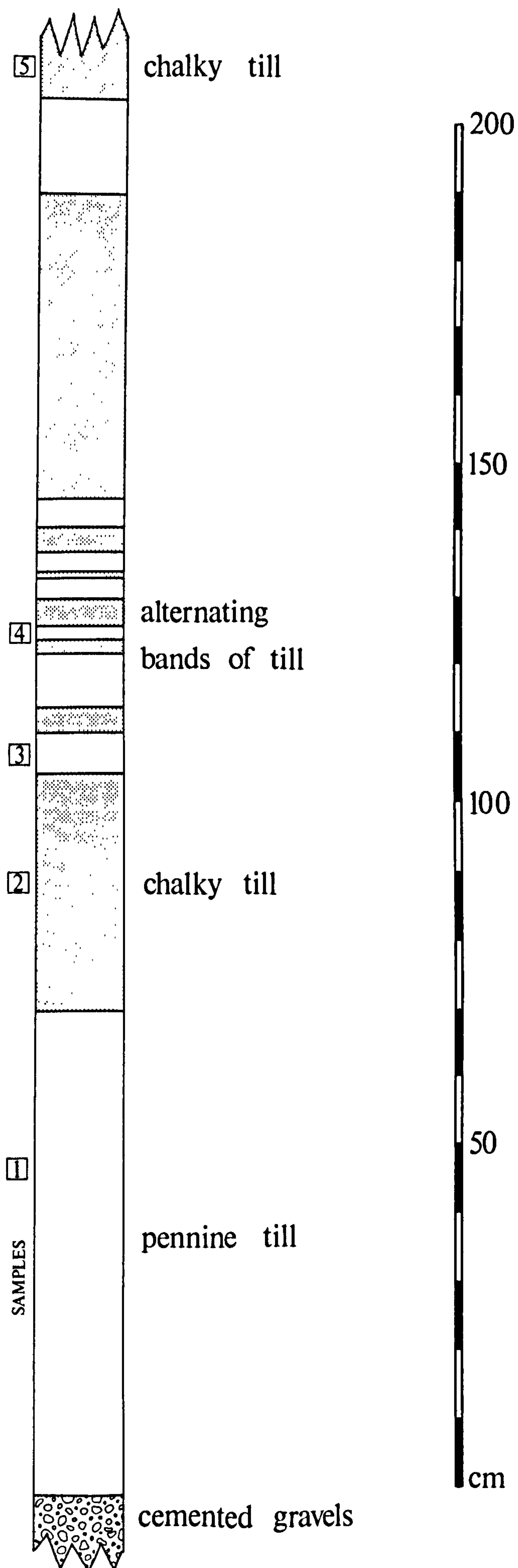
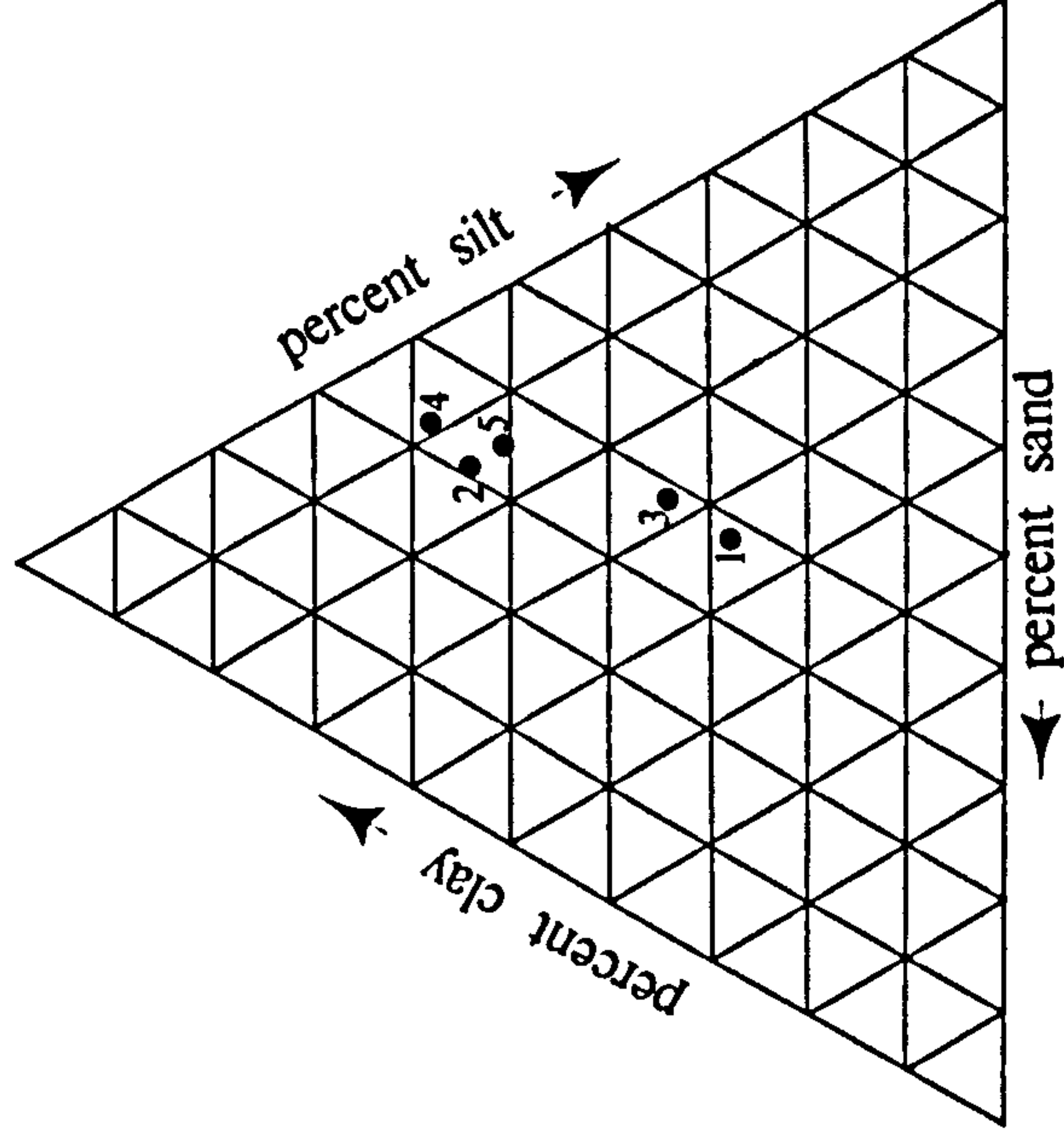
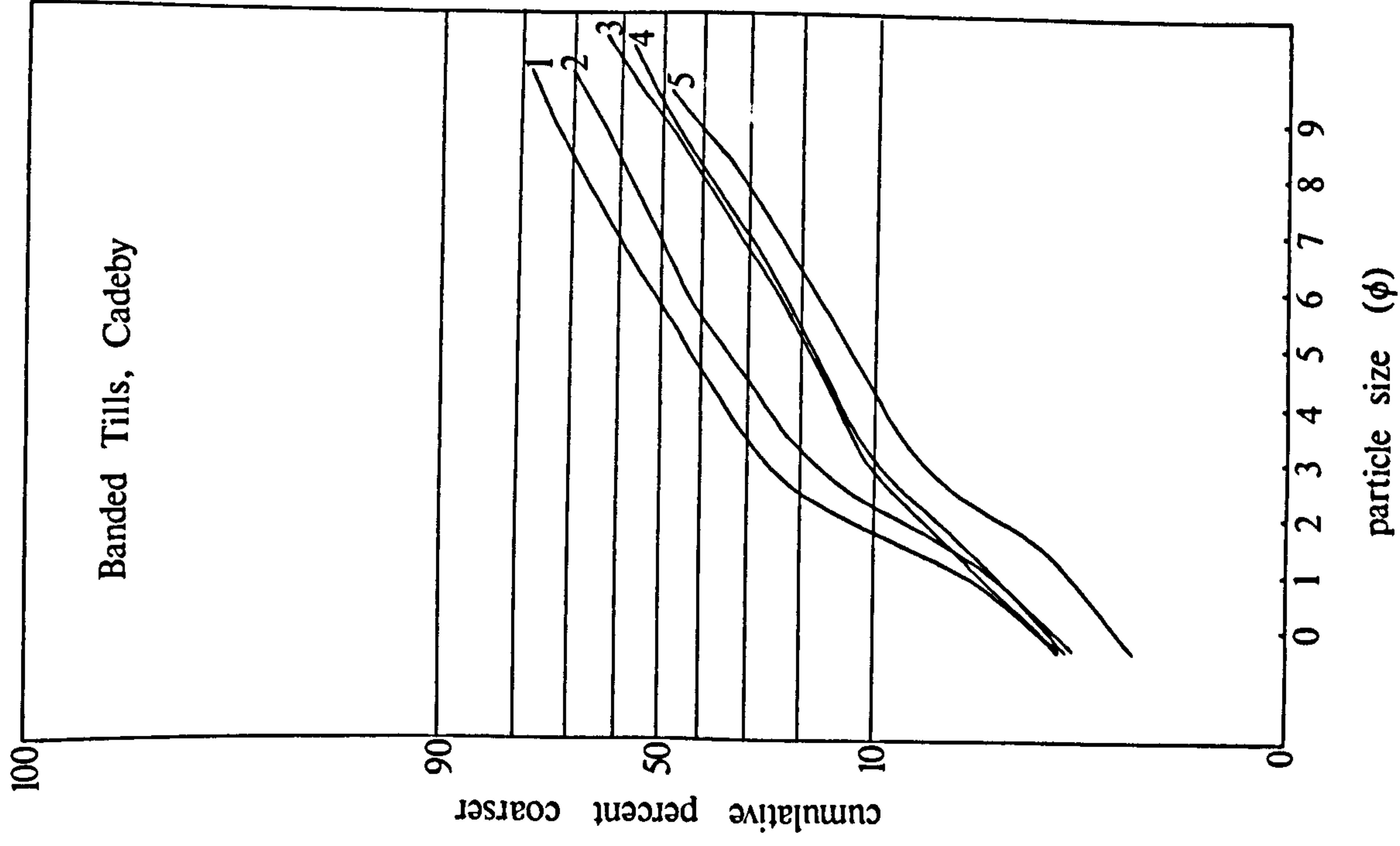


FIG 5.3



# PARTICLE SIZE ANALYSIS



Sample numbers refer to

Fig 5.3



colouration and erratic content of the bands indicate a different ultimate source for the two till matrices. The red colour of some of the bands not being so pronounced as that of the Pennine Till may be indicative of a limited mixing of the two matrix types. Nevertheless the boundaries between individual bands are very sharp indeed and the grey chalky bands seem unaffected by mixing with the red material in respect of colour and particle size.

The bands of till are not entirely horizontal. In the plane of the pit face they describe a gentle syncline which nearly parallels the downwarped surface of the Cadeby Gravel but at the northern edge of the exposure of Chalky Till, the bands dip quite steeply towards the south and the Pennine Till thickens from approximately 1m to over 3m. Superimposed on this synform are several small folds and minute faults all of which can readily be traced on the banded tills. The folds involve only a limited flexuring of the beds and the maximum throw on the faults is no more than 5cm. These structures are believed to relate to the phase of deformation which was responsible for the downwarping of the underlying sands and gravels and discussed below (Chapter 7).

#### 5.4

There is a growing body of empirical and theoretical work on modes of till deposition, the associated macrofabric types and fabric-forming processes (Boulton, 1970, 1972; Andrews and Smith, 1970; Mark, 1974). It is becoming clear that till fabrics alone can yield little of value in terms of inferring either the mode of till deposition or the direction of ice movement (Rose, 1974).

At Cadeby several problems presented themselves. Firstly,



the thickness of till exposed is generally no greater than 3m, often only 2m. The effects of weathering can be seen to a depth of 2m below present ground level and periglacial structures (see 9.2) have resulted in a cryoturbated layer beneath the soil. Consequently only a limited layer near the base of the till sequence has been able to provide undisturbed samples. This constraint was particularly severe on the exposures of Chalky Till, only one of which (that above the banded till sequence) was suitable and this face was rapidly affected by slumping. Secondly, the nature of the clasts within the till is such that very low a/b axis ratios had to be accepted. Few blade- or rod-shaped particles occur in an erratic suite which has a large component of Dunter pebbles, skerry and sub-rounded chalk and limestone fragments. This restriction is thought not to have materially affected the character of the fabrics and tests have been carried out to show that the preferred orientations do not become notably more significant when the pebbles with weaker a/b ratios are excluded (Appendix 3). In practice no pebble has been used with an a/b ratio of less than 5:4, usually 3:2. Only those pebbles with a-axes between 1 and 10cm were measured.

Following Andrews (1971), it was decided that three dimensional macro/fabric analysis has the potential to yield much more information than simple two dimensional (horizontal plane) analysis with relatively little extra expenditure in processing effort and time. A program modified from that presented by Andrews and Shimizu (1966) was used to compute the vector analysis and print out the fabric diagrams, but greater reliance has been placed on the statistics generated from the eigenvector program developed by Mark (1973). Mark has shown that standard rotational vector techniques based on



unidirectional data rotated onto a hemisphere and tested by the Fisher distribution (Fisher, 1963) can give false results (see also Sheidegger, 1965). The eigenvalue method which transposes the matrix of Cartesian co-ordinates associated with any one axis treats the distribution as spherical and thus overcomes the problem of assigning a 'directional sense' to each observation. In other words, each observation is treated as an axis rather than as a vector which is by definition unidirectional. Output from the program supplied by Mark gives the three eigenvectors of each sample with their associated eigenvalues. The largest eigenvector gives the axis of maximum clustering of the pebble a-axes (the preferred orientation), and the smallest eigenvector yields the axis of minimum clustering which approximates to the pole to the plane of maximum clustering. The related eigenvalues indicate the strength of this clustering and can be tested against random fabrics in order to derive the statistical significance of the preferred orientation (Mark, 1973, 1974).

Eleven samples each of 25 stones were examined and the results are presented in Tables 5.3 and 5.4 with contoured diagrams of the fabric types shown in Figs 5.5 to 5.8. The fabric diagrams 1-8 represent the eight samples taken from the Pennine Till. Each sample was collected from an area of face no more than 50cm square. Stones were marked with paint in the field and reorientated in the laboratory where the a-axes were defined and measured. The constraints on sampling mentioned above prevented any systematic vertical sampling pattern as suggested by Andrews (1971) or used by Rose (1974). Samples 1-8 were taken exclusively from the basal metre of the Pennine Till. These samples fall into three groups although the entire set was taken from pit faces so that no



sampling point was more than 50m away from any other. Samples 1-3 and 4-6 were taken from two sites where each sample was only 2m from the others in the group and where the Pennine Till lay conformably and horizontally over the Cadeby Gravel. Samples 7 and 8 were taken from the Pennine Till where it underlies the banded tills and the whole sequence has been folded.

TABLE 5.3

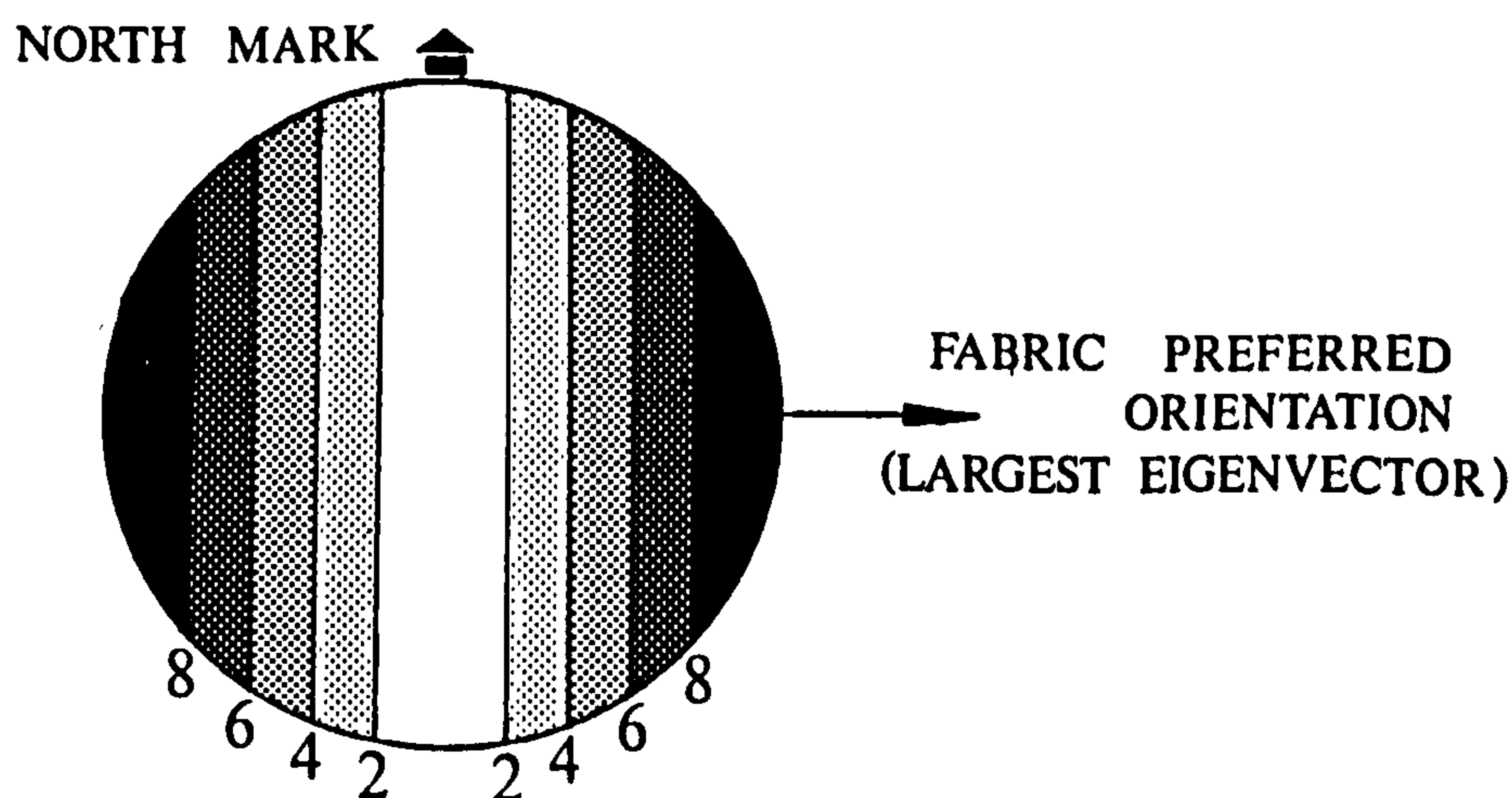
Till Fabric Preferred Orientation, Cadeby

Sample	After Andrews (1971)		After Mark (1973)	
	Orien- tation	Dip	Orien- tation	Dip
1	106	11	107	10
2	113	11	128	29
3	125	7	130	18
4	122	20	127	23
5	160	13	161	13
6	128	9	128	13
7	279	3	284	2
8	89	11	91	11
9	120	9	133	10
10	299	1	309	9
11	287	11	289	11



# KEY TO TILL FABRIC DIAGRAMS

Contoured fabric diagram:  
Interval = two  
standard deviations.  
Upper hemisphere.



## SUMMARY OF SAMPLE MEAN VECTORS (Polar equidistant nets : lower hemispheres)

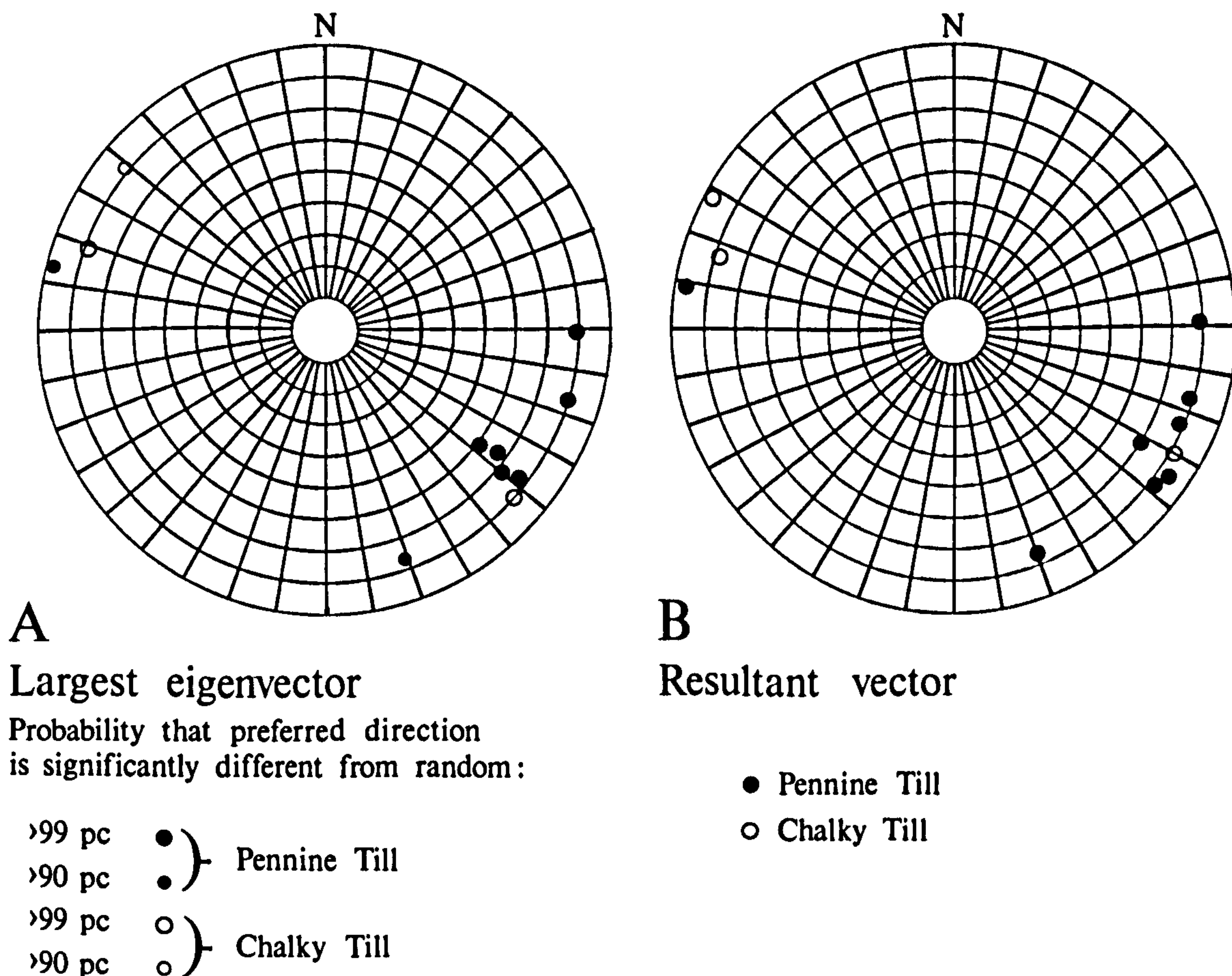


FIG 5.5



PENNINE TILL FABRICS

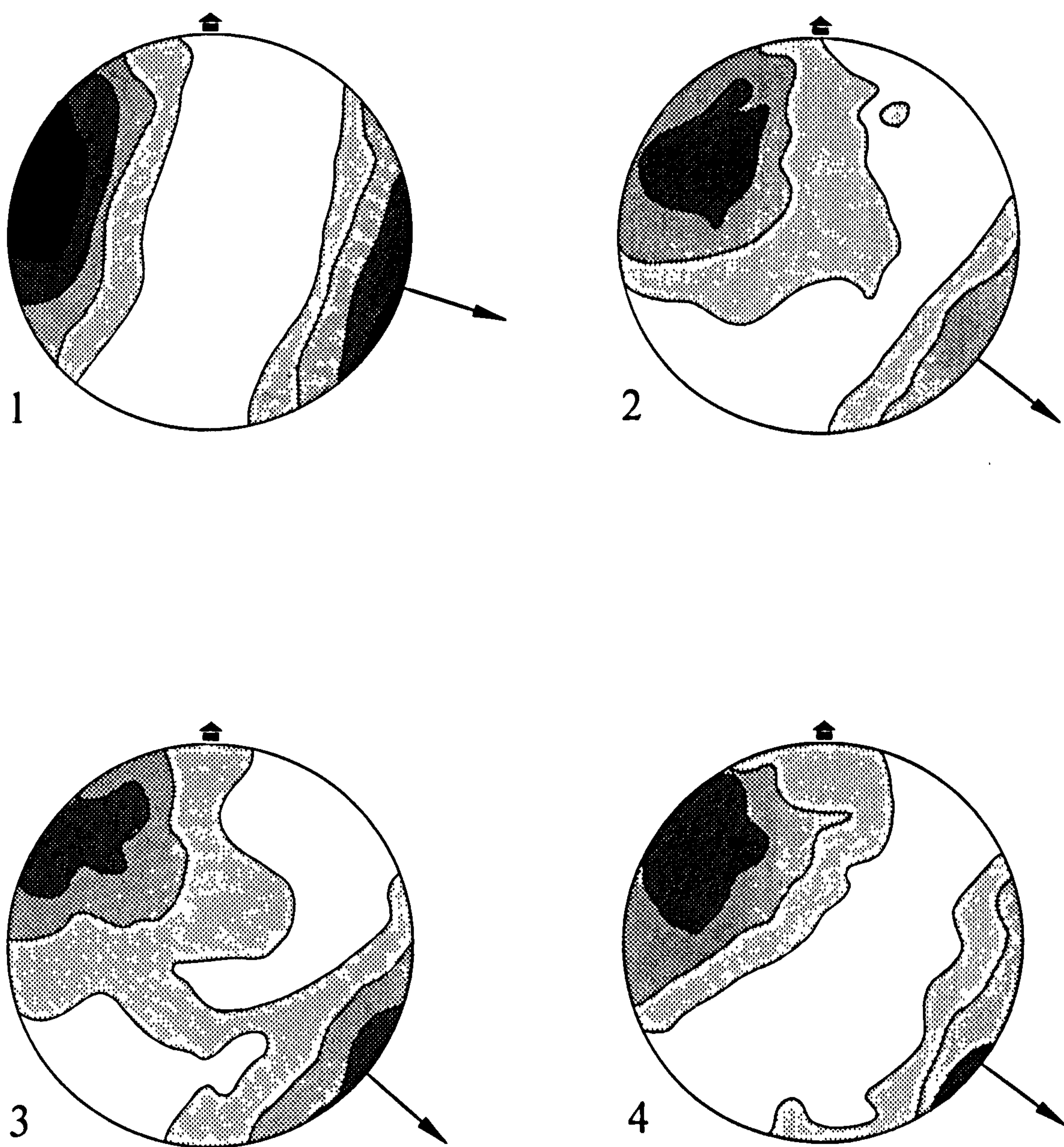


FIG 5.6



PENNINE TILL FABRICS

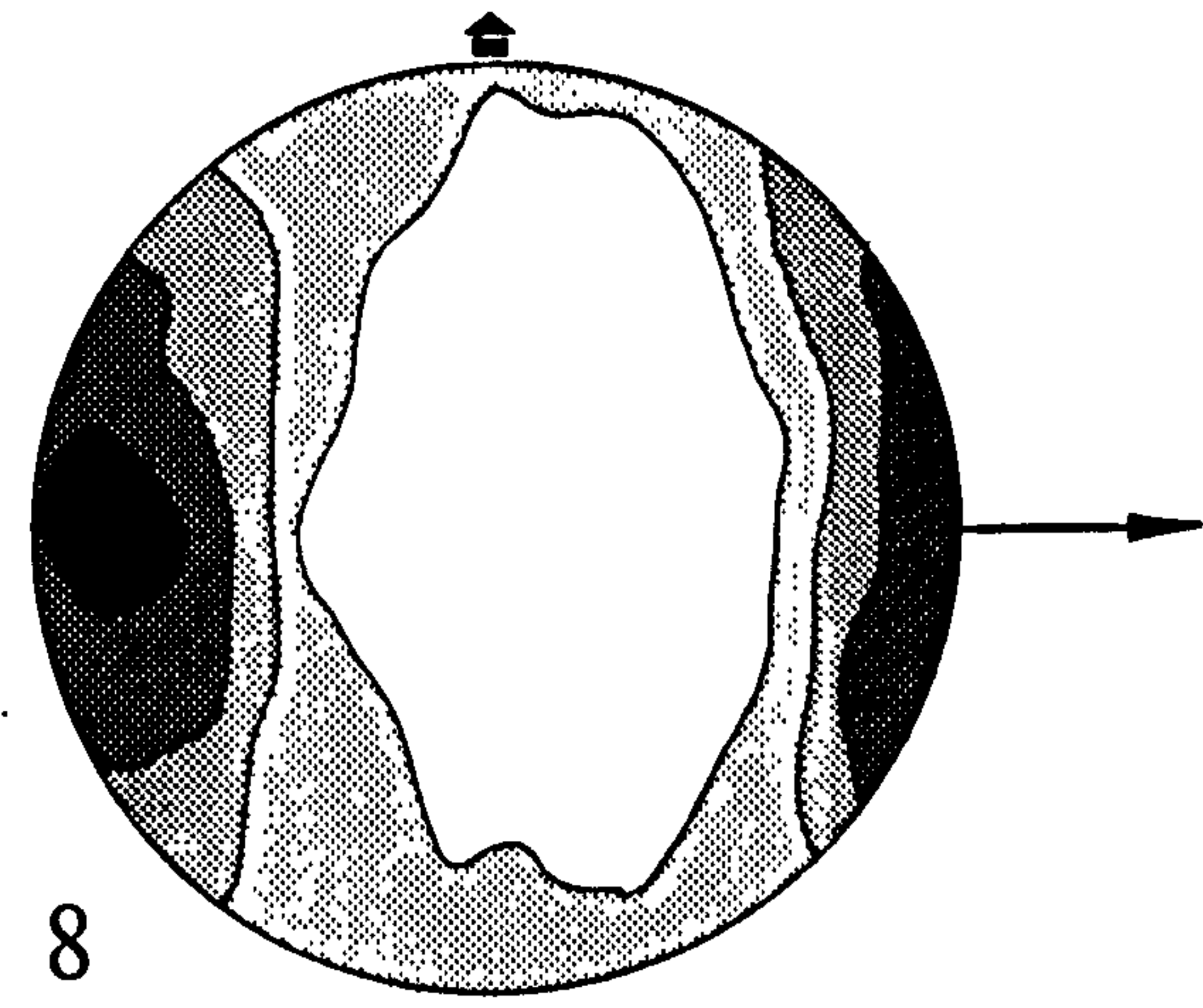
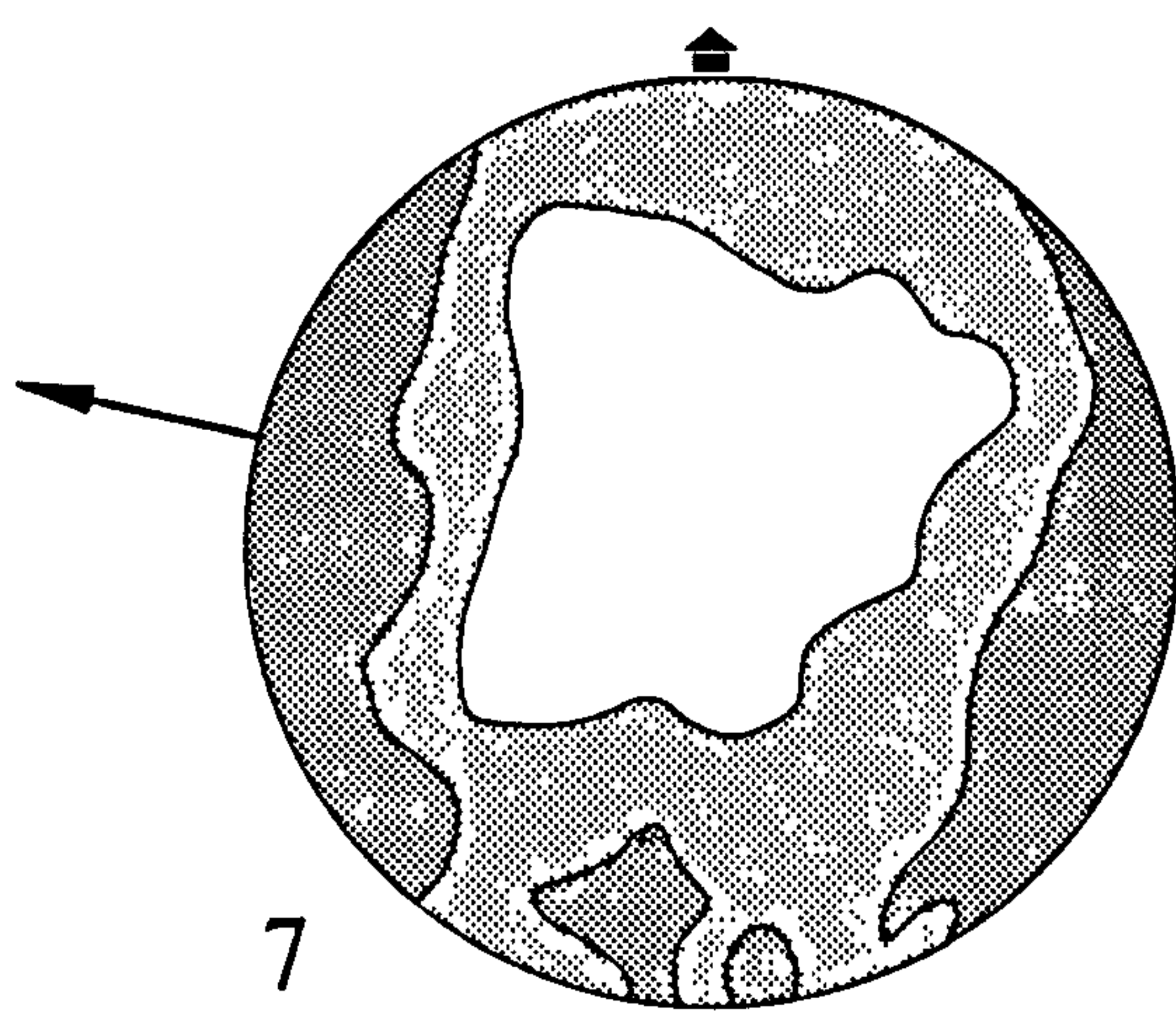
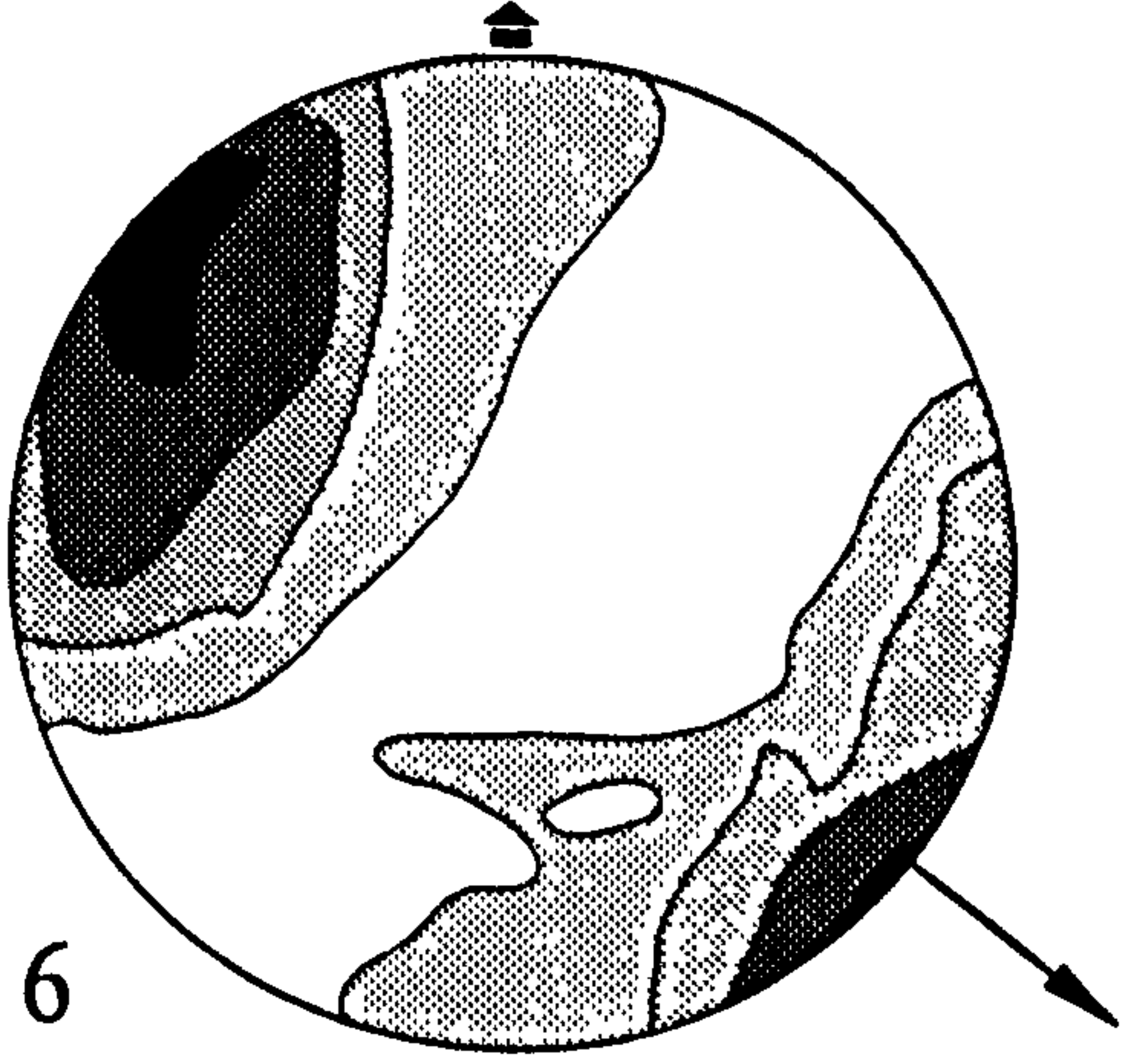
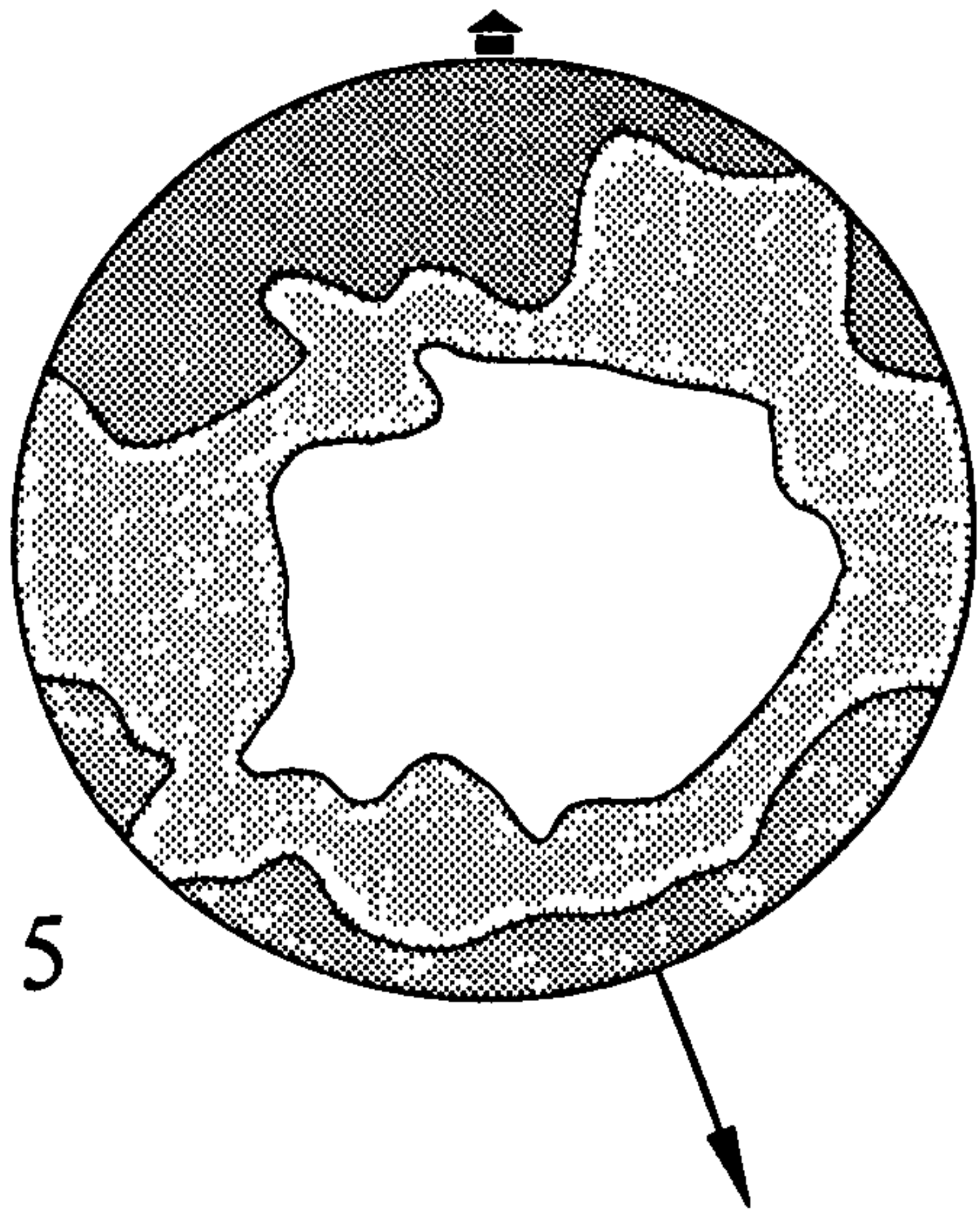


FIG 5.7



CHALKY TILL FABRICS

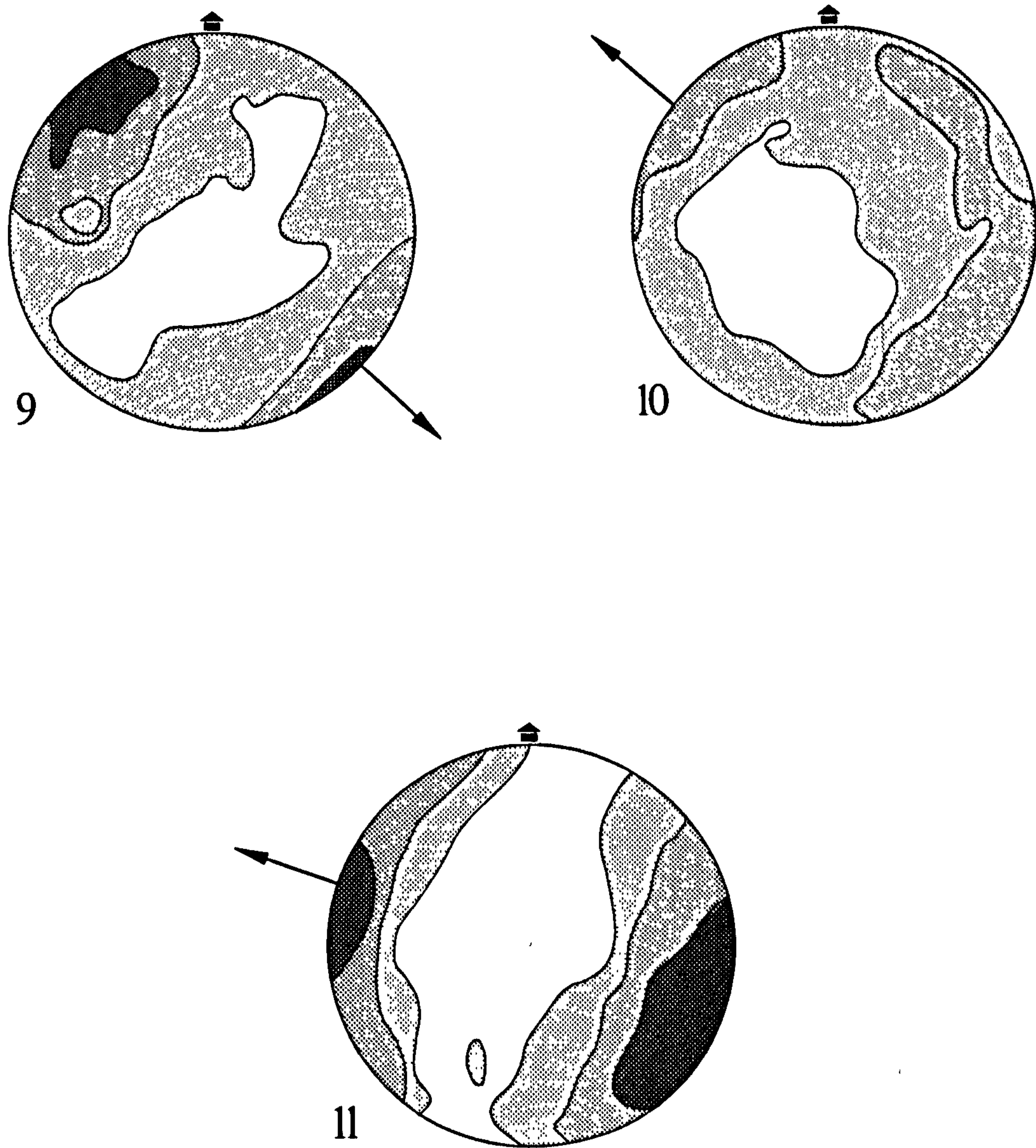


FIG 5.8



TABLE 5.4

Cadeby Macrofabric Statistics

## A. Largest Eigenvector

Sample	Orien- tation	Dip	S1	Sig.
1	107	10	.743	***
2	128	29	.598	***
3	130	18	.575	***
4	127	23	.623	***
5	161	13	.498	*
6	128	13	.664	***
7	284	2	.504	*
8	91	11	.686	***
9	133	10	.553	***
10	309	9	.480	
11	289	11	.650	***

## B. Smallest Eigenvector

Sample	Orien- tation	Dip	S3	Sig.
1	247	77	.060	***
2	37	0	.170	**
3	223	12	.175	*
4	0	54	.149	**
5	314	76	.119	***
6	229	43	.126	***
7	184	79	.105	***
8	249	78	.045	***
9	339	79	.175	*
10	58	65	.144	***
11	143	77	.083	***

## Significance Levels:

\*\*\* 99%  
 \*\* 95%  
 \* 90%

S1 and S3 are the largest and smallest eigenvalues respectively.



All these eight fabrics show a preferred orientation which differs significantly from random at the 90 per cent level or greater, although there is variation between the fabric strengths of individual samples as measured by the largest eigenvalue (Table 5.4). Of samples 1-6, only no. 5 shows any hint of bimodality which could be expected to weaken the largest eigenvalue. The distribution of sample preferred orientations is plotted in summary form on a polar equidistant net (Fig 5.5A), which shows a clustering of axes dipping towards the southeast and particularly about  $130^{\circ}$ . A very similar pattern emerges in the plot of resultant vectors from the vectorial analysis performed on the same data as a check.

A discussion of the full implications of these fabrics is reserved for the chapter which describes the ice advance responsible for the deposition of the tills but some further consideration seems appropriate here. The horizon of Pennine Till from which samples 1-6 were taken shows no stratification and appears to be structureless. It is unaffected by any banding of the tills and no flow structures can be identified in it. Furthermore, five of the six fabrics show highly significant preferred orientations (greater than 99 per cent) all of which trend in the same direction. Rose (1974) has employed similar reasoning to suggest that a till at Hertford is the product of lodgement and this would seem to be the case at Cadeby for the majority of the Pennine Till which displays a consistent fabric type. Mark (1974) has proposed a scheme which relates fabric-forming processes and hypothetical fabric types with a view to interpreting the results of three dimensional fabric studies. The Cadeby fabrics 1-6 show similarities to type A which is regarded as the product of lodgement at the ice-till interface. As the independent evidence at



Cadeby of the physical character of the Pennine Till does not accord with the structures which would be expected with flow or melt-out processes, it is concluded that the overwhelming evidence implies a dynamic subglacial depositional environment with an energy source acting from the northwest sector. Discounting the alternative that the ice movement could have acted from the southeast, the mean dip of the pebbles is down-glacier, a somewhat unusual situation, although Saunders (1968) discovered a similar tendency for till macrofabrics in the Lley Peninsula. This would seem to preclude the possibility of melt-out from englacial thrust planes which would dip up-glacier, i.e. towards the northwest and impart a similar alignment to the resulting melt-out till.

Fabrics 7 and 8 were taken from the Pennine Till where it rests on the downwarped surface of the Cadeby Gravel. The till might not be expected to show the same fabrics as elsewhere, either because it accumulated on a sloping surface or because having been deposited, it underwent the same disturbances as affected the Cadeby Gravel. Fabric 7 is not very strong, only being significant at the 90 per cent level and the largest eigenvector rather than dipping towards the southeast, dips at  $2^{\circ}$  towards  $284^{\circ}$ . Its orientation however can be regarded as  $284^{\circ}$ - $104^{\circ}$ , and this broadly parallels the other fabrics. Fabric 8 is much stronger with the orientation towards  $91^{\circ}$ , rather more easterly than the others. Both of these last two fabrics could probably be attributed to variation within the Pennine Till, but it may be that their divergence is a result of the tilting of the beds at this point.

The Chalky Till fabric samples (9-11) were taken from the same exposure of till and within 3m of each other. This



exposure is on the same face as the banded tills and the Pennine Till samples 7 and 8. It was the only available Chalky Till face suitable for sampling. Inasmuch as generalisations can be made on the basis of three samples, the fabrics appear to be weaker than the Pennine Till ones, but with the exception of no. 10, still showed significant preferred orientations. The mean of the eigenvalues associated with the largest eigenvectors of the Chalky Till fabrics is smaller than the corresponding value for the eight Pennine Till fabrics. The preferred orientations show a similar trend from northwest to southeast although in two cases the dip is towards the northwest. These fabrics can add little to the character of the Chalky Till as described above but it must be noted that the preferred orientation is broadly similar to that of the Pennine Till - a rather surprising attribute if this is connected with the direction of ice movement. It seems more probable however that here the Chalky Till has been emplaced as a flow rather than as a lodgement till.

## 5.5

Lying above the Chalky Till and generally preserved only along the watersheds are a further series of gravels stratigraphically distinct from the Cadeby Gravel being separated from it by the till sequence. This relationship is displayed at the Cadeby quarry (Fig 4.2) where a thin bed of Flinty gravel rests on Chalky Till. North of Cadeby, at Bull in the Oak a considerable spread of Flinty gravels caps the interfluve. It clearly overlies Chalky Till which is exposed to the west, south and east of the outcrop but in the northerly direction towards Osbaston Hall, the tills thin and the Flinty gravel is difficult to separate from the Cadeby Gravel.



Flinty gravel is associated with the low-lying Chalky Till at Coton and is exposed at Dadlington where Fox-Strangways (1900) noted that the pit, now disused and overgrown, contained a high proportion of flints, chalk fragments and oolite. At Market Bosworth excavations adjacent to the market square for the foundations of the Midland Bank penetrated sands with bands of flinty gravels. Unlike the Cadeby Sand and Gravel, however, it has not proved possible to subdivide this other fluvioglacial formation.



## Part 2

"The world went cold, and snow fell  
everywhere, and only white creatures,  
Polar bears, white foxes, and men like  
awful white snow-birds, persisted in  
ice-cruelty."

D.H. Lawrence,

Women in Love



6

Interpretation 1



The preceding chapters have dealt with the individual formations of the Pleistocene geology of western Leicestershire. Before the events which led to their deposition are reconstructed, a review of the relationships between the various drift formations is presented through an examination of the beds in the vicinity of Cadeby where the full sequence has been mapped and can be related to the exposure at the Tilcon pit.

A levelled traverse was run from a point on the interfluve crest near Bull in the Oak (SK 423031) southwards to the stream which flows beyond Manor Farm and which exposes Keuper Marl in its bank at this point. The traverse was tied in to bench marks and related to a series of auger holes so that the height relationships of each formation could be fixed. The measured section revealed by this survey is shown in Fig 6.1, together with the surface geology of the area. The Cadeby sequence showed the seven divisions described in chapters 3-5 and has been adopted as the type sequence for western Leicestershire and as the basis for correlation with adjacent areas. (Table 6.1).

The traverse involves a fall of 21m (70ft) over a horizontal distance of 700m. A thin band of Basal Till represents the lowest drift formation and is followed by Bosworth Clays, relatively thin here, which in turn are overlain by the Cadeby Sands at 115m (377ft). At this same height 1km to the east in the Cadeby pit silts and sands of the Cadeby Sand rest on bedrock. The interstratified Cadeby Sand and Gravel can be traced around the slopes and conveniently divides the drifts into two parts; the till and lacustrine material below the Cadeby Sand and Gravel and the overlying tills. At 123m (405ft), the Pennine Till overlies the Cadeby Gravel. Auger holes along the traverse at this point showed



# THE PLEISTOCENE SEQUENCE AT CADEBY

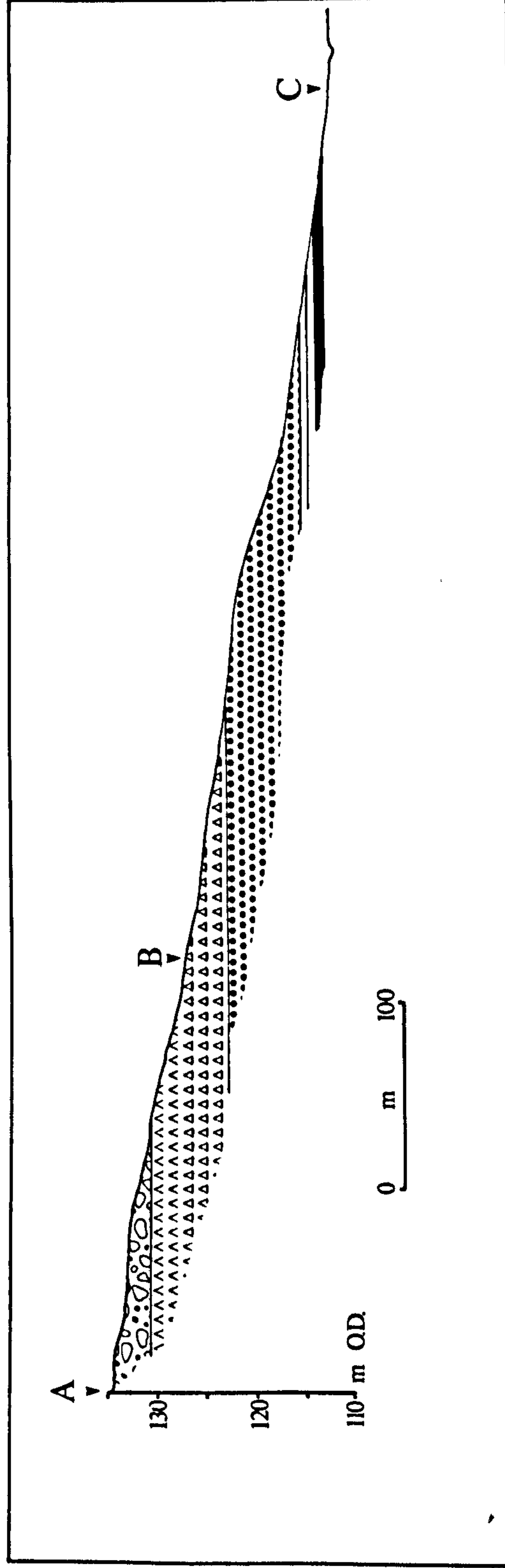
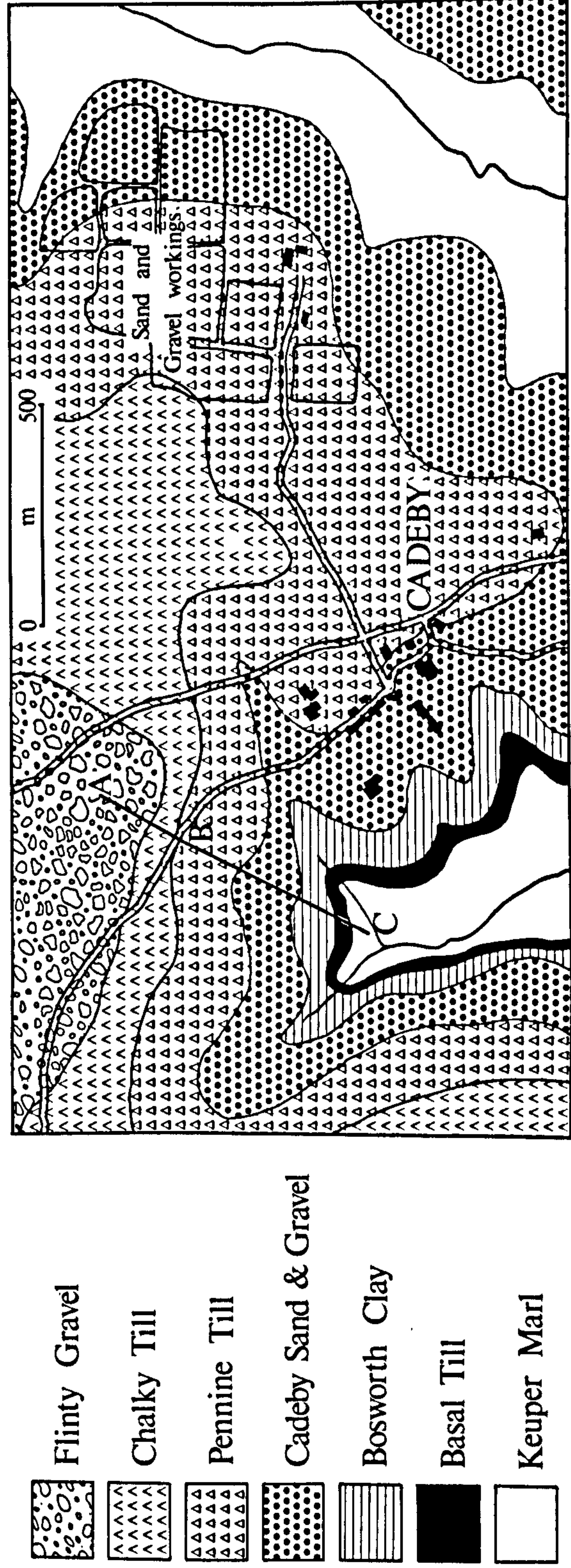


FIG 6.1



TABLE 6.1

West Leicestershire: Type Sequence

Formation	Approx. max. thickness	Stratigraphy
Flinty Gravel	4m	Fine, medium and coarse gravels with substantial amount of eastern material.
Chalky Till	13m	Cretaceous and Jurassic erratics in a grey-brown clay matrix.
Pennine Till	9m	Carboniferous and Triassic erratics in a red or red-brown matrix.
Cadeby Gravel	8m	Cross-bedded, sometimes poorly sorted gravels with some lenses of sand. Carboniferous and Triassic clasts dominant.
Cadeby Sand	5m	Cross-bedded, well-sorted sands with lenses of gravel.
Bosworth Clay	50m +	Largely red-brown, brown and grey stoneless clays and bands of silt, sand and a little gravel. Clays often laminated.
Basal Till	4m*	Carboniferous and Triassic erratics in a red to red-brown clay matrix. Locally some chalky material.

\* The chalky facies of the Basal Till at Nailstone is rather thicker, say 10m.

that the Pennine Till included some bands of chalky material immediately below the appearance of the major spread of Chalky Till. The traverse ended on fairly coarse gravels which capped the higher ground of the interfluvium and were of a flinty composition.

Observations from the remainder of the Bosworth Clay basin suggest that this type sequence, when fully developed, contains no major erosional unconformities



and that each formation normally rests conformably on the subjacent one. Each rock-stratigraphic unit can be matched with a particular event and the implication of this unbroken sequence is that these provide a continuous record of the series of events from the ice advance which was responsible for the Basal Till to the deposition of the water-lain Flinty gravels. Nowhere within this sequence are found any interglacial deposits and it is concluded that the whole sequence is the product of one cold period which can be demonstrated to be the Wolstonian (8.1).

## 6.2

The Basal Till is the first indication of sedimentation onto the sub-drift surface in the area. Although it is relatively thin, its discovery at several points within Leicestershire both within the area subsequently inundated by Lake Harrison and on the higher ground outside it has left the writer in no doubt about the reality of the formation and the ice advance which it is thought to betoken.

The sedimentology of the deposit indicates that it is rather different texturally from the Bosworth Clay with which it could be confused in terms of colouration and stratigraphic position (Fig 3.2). The distribution of the deposit as a veneer draped over the sub-drift surface could lead to the view that it was a solifluction deposit and not the result of deposition by ice. The thickness attained by the deposit locally, i.e. at Nailstone, would seem to be too great for head, and the numerous erratics within it would argue against such a proposal. Even if such erratics could have been provided by the dissection of an earlier drift sheet, there is no recorded remnant of such a deposit anywhere within Leicestershire and only very limited evidence within the Midlands as a



whole - the Bubbenhall Clay (Shotton, 1953); the Lower Glacial Deposits of North Birmingham (Kelly, 1964) - and it would be surprising indeed if any such earlier deposit could have provided the chalk and flint fragments which have been recovered from the Basal Till at some sites (3.1). Some pains have been taken to marshal arguments which firmly establish the nature of this deposit as a true till for previous authors (with the exception of Bishop) describing the Lake Harrison sequence have not recognised an ice advance which covers the area immediately prior to the empoundment of the proglacial lake. It is unfortunate that there are no good sections in this till which could permit fabric analysis, but samples have been subjected to particle-size analysis and the matrix shows the heterogeneous nature to be expected with a till (Fig 3.2). The Basal Till matrix is very similar to that of the Pennine Till. The slightly greater percentages of sand-sized particles within the Pennine Till matrix can be explained by the nature of the terrain over which the respective ice sheets were advancing. In the case of the Basal Till it would probably have been one largely of Keuper Marl, whereas the Pennine Till glacier overrode fluvioglacial sands and gravels incorporating these to form part of the till matrix.

There would appear to be two facies of the Basal Till. The most widespread is that with a reddish matrix which incorporates Bunter pebbles, Keuper sandstones and a few Carboniferous erratics and floors the central and western parts of the study area. At Nailstone, Osbaston Hollow and Stapleton to the east of the area chalk fragments are included in a variable matrix which ranges from a Keuper-rich colour to the grey-brown associated with the Chalky Boulder Clay. This latter facies is very restricted and patchy. The



provenance of the erratics within the Basal Till is dominantly northern or northwestern, and it is from this sector that the ice sheet is thought to have moved. The limited admixture of chalk and flint attesting an eastern or more probably a north-eastern provenance can perhaps be associated with a stream of ice moving across Eastern Yorkshire and merging with the northwest ice in the middle Trent valley where both chalky and red tills have been recorded at low points in the stratigraphic succession near Derby (P. Jones, pers. comm.)<sup>~</sup> That the ice advance was a complex one involving the transport of material of diverse provenance there can be little doubt. The banding of the Basal Till detected by augering at Nailstone Gorse (see 3.1) shows the interdigitation of the two till types and several exposures near Leicester indicate that chalky material was introduced to the area at an early stage in the till sequence.

Within the study area no fluvioglacial deposit has been observed beneath the Basal Till. A consideration of the sub-drift topography of the Hinckley valley shows that any ice advancing from the northern sector would be moving downvalley and the drainage of meltwaters in the direction of the proto Soar would be unimpeded (Fig 2.1). These meltwaters would be channelled towards the axis of the Hinckley valley which has been plugged by the later drifts. Only at Compass Fields Farm, Stoke Golding does a borehole log record any material which could be interpreted as fluvioglacial immediately above bedrock. Although similar patches of sand and gravel relating to the outwash of this ice sheet could remain buried at depth, it may be that the overlying ice incorporated them within the Basal Till.

The regional correlation which will be fully substantiated



in the next chapter establishes the Basal Till as the correlative of the Thrussington Till mapped in the Leicester area by Rice (1963). At Leicester, Rice described <sup>below the Thrussington till</sup> a series of well-bedded sands and gravels, the Thurmaston sand and gravel, which thins against rising bedrock slopes away from the axis of the proto Soar. At Huncote (SK 511980) only 6km west of the study area, sands and gravels which can be equated with the Thurmaston series are capped by tills. The direction of dip of the foresets in the sands is strongly towards the north, paralleling the proto Soar. The tills overlies a planar, almost horizontal surface of sand with a sharp junction and no evidence of any disturbance or intervening erosion. Indeed the whole sequence at Huncote from the base of the gravels which rest on Keuper Marl to the red and chalky tills seems to have accumulated without a break. Within the sands ice wedge casts have been observed which confirm that the deposit accumulated in a cold environment and support Rice's view that the Thurmaston sand and gravel originated as outwash (Plate 5).

The borehole evidence in the plug of drift which now forms the Soar/Avon watershed in south Leicestershire indicates that near the centre of the proto Soar valley sands and gravels appear at the base of the succession and reinforce the correlation that the Thurmaston sand and gravel is the northern equivalent of the Baginton-Lillington series of the Coventry district (Rice, 1963). This view is not necessarily at variance with that of Shotton (1953) who regards the Baginton-Lillington series as the product of normal fluvial aggradation, for above the confluence of the Hinckley valley with the proto Soar, streams draining the upper part of the valley with little or no input of outwash may have contributed to the ice



melt which was derived from the northwest via the Hinckley valley. However a fluvioglacial origin for these deposits does overcome the problem of explaining the large quantities of Bunter pebbles in the gravels as a result of the reworking of an earlier drift sheet for which there is no evidence in Leicestershire.

The evidence from Huncote and elsewhere demonstrates that arrival of ice immediately following the aggradation of the basal sands and gravels. This ice blocked the free drainage of water along the line of the Soar and limited ponding in proglacial lakes is evidenced by the Glen Parva Clay which was subsequently overridden by ice depositing the Thrussington till (Rice, 1963). In contrast, the Hinckley valley sloped away from the advancing ice and the Basal Till was deposited largely onto bedrock.

Near Coton at Kingshill Spinney an anomalously low depression on the sub-drift surface has been infilled with sand and brickclay (see 2.2). It is certain that this depression could not have been excavated by normal fluvial erosion for the borehole here recorded rockhead at 53m (176ft) O.D., and there is no possible outlet for such a channel into any preglacial valley at this level. The steep side to this depression which is confirmed by bedrock appearing at the surface a short distance to the west, would seem to indicate that this slope cut in red marl could not have remained unsupported for long. Anomalously low depressions have been recorded from other areas. Beneath the Sow valley in Staffordshire Morgan (1973) reported a trench with a floor on bedrock at no more than 29m (95ft) O.D. Beneath the Ouse and Nene valleys Horton (1970) described ungraded, buried channels and depressions which are thought to have been excavated by river or



glacial action prior to the deposition of the Chalky Boulder Clay. Around Narborough chalky drift, some of it waterlaid, occurs over a large area in an elongated depression which reaches levels well below the reconstructed preglacial surface (Rice, 1968, 1972). The nature of the infill is important in deducing the origin of these overdeepened features. At Kingshill little detail is known apart from those samples recovered by augering near the surface which showed varve-type bedding and almost certainly belong to the Bosworth Clay sequence. The record of sands at the base of the depression may be indicative of cutting by subglacial meltwater and the position of the channel in the centre of the preglacial valley (Fig 2.1) would be the most likely spot for such overdeepening to take place. Glacial scouring by ice is an alternative explanation but it is surprising that no till has been recorded in the borehole, although in a depression of limited size such as this, the infill of presumably waterlaid brickearths could well have accumulated subglacially to be covered by the Bosworth Clay series when the ice withdrew. Pleistocene faulting of a type similar to that described by Shotton (1965) in the motorway cuttings near Leicester is not thought probable because a downthrow of about 25m (83ft) would be necessary and that would have brought younger beds (i.e. the Cadeby Sand and Gravel) to ground level at Kingshill.

Shotton's 1953 reconstruction of Lake Harrison envisaged the ponding of a large stretch of water against the rising slopes of the proto Soar valley and the Jurassic scarp as ice moving from the north blocked the natural outlet. The drift stratigraphy in western Leicestershire indicates that the extensive Basal Till was buried by the deposits of the glacio-lacustrine phase and therefore ice covered the area before wide-



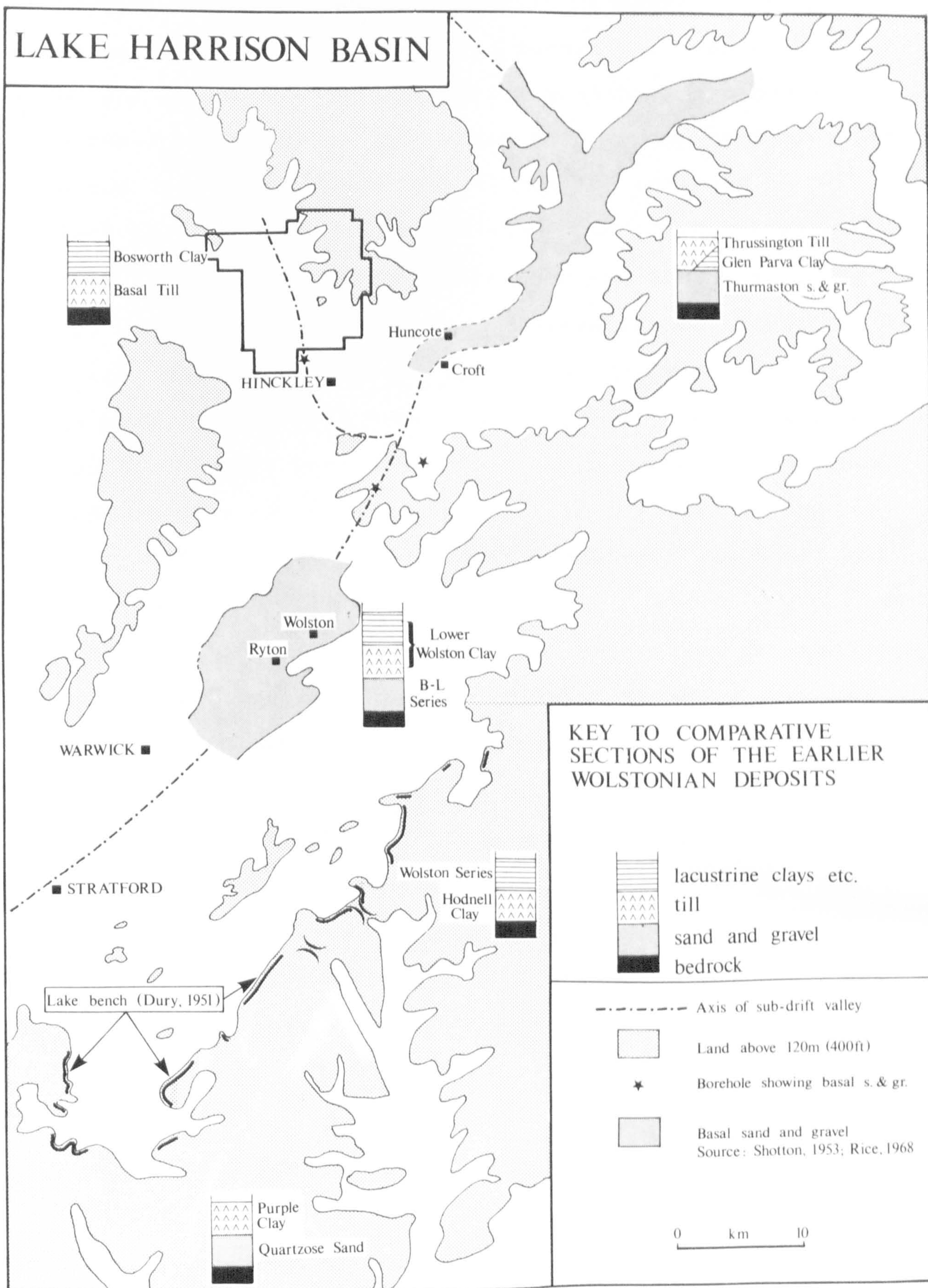


FIG 6.2



spread ponding took place. Although local ponding is evidenced by lacustrine material at Glen Parva to the south of Leicester (Rice, 1963), no extensive proglacial lake is demonstrated in the stratigraphical record for over a large part of the proto Soar system tills lie either on bedrock or on the basal sands and gravels which were deposited in advance of the ice (Fig 6.2). This lack of ponding can best be explained by envisaging an ice advance from the northwest moving across the line of the proto Soar and thus permitting marginal drainage in a northeasterly direction towards Leicester. Only when the Soar itself was blocked would conditions have favoured the empoundment of the lake in which the Glen Parva clays were deposited. This 'ice-dam' may have been completed by ice from the north bringing with it the eastern fraction of detritus present locally in the Basal and Thrussington tills.

Site investigations and subsequent excavation for the M69 (Leicester-Coventry motorway) which was under construction in 1975 have provided subsurface information for a section through the drift plug between the present Avon and Soar basins. An interpretation of the exploratory boreholes for this motorway based on Wyatt (1974) is presented as Fig 6.3. Overlying the basal sands and gravels at the Leicester end of the section, the red till is strongly developed and a red till interposes between bedrock and the stoneless clays over much of the southern part of the section. These tills are correlated with the Basal Till of west Leicestershire on the basis of lithological similarity and stratigraphic position: they represent the first evidence of direct deposition by ice in both areas. The motorway boreholes establish the near continuity of the Basal Till as far south as the Sowe valley near



# SECTION ALONG M 69

AFTER WYATT, 1974

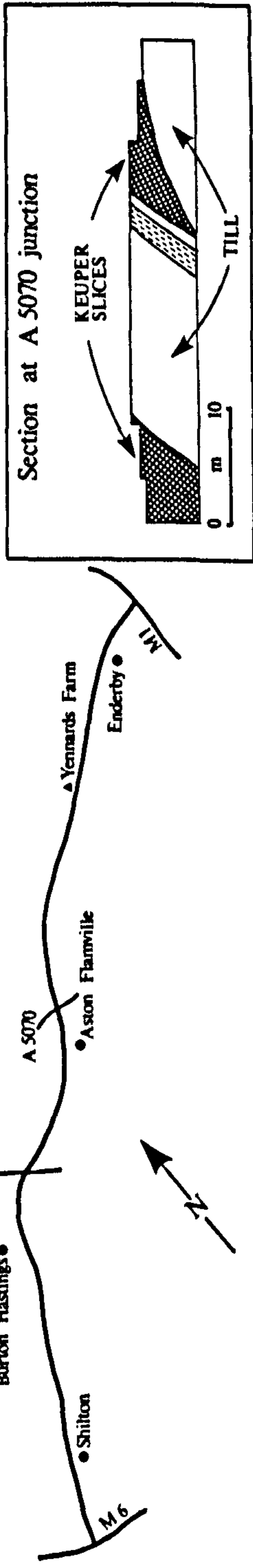
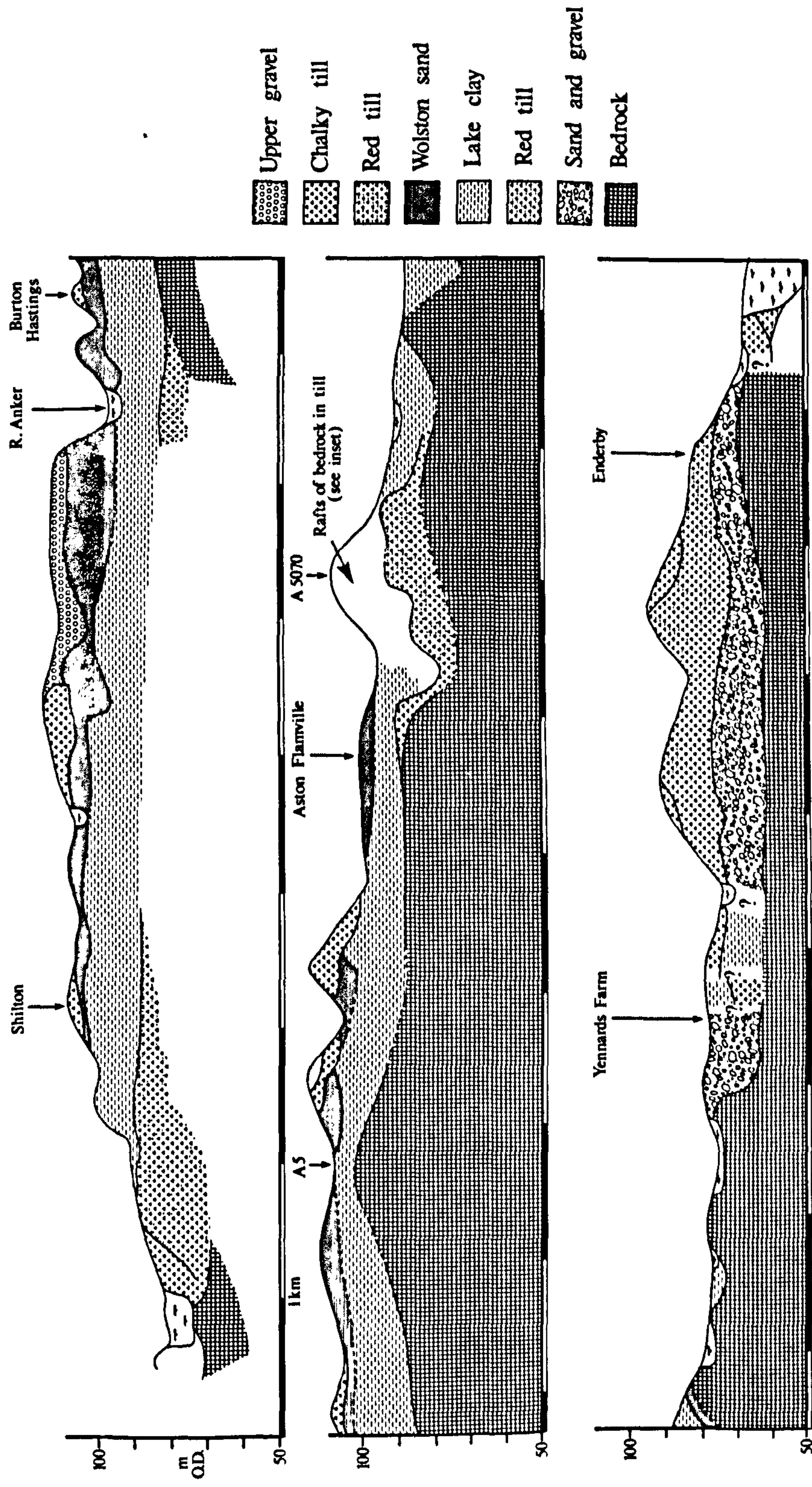


FIG 6.3



Ansty on the northern outskirts of Coventry. Beyond this point the evidence is more fragmentary and reconstruction of the limits of the ice advance under consideration must be more tenuous.

At the Wolston Grounds and Ryton Wood sections described by Shotton (1953) the Lower Wolston Clay overlies the Baginton Sand, the upper member of the basal sand and gravel layer. Although Shotton interpreted the Lower Wolston Clay as a lacustrine deposit, the lower part of the unit at Wolston contains a fair number of erratics, has the character of a till and can be distinguished from the upper part of the exposure which comprises undoubted still-water bedded deposits. Similarly, at Ryton Wood the clay exposed above the sands is a till with an erratic suite comparable to that of the

#### Basal Till

In the Itchen valley, Bishop's mapping of the small outliers of drift showed that the bedded deposits he correlated with the Wolston series were underlain by the Hodnell clay (Bishop, 1958). This chalk-rich till demonstrates that the pre-Lake Harrison ice advance involved the transport of material from an eastern source as shown in the complex lithology of the Basal Till at Nailstone (3.1). In the vicinity of Moreton-in-the-Marsh on the watershed between the Stour and Evenlode basins, Briggs and Gilbertson (1972) argued that the Purple Clay which includes a strong component of Bunter pebbles, could be traced both below the level of Lake Harrison and also to heights of 150m or more into the Evenlode valley which were beyond the limit and well above the level of any ponding. Briggs (1973) regarded the Purple Clay as being varied in character but essentially a till associated in some localities with the Quartzose Sand with which it bears strong similarities



in heavy mineral content and which he inferred as the outwash material from the ice sheet which deposited the clay. (The Quartzose Sand is equated with the Stretton Sand from which Shotton (1973) has described a vertebrate fauna, probably Hoxnian, which if correctly assigned and in situ would preclude an interpretation as outwash).

The tills detailed above all share a similar stratigraphic position. The evidence for their continuity in the northern part of the region is good and an ice advance at least as far south as Coventry seems inescapable; the simplest interpretation of the stratigraphies represented in the Itchen and Stour/Evenlode areas is to match the Hodnell and Purple Clays with the Basal Till of west Leicestershire and the lower part of the Lower Wolston Clay. This arrangement describes an ice advance which reached into the upper parts of the Thames basin. The lithology of the till deposited by this advance ranges from the chalk-rich Hodnell Clay to the chalk-free Lower Wolston Clay and Purple Till with many sections (e.g. Huncote) showing both till types. That chalk-laden ice reached Leicestershire at an early stage is demonstrated by a temporary section near Stony Bridge (SP 499975) on the line of the M69 which showed Chalky Till resting directly on an undisturbed surface of the basal sands and to the north, in Charnwood Forest, Bridger (1971) recorded eastern material near the base of the local sequence.

### 6.3

The thickest and most widespread Pleistocene deposit within the study area is the Bosworth Clay. The laminated beds of this formation attest to its lacustrine origin and this interpretation is reinforced by its distribution which shows a



thinning against the higher ground to the east commensurate with the shallowing of the basin in which the clays accumulated (Fig 3.1). The highest point at which the Bosworth Clay has been found is near Twycross where it reaches 119m (390ft). Although some of the material described as 'brickearth' in the Kingshill Spinney borehole may have accumulated subglacially as an infilling to the depression, the upper part which has been sampled by augering, bears all the characteristics of the Bosworth Clay. The thickness of Bosworth Clay can give a minimum limit to the depth of the lake. A more realistic reconstruction can be made by estimating the level of water in the lake. Discounting the effect of any postglacial tectonic warping, the feather-edge of the lacustrine sediments should approximate to the edge of the lake itself and thus give a minimum figure for the water level. At Barton in the Beans and Osbaston the feather-edge has been fixed quite accurately. In the vicinity of Cadeby, the lake clays can be followed to the west of the ridge as a narrow band (Fig 6.1) which does not appear in the sequence to the east and therefore the edge of the clays must be buried by the Cadeby Sand under the interfluvium (Douglas, 1974). Southeastwards towards Stapleton the Bosworth Clay appears to the west of the Thurlaston Brook where it used to be worked at Stapleton brickpit (SK430009) but not on the Kirkby Mallory side of the valley, the edge of the deposit having been removed by incision of the drainage. Piecing these fragments together, the edge of the lake clays would seem to vary within the fairly narrow limits of 113m (370ft) to 119m (390ft). As the latter value refers to the observation at Twycross where the lake clay is thin (say 2-3m thick), a water level of at least 120m (395ft) can be envisaged, possibly rather higher. Having



established the level of the lake in western Leicestershire, attention is now turned to the whole Lake Harrison area and its palaeogeography but first the conditions which enabled the ponding to take place and the nature of the empoundment must be reviewed.

The contact between the Basal Till and the Bosworth Clay is inadequately exposed but there is some indication that it is not a sharp erosional one where the till has been buried by lake clays (see 3.1, site no. 2, Stapleton Fields). It can be reasoned that the lake was established as the ice stagnated and withdrew from the region and that no lengthy period of time elapsed between the ice withdrawal and the initiation of the lake which would have resulted in the erosion of the till. The relationship between the Basal Till and the overlying drifts is instructive on this point. Where the till has been covered by the Bosworth Clay series its preservation seems almost complete: its present distribution in this area is a thin sheet which gives a narrow, almost unbroken outcrop around the Bosworth Clays (Fig 3.1). Outside the lake basin however, at heights above 116m (380ft) the Basal Till is patchy and where it is still preserved as at Stapleton, it is overlain by stratigraphically higher beds than the Bosworth Clay, usually the Cadeby Sand. This pattern indicates that the lake deposits acted as a protective blanket covering the Basal Till, and that the till above the shores of the lake underwent erosion which in many instances was sufficient to effect its complete removal.

As the ice withdrew from the maximum limit reached by the pre-Lake Harrison advance, Lake Harrison itself would have been established and maintained so long as withdrawal did not extend beyond the lower reaches of the proto Soar allowing the



waters to escape northwards. This condition clearly limits the oscillation of the ice front to a position to the south of the present Trent valley. If the lake was drained for any length of time by such an unblocking, it is surprising that there is neither evidence of significant dissection of the Basal Till beneath the Bosworth Clay nor of the lacustrine sediments extending further to the north in central Leicestershire. Shotton's reconstruction of the basin in which the clays accumulated necessitates a similar front of Severn valley ice plugging the head of the proto Soar valley which has been reconstructed at a height slightly below 91m (300ft) between Church Lench and Bredon Hill (Shotton, 1953, Fig 11).

The Bosworth Clay extends as far north as Twycross (Fig 3.1) and has been recorded to the north of the proglacial col at the head of the Hinckley valley in the Mease catchment. The feather-edge of the clay gives the limit of the lake to the east against the Charnwood area but to the west where the high ground of the Hartshill Range would have impounded the lake, the Anker has removed most of the drift. Only at Bedworth, where the occurrence of laminated silts and clays has long been known (Whitehead et al., 1923) is there evidence of lacustrine material. Lake clays occur at Earl Shilton and Hinckley which can be directly correlated with the Bosworth Clay but east of Earl Shilton towards the axis of the proto Soar, the succession as revealed by the M69 boreholes and cuttings shows a complex sequence in which tills predominate. The zone in which tills replace lake clays represents the site of the ice dam, south of which lay the proglacial lake. The limits of this area can be fixed only tentatively. The sequence around the village of Aston Flamville and at Nickle Hill (SP 465917) is comparable with that in the study area and



a lobe of ice is suggested with its western margin stretching southwestwards from Kirkby Muxloe via Thurlaston and Elmes-thorpe to curve around to the east near Sapcote. This line gives an approximate northeastern limit to the lake, although at some stage open water may have extended towards Leicester. There is evidence to show that the oscillation of this ice front has disturbed the lake floor beds and incorporated them within the till which has been exposed at Aston Firs on the junction between the M69 and the A5070 (Fig 6.3). This section shows a series of thrust planes dipping towards the north along which slices of till, lake clay and bedrock have been moved. The whole series can be regarded as a till with particularly massive erratic blocks. The largest raft of Keuper Marl of which the lower edge is shown to the left of Fig 6.3, is over 100m in length.

The transition between the Leicester sequence detailed by Rice (1963) and the Lake Harrison sequence is a rather confused one. The period necessary for the accumulation of the substantial thicknesses of clays and silts on the floor of the lake cannot readily be estimated but must have involved a considerable length of time during which the ice front could have shifted. The distribution of the in situ lacustrine deposits indicates that the general attitude of the ice front during the life span of this northern part of Lake Harrison seems to be along a line extending from north of Twycross eastwards to Charnwood Forest and then in the lobe described above.

The deposition of the Bosworth Clay was undoubtedly contemporaneous with the Lower Wolston Clay, for the evidence of the M69 boreholes shows the two series to be continuous. The height of the interface between the Bosworth Clay and the Cadeby Sand is the subject of the next section of this chapter



but the nature of the junction leads to the belief that in the northern part of the Hinckley arm at least, the deposits of the lake were built up almost to water level even away from the edge of the lake. The boundary is a transitional one from clays through silts to current-bedded sands which represent the start of the outwash phase. Nowhere do these sands show the deltaic bedding with steeply dipping foresets which would be expected were the outwash released into a deep lake, rather the sands show delicate cross beds such as would be associated with the braided channels of the outwash sandur extending across the silted lake.

The surface of this lake was estimated to be at 125m (410ft) by Shotton (1953), a level which is entirely consistent with the observation in western Leicestershire of the clays thinning against rising ground at about 119m (390ft). It is much more difficult however, to reconcile this with the scheme of events proposed by Bishop (1958, Fig 11) for the stages of Lake Harrison. With regard to the pre-Lake Harrison ice advance documented above, the label of an 'extra-morainic' lake now seems unfortunate. The first widespread stage of the lake envisaged here would have developed in front of a retreating and stagnating ice margin. There are several possibilities for controls on the lake level. The only break in the Jurassic escarpment below 122m (400ft) within the region under consideration is between Saddington and Smeeton Westerby in the gap under which the Grand Union Canal has been tunnelled (Fig 1.1). Augering in this col has proved bedrock (Lias Clay) at 119m (390ft). It seems perfectly plausible that this gap was used as a spillway into the Welland when the ice had retreated to its northernmost point near Leicester although



its use would have been limited as the readvance would have sealed the gap at an early stage. Alternatively it is possible to envisage drainage marginal to the Severn ice parallel to the Cotswold scarp or even drainage through the ice beyond the col near Bredon Hill. Bishop's evidence that the lake bench recognised by Dury (1951) in part truncates the Wolston series might preclude the use of the Fenny Compton gap as an over-spill at this stage for the bench itself passes into the gap. It may be however, that before the benching, the gap was at a similar height and neither plugged by ice nor at 133m (435ft) as required by Bishop's analysis.

Such is the size of the lake and such the paucity of evidence now available that many of these finer points must remain conjectural. The evidence presented from this research in western Leicestershire amply confirms the existence of the lake which assumed a height at some stage of 120-125m and suggests that sediment built up to near this level.

#### 6.4

There remains a further important relationship of the Dosworth Clays. The height of the lake has been estimated from the level reached by the edge of the lacustrine sediments as they thin against rising slopes. Where the lake clays are thicker, their upper limit is below that estimated from the feather-edge. This discrepancy can have two explanations: either the sediment was not built up to the surface away from the lake margins or the effects of compaction have acted to reduce the volume of the deposit. Limited evidence has been identified above (6.3) to suggest that the former explanation may not account for much of the difference although it cannot be discounted totally. Shotton (1953, Fig 2) recognised that comp-



# THE EFFECT OF COMPACTION

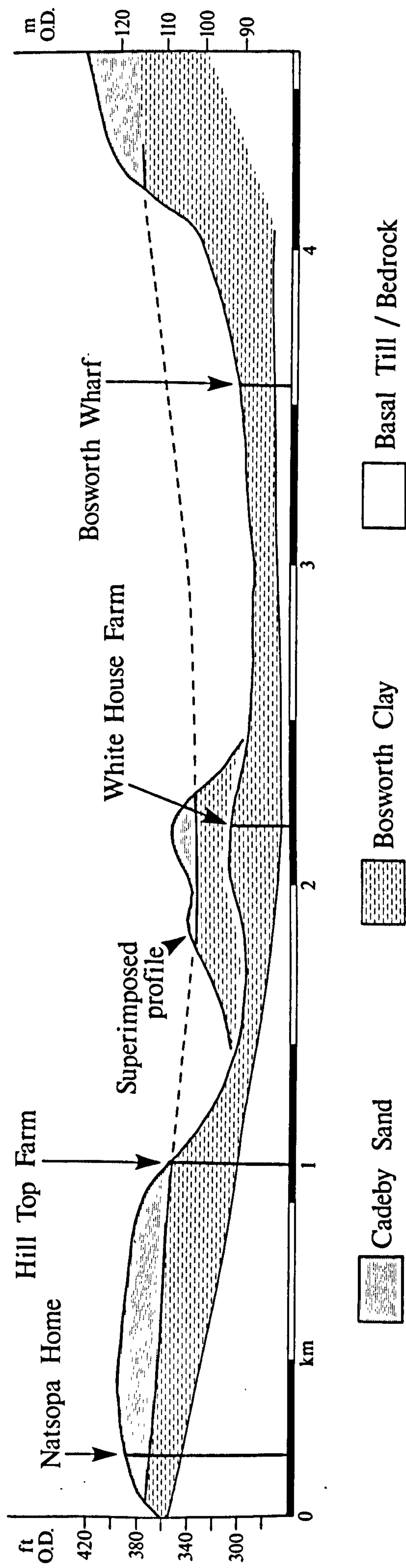


FIG 6.4

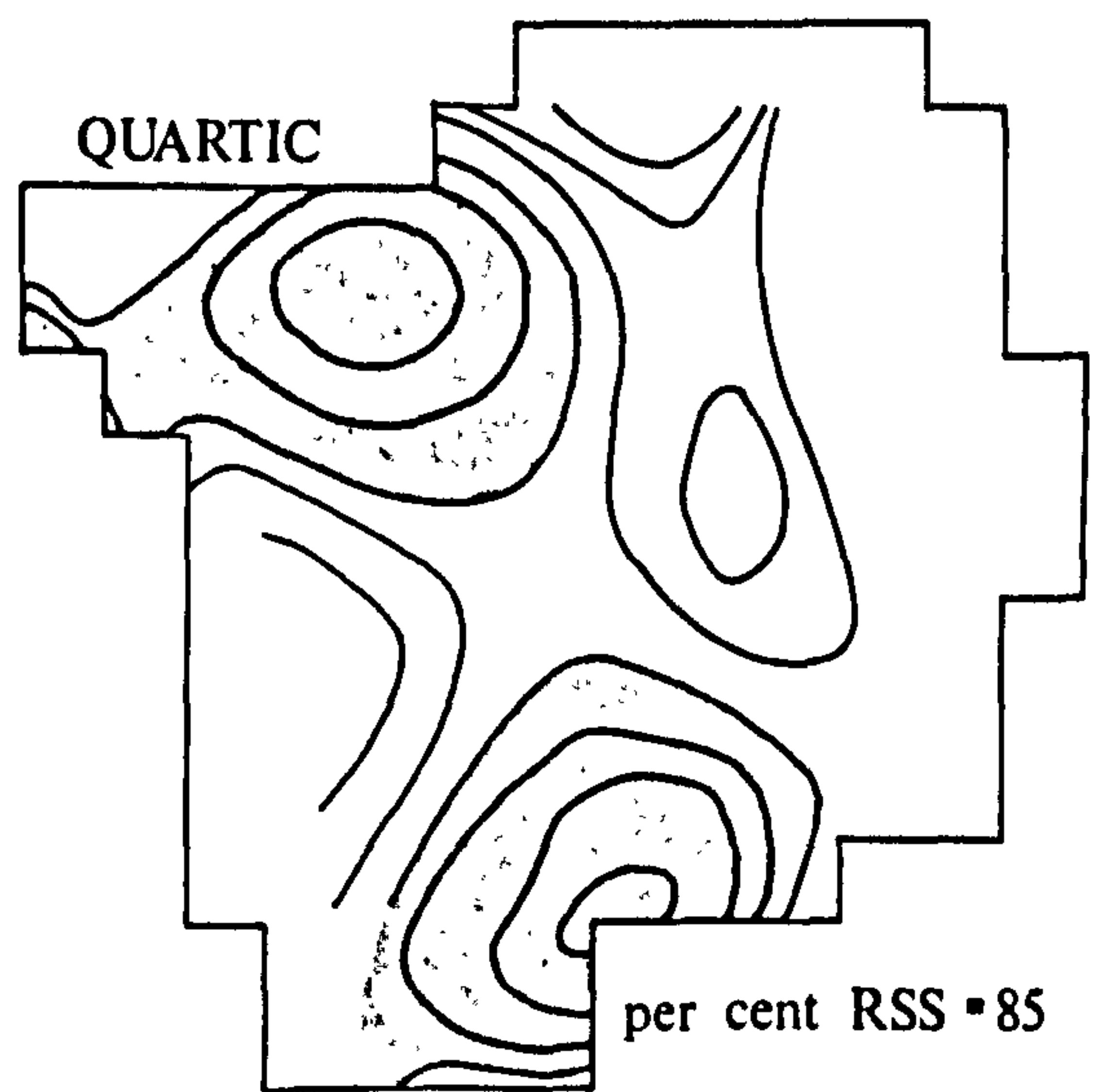
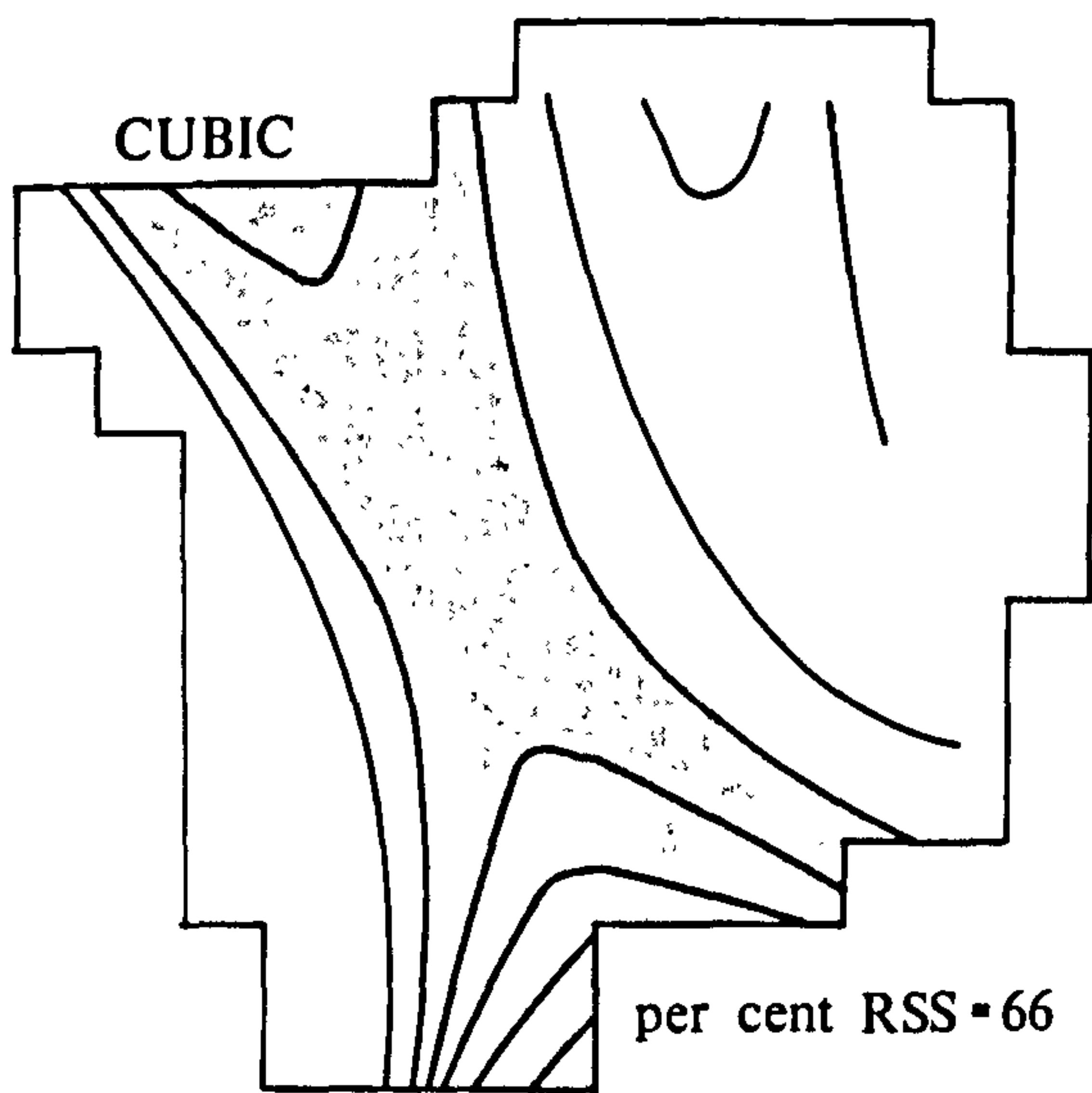
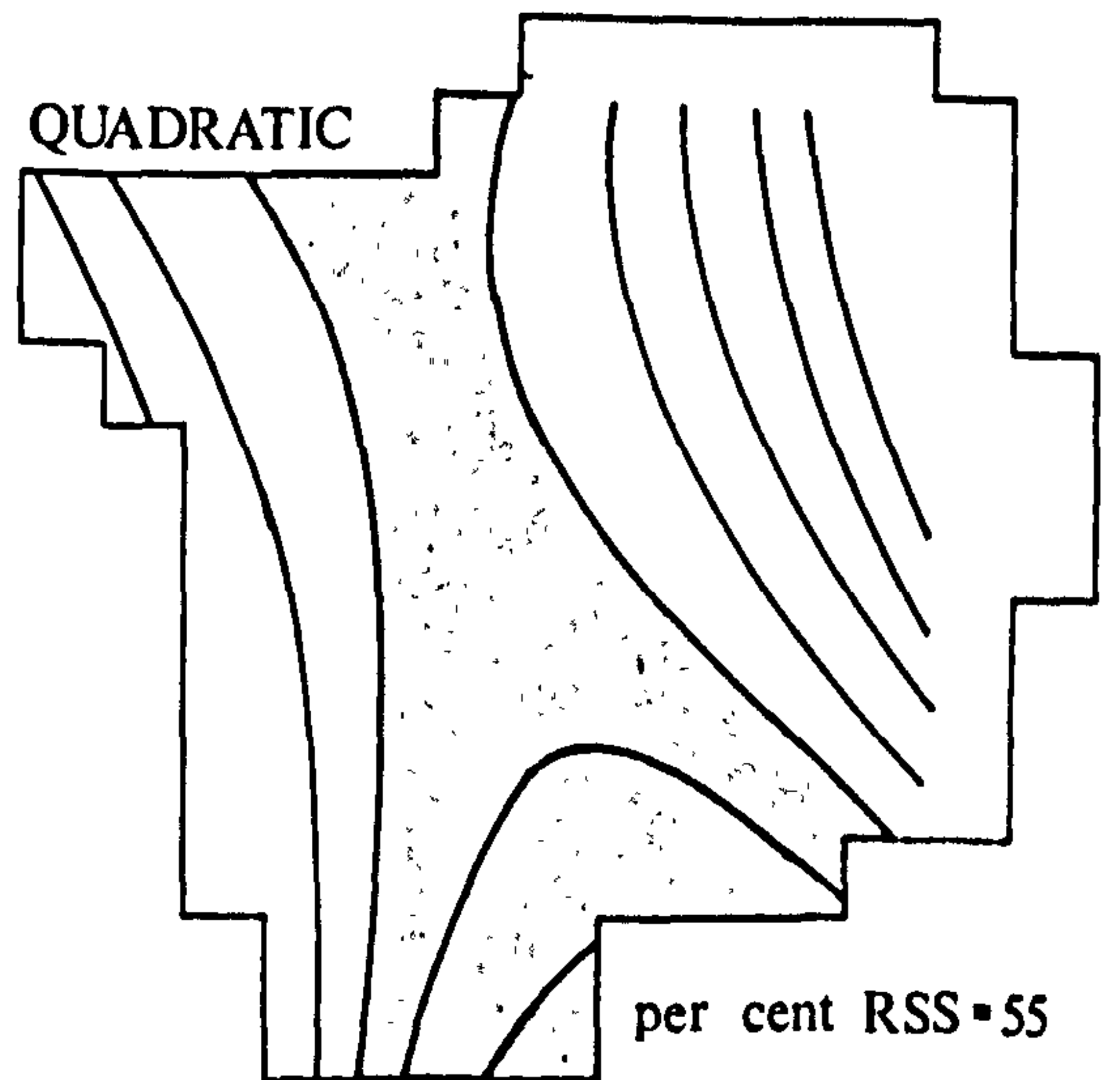
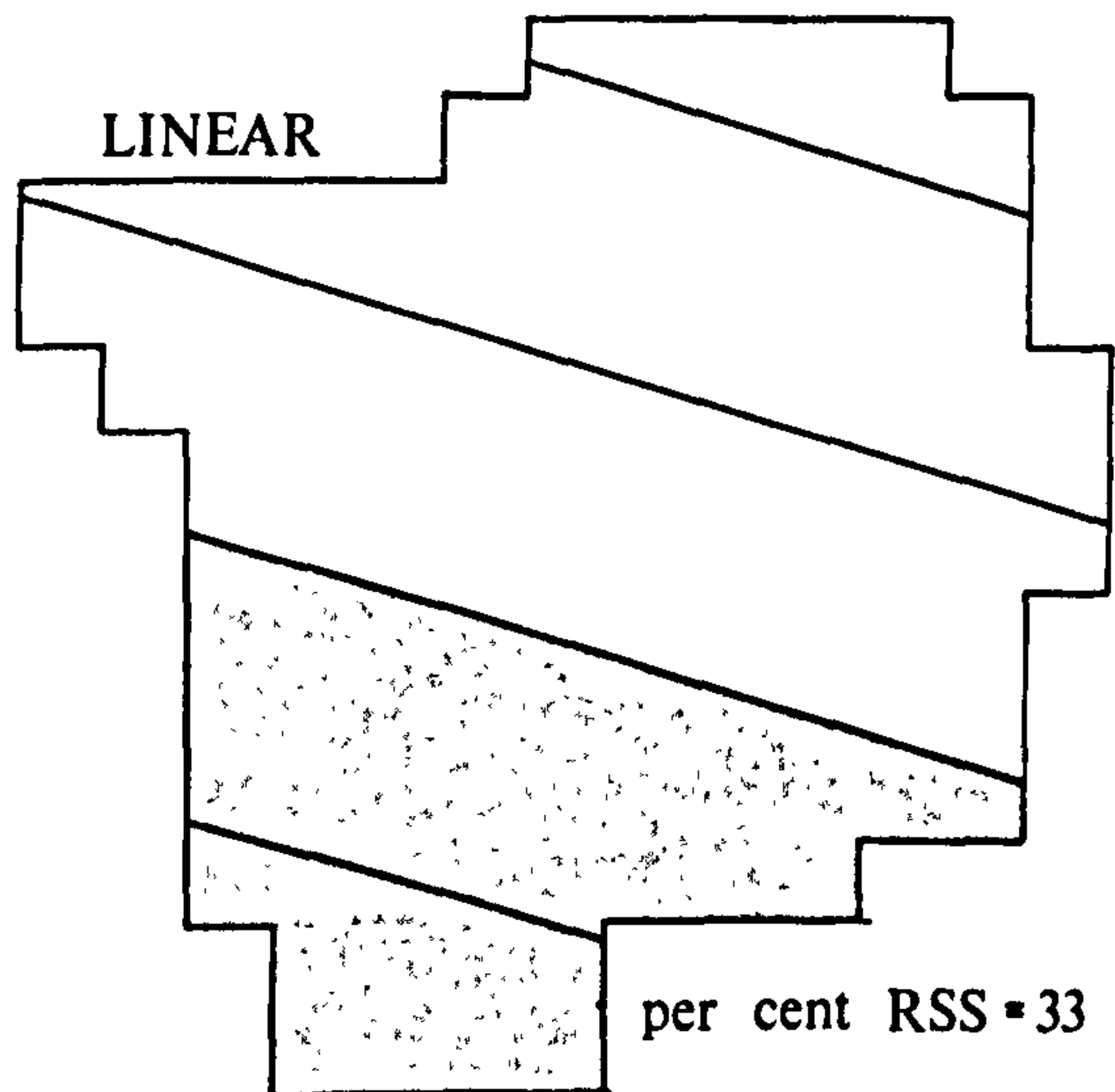


action of the Wolston series had taken place and showed that the junction between the upper clays and the overlying gravel fell some 15m (50ft) along the length of the Dunsmore plateau. A similar case can be made for a section from Wellsborough to Market Bosworth for which there is borehole evidence to fix the level of the various beds (Fig 6.4). The interface between the Bosworth Clay and the Cadeby Sand dips towards the centre of the sub-drift valley as the thickness of the underlying clays increases. Data from borings which fix the heights of the top of the clays and the underlying junction with Basal Till or bedrock have been used to assess the degree of compaction. Taking a value of 119m (390ft) for the original surface of the Bosworth Clay, the mean value of the original assumed thickness to have disappeared through compaction is 36%.

In an attempt to explore the shape of the surface given by the top of the lacustrine material, 64 points at which the height of the Bosworth Clay and Cadeby Sand interface had been measured were used to compute trend surfaces which could model the characteristics of this interface. The first to fourth order surfaces are mapped in Fig 6.5 and the statistics for all six surfaces generated are presented in Table 6.2. The quadratic and cubic surfaces describe a trough trending in similar fashion to the sub-drift surface from NNW towards SSE. The quartic and higher order surfaces resolve this simpler pattern into progressively more complex ones. Analyses of variance were performed to test the significance of increments in explained variance given by progressively higher order surfaces (Chayes, 1970; Davis, 1973). The level of significance for the increment of variance explained by the cubic surface over the quadratic was less than that for the same



# TREND SURFACES FOR THE CADEBY SAND / BOSWORTH CLAY INTERFACE



Surface below 360 ft (110 m) Contour interval 5 ft (1.5m)

FIG 65



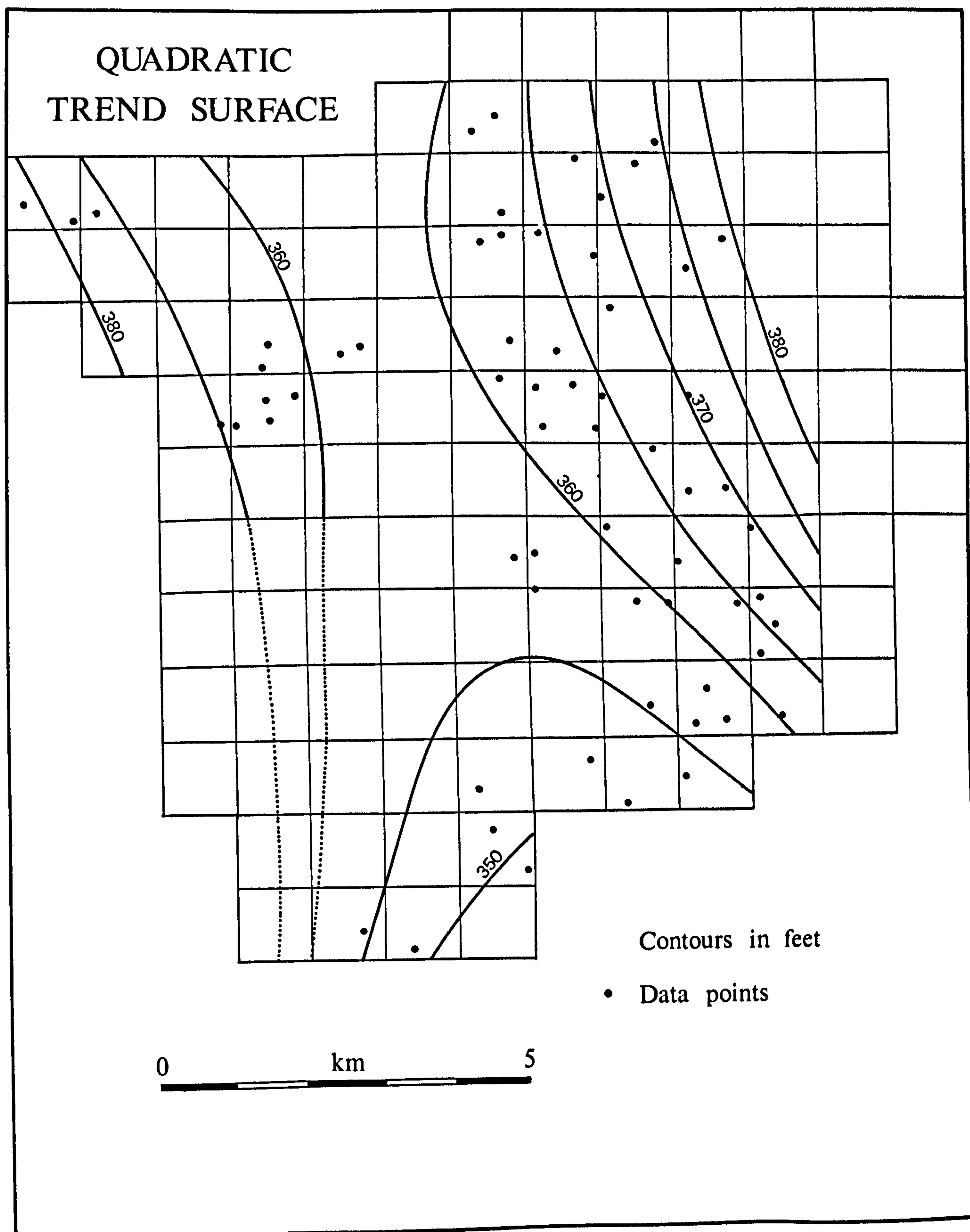


FIG 6.6



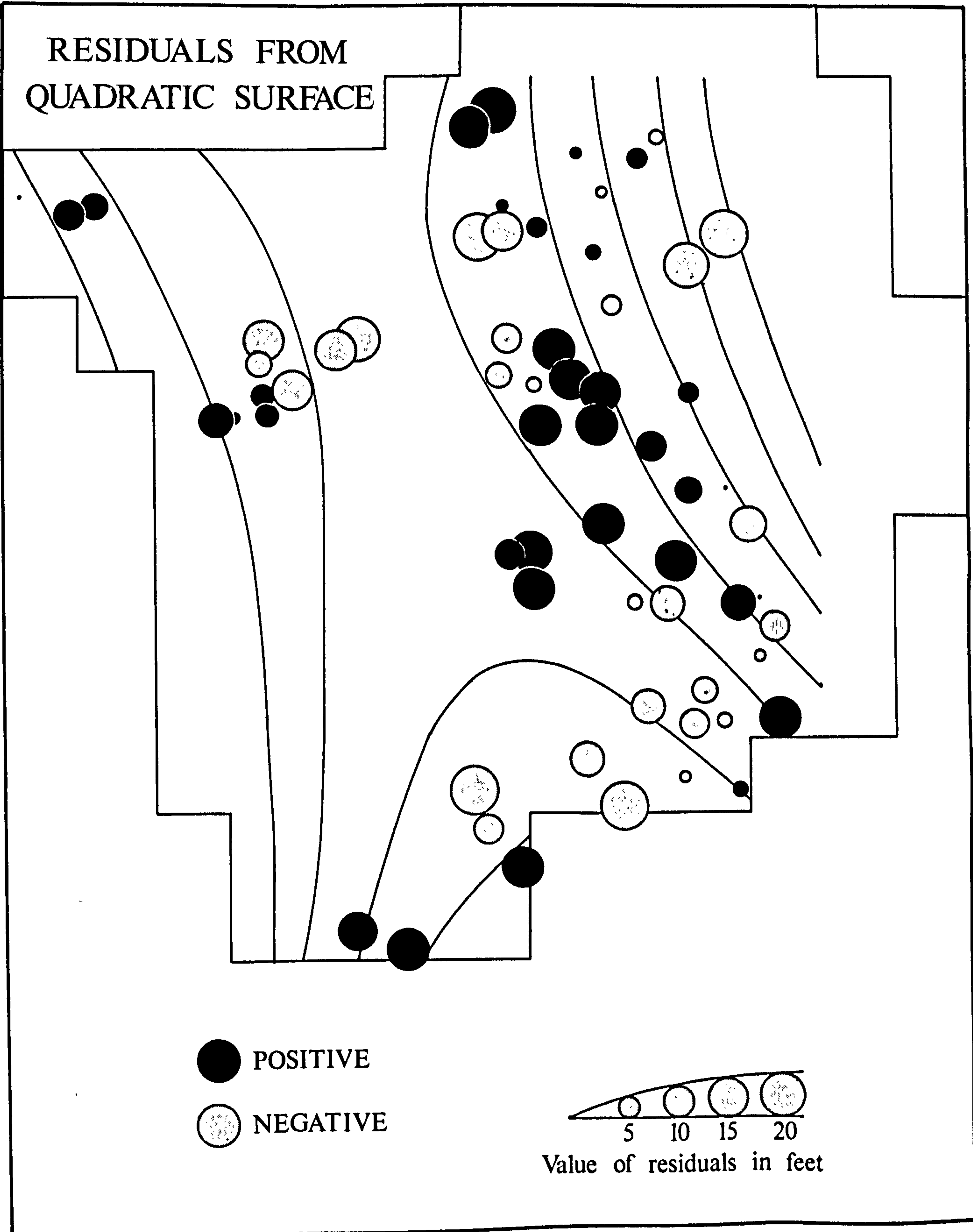


FIG 6.7



measure for the quadratic over the linear surface and thus the quadratic surface has been used for further analysis (Table 6.3, Figs 6.6, 6.7).

TABLE 6.2

Trend surface analysis

	Surface Order					
	1	2	3	4	5	6
Standard deviation	12.86	10.48	9.18	6.06	5.28	4.25
Variation explained (%) by surface	32.68	55.35	65.73	85.04	88.64	92.65
Variation not explained (%) by surface	67.32	44.65	34.27	14.96	11.36	7.35
Coefficient of correlation	.5717	.7440	.8108	.9222	.9415	.9626

TABLE 6.3

Results of analysis of variance for all surfaces

Surface order	% RSS	Significance
1	33	99.9>F
2	55	99.9>F
3	66	99.5>F>99.0
4	85	99.9>F
5	89	95.0>F>90.0
6	93	99.0>F>97.5

The effects of compaction are likely to have been largest where the lake basin was deepest. This relationship is borne out by the trend surface analysis, the axis of the quadratic trough almost exactly paralleling the centre of the reconstructed sub-drift valley (Figs 2.1, 6.6). The upper surface of the



Bosworth Clays describe an open-ended basin with effective shrinkage of the order of at least 9m (30ft) along the centre of the basin (assuming the initial build up of sediment to have reached 119m (390ft)). The pattern of residuals from the quadratic surface shows two clusters of negative values, i.e. areas in which the real interface is lower than the trend (Fig 6.7). Further comparison with the sub-drift surface indicates that these clusters coincide with two left bank tributaries to the Hinckley valley and presumably the site of local basins of compaction. The intervening cluster of positive residuals reflects the buried rib of bedrock at Market Bosworth over which only a thin layer of lake clays accumulated with correspondingly less scope for compaction. Thus whereas the trend maps the major basin of deposition, the residuals demonstrate local variation to which physical meaning can be attached.



7

Interpretation 2



The extinction of Lake Harrison by the readvance of ice was heralded by the deposition of an extensive outwash plain. The sequence of lake clays, cross-bedded sands and gravels and till recurs over much of western and southern Leicestershire. The continuity of the sands and gravels within the study area has been demonstrated (Fig 4.1), and the stratum can be shown to be continuous with the interbedded sands figured in the Hinckley boreholes and the outcrop can be traced around the plug of drift which now forms the Avon/Soar watershed.

At Cadeby, the formation was split into the Cadeby Sand and an upper Cadeby Gravel. There is borehole evidence to suggest that this division can be recognised elsewhere and pits at Heather and Dunton Bassett show a graded sequence with sands passing into gravels (Fig 7.1). This has been interpreted as signifying the greater competence of the meltwater streams to shift material as the ice front pressed southwards. The remaining fragments of this sandur have been mapped (Fig 7.1) and it is not difficult to envisage a once much broader sheet which entirely covered the lake deposits. This reconstruction however, does not carry with it the implication that the deposition of the sandur was everywhere contemporaneous, but was built out over the lake deposits from the north. Its importance lies in the fact that it describes a single event and represents a lithological datum.

Shotton has described this formation and equated the interbedded sands at Hinckley and Sibson (Wellsborough) with the Wolston Sand (1953, fig 5) and mapped its distribution (fig 8) together with contours on the plane separating the Wolston Sand from the underlying clays. The effect on this plane of the compaction of the lake deposits has been recorded above and it has been argued that the outwash was deposited



# REMNANTS OF THE CADEBY SANDUR



Sources : Shotton (1953); Rice (1968); Geological Survey 155, 169

FIG 7.1



on a fairly even surface where the clays had been built up to lake level. Shotton's interpretation of the Wolston Sand does not accord with the view that it represents part of a sandur. Arguing that the Wolston Sand can be correlated with what Rice (1963) subsequently termed the Wigston Sand and Gravel near Leicester, Shotton suggested that its deposition must have meant a glacial retreat and that the sands are evidence of much increased summer melting. (Shotton, 1953, p.253). In section, the formation consistently shows cross-sets rather than either the level-bedding or deltaic fore-sets and would seem to indicate deposition by moving water rather than in still water.

Although the correlation between the Wolston Sand and the Wigston Sand and Gravel seems well founded, there is a gap in the distribution of the sands between Dunton Bassett and Wigston and within the area mapped by Rice the deposit "is so irregularly distributed that rarely can an outcrop be traced continuously for more than a mile or so" (Rice, 1968, p.485). Here too it contains numerous till lenses in sharp contrast to the well-sorted Cadeby Sand and Gravel and Rice has suggested that it may have been laid down "at or beneath the ice margin". A subglacial origin for the Wigston Sand and Gravel could account for the rather low level of the deposit, for if it were deposited as part of the sandur which sloped away from the ice front, it would be expected to be rather higher than the corresponding sands to the south. However, the latter are consistently higher despite the more pronounced compaction of the underlying clays which might be anticipated here.

Outside the Leicester area, however, the Cadeby Sand and Gravel/Wolston Sand horizon describes a sheet of material much of which has been preserved (Fig 7.1) and is well illustrated



by the M69 section through the higher ground southeast of Hinckley (Fig 6.3). That such a wide sandur could develop is testimony to the nearly horizontal landscape of the infilled Lake Harrison which the meltwater streams would have traversed. Yet the outwash was not only deposited onto the lake clays, for at Cadeby and elsewhere, the sands rest directly on the Basal Till or bedrock above the level of the lake. Against the higher ground which fringes Charnwood Forest, the sands and gravels thin out and are overlapped by the tills east of Barlestone and towards Bagworth at a little over 125m (425ft). At Cadeby the mean direction of the streamflow responsible for the sand (as reflected by the bedding) conforms to the gentle bedrock slope westwards towards the margin of the lake. A similar situation obtains at Heather where the gravels are much thicker than indicated by the Geological Survey map (Spink, 1964) and palaeocurrent directions have been estimated by the writer which indicate flow towards the south. The configuration of this sandur is rather different from that of the outwash which preceded the Basal Till and was almost totally confined to the valley floors; but the contrast seems wholly consistent with the differing topographies: the preglacial one showing greater relief and more pronounced lines of drainage than that which immediately followed the lengthy empoundment of Lake Harrison.

The composition of the Cadeby Sand and Gravel is variable with flinty and pebbly <sup>(i.e. Bunter)</sup> facies <sup>p.49.</sup> (4.2). It may be worthy of note that those areas where the flinty facies is dominant (and within the study area they are relatively restricted) coincide with those areas of the Basal Till which contain an easterly component of erratic material. This pattern may be the result of a reworking of local materials by the channels of the sandur rather than firm evidence of the provenance of the ice



sheet which was supplying the meltwaters. However, the overall composition of the sand and gravel sheet at a regional level shows that the eastern material is much more frequent in the easterly parts of the sandur. At Dunton Bassett (SP 538904) and Smockington (SP 462895) the gravels contain numerous flints. The stone counts presented by Rice (1963) for the Wigston Sand and Gravel show sharp diversity in their type as do the till layers which envelop this stratum. At Keyham and Scraptoft large quantities of Jurassic material were recorded and over the central Leicestershire region as a whole Rice has observed that, "the bed is particularly noteworthy as the earliest to contain Cretaceous rocks in quantity." (Rice, 1968, p.473). Whereas to the west at Cadeby and to the south in the Coventry area, the pebbly facies is prevalent (Table 7.1).

TABLE 7.1

Comparative Stone Counts

Cadeby Gravel      Wolston Sand\*

Rock type		Percentages
Carboniferous	6	15
Bunter	52	49
Keuper	34	18½
Lias	}	2½
Flint		9½
Other	1	5½

\* from Shotton (1953).

This analysis merely reinforces the evidence from the later tills that the ice sheet as it began to readvance over the silted proglacial lake contained material from more than one source.



The tills which covered the Cadeby sandur represent the second major ice advance, the earlier one being that which preceded the existence of Lake Harrison.

Within the study area the upper clays are represented by the Pennine and Chalky Tills which contain no material which could be regarded as being deposited within a lake. This contrasts with the evidence for the Coventry area where Shotton has attributed much of the Upper Wolston Clay to a lacustrine origin. Given the certainty of the equivalence between the Cadeby Sand and Gravel and the Wolston Sand, the phase of ponding represented by the Upper Wolston Clay was established after the ice had readvanced across Leicestershire. The M69 boreholes only indicate tills above the Wolston Sand horizon and thus the Upper Wolston Clay lake must have been restricted to the southern part of the Lake Harrison basin. Indeed, if the postulated Severn ice block allowed the basin to remain watertight, Lake Harrison may have persisted beyond the southern limit of the outwash plain as ice overrode the northern part. Perhaps the apparent conflict between this interpretation and the palaeogeography presented by Bishop (1958, fig.11) can be explained by Bishop's recognition of only one major ice advance. (The Hodnell Clay ice advance was not given the status of the advance proposed here, but was regarded more as an oscillation). Thus the first phase of Lake Harrison, the lake of the Bosworth and Lower Wolston Clays, was established during the retreat of the Basal Till ice advance and the lake was extinguished only with the re-advance of the ice.

The evidence from the samples and borehole records of the M69 reviewed by Wyatt (1974) supports a subdivision of the lake clays into a lower part where red-brown material



TABLE 7.2

Glacial Deposits and Provenance in Leicestershire

Schematic sequence of events	Western Leicestershire	Central Leicestershire	M69 Motorway	Dunton Bassett
Readvance of ice	Pennine and Chalky Till often banded at junction	Upper Oadby Till: chalky Lower Oadby Till: red	Largely, but not entirely chalky tills	Chalky and red tills
Outwash	Cadeby S & Gr: predom- inantly non-eastern	Wigston S & Gr: great diversity in provenance	Generally non-eastern	Both flints and Dunter pebbles in large nos.
Lake Harrison	Both red and bluish- brown lacustrine mat- erial.	Thrusington Till: largely northern with local inclusions of eastern material	Lake clays sub-divided into upper (blue-brown) & lower (red) types	Red and chalky flow tills intercalated with lake clays
Ice advance	Basal Till: largely northern material with patches of eastern		Both till types with at least 1 example of chalky till at base	Chalky till
Outwash	-	Thurnaston Sand and Gravel: <u>no</u> Cretaceous material	<u>No</u> Cretaceous material	-

Sources: Rice (1963) and fieldwork.



predominates and an upper part which is more calcareous and in which the clays assume a bluish-brown colour. This distinction has been explained by invoking a shift in the input of material into the lake corresponding with the later dominance of ice containing Cretaceous material. A similar distinction can be recognised in western Leicestershire, although the blue clays and associated 'race' are by no means exclusively restricted to the upper part of the deposit (e.g. Bosworth Wharf, 3.2). If this interpretation is correct (and it seems unlikely that the contribution of an ice sheet charged only with Triassic and Carboniferous detritus would produce the high carbonate levels recorded from the upper parts of the Bosworth Clay), then the dominance of eastern ice is evidenced before the deposition of the Cadeby Sand and Gravel which together with the Pennine Till suggests a reversion to a non-eastern glacier. Great caution needs to be exercised in such explanations given the lack of any proof for the sources of this material. Suspended sediment from land streams draining the Liassic rocks may have contributed much of the more calcareous deposit. The ice front which held back the lake to the north was very extensive blocking free drainage in the Tame, Anker and lower Soar valleys and it is difficult to avoid the conclusion that the lake was ponded by ice containing both eastern and non-eastern material. Thus the boundary between the Bosworth Clay and the Cadeby Sand and Gravel, besides signifying a change in depositional environment, shows a switch from material which was probably derived from an eastern source (the upper part of the lake clays) to outwash which in western Leicestershire at least, contained little eastern material. Once again it may be dangerous to adopt too literal an interpretation of this apparent change in provenance but the possibility must be



acknowledged that unlike the outwash, the lake floor sediment may not have been derived from the adjacent ice-front.

At the start of the ice readvance which deposited the Pennine and Chalky Tills, there is ample evidence to indicate that the ice sheet which framed Leicestershire to the north and east was already a compound one. The structure and macrofabrics of the tills at Cadeby have been described above (5.3, 5.4), and it is now possible to assess how far these sedimentological properties elucidate the nature of the advance and particularly the way in which material of diverse provenance can be incorporated in one composite till sheet.

The Cadeby till sequence can be divided conveniently into three parts: the Pennine and Chalky Tills with the intervening banded sequence. The absence of any structures within the Pennine Till and the consistent direction and strength of the macrofabrics have been taken as evidence of deposition by lodgement (5.4). Only a single occurrence suggests otherwise. On one face a layer of Pennine Till penetrates the underlying outwash sands. The sands partly enclose and have been deformed by this tongue of till which was probably emplaced as a flow when the till was saturated with moisture. Following Boulton (1972), there seem to be three possibilities to be considered in the interpretation of the till sequence. The contrasting bands of the overlying series of banded tills are too delicate to have been deposited through basal lodgement from discrete ice sheets alternately advancing and retreating. (Plate 6, Fig 5.3). Secondly, if they are regarded as flow tills, the astonishing lateral persistence of bands no thicker than 2cm would argue for an extremely fluid flow capable of spreading out over a considerable area with little variation in thickness. Thirdly, however, deposition as melt-out till from englacial debris bands



presents other problems. If each band of till represents a layer of material from one or more thrust planes, it is difficult to envisage the ice containing so many planes with alternating debris types, although it is possible that the ice was advancing across a landscape where both these till lithologies were exposed and they could have been incorporated in the ice by basal freezing. Yet it is this explanation which seems the most probable to the author, for interpretation of the bands as flows deposited subaerially presupposes the existence of two discrete parent ice masses each acting as an alternate source of material. Such a circumstance may be plausible on a local scale to explain one occurrence but the banding has been detected at so many sites that a more general explanation seems necessary.

The entire sequence of tills could be ascribed to one advance of chalk-rich ice which overrode a series of Trias-derived deposits incorporating them as a basal layer which was subsequently deposited as the Pennine Till. Rice (1972, p. 70) for instance has argued that, "Trias-rich lenses in the Oadby till might be attributed to secondary derivation", and the exposures at Aston Firs, the A5070/M69 junction, indicate the power of the ice to pick up and incorporate diverse materials (Fig 6.3). In the case of the Pennine Till, however, difficulties attach to such an interpretation. Firstly, the Pennine Till is so lithologically distinct from the Chalky Till that if in fact it were laid down under eastern ice a greater admixture of Jurassic and Cretaceous fragments might be expected. Secondly, at Cadeby the preferred orientation of the Pennine Till macrofabrics indicate movement from either the southeast (improbable) or the northwest which would seem to preclude chalk-bearing ice. (It is of course possible that these fabrics have either been incorrectly



7.2

interpreted or are not representative). Thirdly, a red till similar to the Pennine Till at Cadeby appears in the same stratigraphic position at Dunton Bassett well to the east near the Rhaetic outcrop. This easterly position effectively limits the amount of non-eastern material which a westward or southwestward moving ice sheet could assimilate, thus making the local red till an unlikely product of an advance from the east. It seems therefore, that the initial movement of ice as it advanced over the sandur was from the north or northwestern sectors and that this was eventually overridden by chalk-rich ice producing a composite ice sheet, the deposits of which hint at a variety of depositional modes but which were ultimately characterised by the Chalky Till, for above the banded tills there is no reversion to a Trias-rich till.

The whole question of ice sheet provenance and the nature of the resultant tills needs re-examination. Rice (1972, p. 70) has concluded that, "no major discontinuity in sedimentation" exists between the Trias-rich and chalky tills in central Leicestershire. The evidence from the west of the county certainly confirms that they were the product of a single event and it seems that earlier schemes which linked each till lithology with a separate glacial advance can no longer be sustained. (Deeley, 1886; Fox-Strangways, 1903; West and Donner, 1956). Throughout the entire sequence of Pleistocene deposits in Leicestershire which are almost certainly the product of only one glaciation (Rice, 1972, p.71), only in the basal sands and gravels have no Cretaceous materials been found and only in the uppermost part of the till complex (the Chalky Till of western Leicestershire, the Upper Oadby Till) do Trias-rich deposits appear to be absent. Table 7.2 attempts



to summarise the evidence in Leicestershire regarding the ultimate provenance of the drift materials and shows that from the ice advance prior to the existence of Lake Harrison, during the ponding of the lake and during the readvance of the ice, the ice sheet was a composite one.

### 7.3

Two types of structure which involve the tills have been identified. The first is that described at Cadeby (4.1, 5.3) which involves a rather angular folding of the tills and the underlying sands and gravels. The structure is poorly exposed but the fold axis trends from west to east and the northern limb of the flexure dips towards the north at approximately  $25^{\circ}$ . The feature is interpreted as the result of a disruption of the underlying beds by the passage of ice. At Dunton Bassett in a pit working the same sand and gravel horizon as that at Cadeby, splendid examples of glacio-tectonics have been exposed and the axes of the folds and thrust planes are similarly aligned from west to east, normal to the presumed direction of ice movement.

In several places in the study area augering has been able to detect zones where the tills rest unconformably on older beds often in gentle-sided channels which truncate the underlying drift. The channels are invariably filled with Chalky Till although some patches of Pennine Till have been encountered in them. Spink (1964) has reported relatively narrow channels from the Leicestershire coalfield up to 15m (50ft) deep and plugged with chalky till. The cutting of all these channels was probably accomplished by ice so that they were never open to the air. A comparable channel



has been exposed in the cutting of the M69 at Yennards Farm near Huncote (SP 505980) where the local till sequence, normally conformable on the basal sand and gravel, cuts across the bedding of the sands and brings till to unexpectedly low levels. It is perhaps surprising that these local unconformities are not more frequent and that the passing of the ice sheet was not associated with more localised erosion of the sandur surface.

Associated with the Chalky Till is the Flinty Gravel which is regarded as the product of the final decay of the ice sheet and can be equated with the Dunsmore Gravel which caps the succession near Rugby (Shotton, 1953).



# 8

## Correlation and Chronology



The type sequence described in 6.1 is used as the basis of the correlation presented here. The reconstruction of events discussed in the last two chapters has been founded largely on the glacial stratigraphy of western Leicestershire which in turn has been matched with other areas within the compass of Lake Harrison. Although the model of events proposed differs from other interpretations, the correlation of the drifts is similar to that given by Shotton (1973A). It remains to justify the correlation of the west Leicestershire sequence with that of Shotton (1953) and Rice (1963) and to evaluate the strength of other correlations (Table 8.1).

The equivalence of the Cadeby Sand and Gravel and the Wolston Sand underpins the correlation between the northern part of Lake Harrison and the sequence exposed by the Warwickshire Avon. In both areas this horizon is readily mapped and the formation has been preserved over much of its original extent (Fig 7.1). Having established this stratigraphic datum, the underlying and overlying clays in both areas can be matched. The co-extension of the underlying clays is proven by the M69 borcs (Fig 6.3) and thus the Bosworth Clays and the Upper part of the Lower Wolston Clays can be correlated as can the Basal Till and the lower part of the Lower Wolston Clay. Similarly the Upper Wolston Clay and the Pennine and Chalky Till can be regarded as approximate equivalents.

Rice (1963) has presented strong arguments which link the Leicester succession with that near Coventry. There is a remarkable similarity between the basal sands and gravels of the two areas and their correlation seems certain (Fig 6.2). An independent check establishes the relative equivalence of the Oadby Till with the Pennine and Chalky Till and thus



TABLE 8.1

Correlation of Wolstonian deposits in the Lake Harrison area

Stour & Evenlode	Itchen Valley	Rugby, Coventry & Leamington	Western Leicestershire	Central Leicestershire
Chalky Till	Grange Clay	Dunsmore Gravel Upper Wolston Clays	Flinty Gravel Chalky Till Pennine Till	Upper Oadby Till Lower Oadby Till
Purple Clay	Wolston Series Hodnell Clay	Wolston Sand Lower Wolston Clay	Cadeby S & Gr Bosworth Clay Basal Till	Wigston S & Gr Thrussington Till Glen Parva Clay
Quartzose & Paxford Gr (Stretton Sands ?)		Baginton Sand Baginton-Lillington Gr		Thurmaston S & Gr
Briggs & Gilbertson (1972)	Bishop (1958)	Shotton (1953)	Douglas (1975)	Rice (1963)

For explanation see text



with the Upper Wolston Clay. On the Beaumont Leys interfluve which separates the Rothley brook from the Soar valley, Oadby Till rests on patches of Wigston Sand and Gravel. This till can be traced southwestwards beyond the western edge of Rice's map (Rice, 1968, fig 14) towards Leicester Forest East and Cross Lanes (SK 506019) where the till overlies the sand and gravel horizon which can be traced via Desford to the study area where it has been mapped as the Cadeby Sand and Gravel. Thus the correlation of the main formations in the triangle between Leicester, Coventry and Market Bosworth is firmly based.

Away from the drift plug which carries the main English watershed across the line of the proto Soar valley, correlation depends on the comparison of local sections and cannot be checked by establishing the continuity of beds as post-glacial dissection has destroyed much of the drift. Given the fact that till lithology does not discriminate reliably between the earlier and later ice advances and that ponding undoubtedly took place on more than one occasion, comparison of stratigraphies is fraught with potential difficulties. However, the similarity between sequences presented by Bishop (1958) for the Itchen valley and Briggs (1973) for the Stour/Evenlode area with others in the Lake Harrison basin leads to the correlation presented in Table 8.1.

The internal consistency of these correlations within the Midlands cannot be extended outside the region with the same certainty, for as Wills observed as long ago as 1937, "The weakest links in the chain of evidence are those that connect the Midlands with other glaciated areas". The classic East Anglian succession has recently been the subject of renewed enquiry with the suggestion that the Chalky Boulder Clay which has traditionally been divided into the Lowestoft



(Anglian) and Gipping (Wolstonian) may be the product of only one glaciation. (Perrin et al., 1973; Bristow and Cox, 1973). If this view is accepted on stratigraphic grounds, then the palaeobotanic evidence is difficult to resolve. At the type site of Hoxne, the interglacial deposits overlies Chalky Boulder Clay, whereas in the West Midlands at Quinton and Nechells, tills which can be linked stratigraphically with the chalky tills of Warwickshire and Leicestershire overlies deposits of Hoxnian age (Kelly, 1964). Yet if the Chalky Boulder Clay at Hoxne is regarded as Anglian, there is by implication a boundary, as yet unspecified, which represents an interglacial somewhere between the Chalky Boulder Clay of East Anglia and that of the Midlands. This viewpoint is in seeming contradiction to the conclusion that, "the remarkable constancy of composition of its (the Chalky Boulder Clay) matrix over a considerable area makes it difficult to believe that the Chalky Boulder Clay could be the product of more than one glaciation." (Perrin et al., 1973, p.102). Given the variance of these interpretations, no attempt has been made to relate the deposits of Leicestershire with those of East Anglia.

## 8.2

To correlate the Leicestershire sequence with those of Shotton is to regard them as Wolstonian. Rice (1972) is emphatic that the central Leicestershire sequence is the product of one glaciation, similarly no major time breaks have been recognised in the west Leicestershire type sequence which must be regarded as the result of one cold period.

Absolute dates are not nearly so firmly based for the Wolstonian stage as for the majority of the Devensian.



Furthermore, the absence of interstadial deposits comparable to those which sub-divide the Devensian still further weakens the chronological framework within which the Wolstonian events described in this research can be placed.

Despite the unorthodox claims of Page (1972) for a much younger date for post-Hoxnian deposits (Shotton, 1973B), the overwhelming balance of opinion puts a date for the close of the Wolstonian glacial in the range 100,000 to 120,000 years BP. (see for instance, West, 1968; Coope, 1975). Thus it is not possible to date the Wolstonian deposits of Leicestershire any more precisely than in the glacial which ended about 100,000 years BP. Shotton (1973A, p.4) has suggested that the Wolstonian type site contains stratigraphical units which cover the cycle from cold protoglacial (the Daginton-Lillington Gravel) through full glacial to a period of ice retreat (the Dunsmore Gravel). Yet because this sequence and its northern equivalent in Leicestershire are bounded by erosional unconformities and contain remarkably few biogenic deposits, the Wolstonian stadial to which they relate cannot be inferred. The absence of plant or animal remains from any of the stillwater deposits which have been ascribed to Lake Harrison permits the conclusion that only a minimal amelioration in climate would have been sufficient to cause the ice sheets to retreat from the maximum of the Basal Till advance to a position near Leicester. Indeed the very necessity of ice blocks around the lake argues that the climate was always that of a full glacial.

The only evidence which might hint at the duration of ponding conditions in west Leicestershire is that provided by couplets of clay and coarse silt recovered from a bucket auger bore near Kingshill (3.2). If these are regarded as



annual varves and the assumption is made that their rate of accumulation is representative of the Bosworth Clay as a whole, then their average frequency which is of the order of 5 per cm gives a period of 25,000 years for the deposition of 50m of lake deposits. This seems an almost improbably long time during which the ice-blocks must have remained almost stationary and it may be that the interpretation of these couplets as true annual varves is not valid, for in many instances microvarves have been shown to have doubtful significance as they have no annual implications (Duff, Hallam and Walton, 1967).



9

Postscript



The landforms of western Leicestershire are subtle rather than spectacular. They have not attracted the attention of geomorphologists to the same extent as the more distinctive landscapes of the Jurassic scarplands or Charnwood Forest. That the geometry of the present land surface is radically different from that which existed at the beginning of the Wolstonian will have been evident from the discussion of the sub-drift surface (Chapter 2). Shotton (1953) pointed to the Market Bosworth area as an example of how the present drainage cuts across the preglacial Hinckley valley. Thus the geomorphological evolution of western Leicestershire can only be explained with reference to the Pleistocene geology.

Dury (1972), by extending the traditional meaning of the word pediment to include slopes which contained no pediment angle, showed that such a form was characteristic of profiles from the English Midlands. The important elements of these profiles were constant slopes frequently developed on or below relatively competent beds and above degradational slopes (the 'pediments'), cut across rock and decreasing in gradient in an orderly fashion in a downslope direction. Evidence that soil creep is an ongoing process and that rock waste is moving down the 'pediment' led Dury to suggest that the slopes are still evolving. In the Edge Hill profile, where the slope is cut across the Wolstonian deposits, Dury (1972, p. 148) claimed that "the Lake Harrison fill is being cleared by a process of pedimentation." Furthermore, one of the lower constant slopes on the Edge Hill profile was regarded as appearing to "represent an evolved form of the cliff that once stood at the shore of Lake Harrison."

Many slopes in the western Leicestershire study area were measured with an Abney level during the field mapping of



the Pleistocene sequence and several associations of slope elements similar to those recorded by Dury. (1972) were noted. In the majority of cases the constant slope element was rather short and graded into the lower concave slopes, there being no perceptible break (Plate 1). With few exceptions, the steepest slope elements were related to structural features, usually the outcrop of the Cadeby Sand and Gravel or to coarser horizons of sand within the glacio-lacustrine sequence. With such a strong relationship exhibited between structure and morphology, the use of such terms as 'pediment' and 'pedimentation' seems both undesirable and potentially misleading. However, Dury's findings that slope development processes are continuing to the present day are supported by evidence from the study area. An outlier of Cadeby Sand and Gravel caps the eminence of Ambion Hill. Field boundaries consisting of thick hedgerows at the lower edge of the uppermost (convex) slope element show that they are acting as barriers to the downslope creep of waste: the regolith being much thicker on the upslope side than the downslope. As enclosure took place in Tudor times, the difference in regolith thicknesses can be attributed to contemporary processes. Indeed, adjacent slopes where no similar barriers impede the removal of waste have a smoother profile.

That a large part of the fill of Lake Harrison and the other Wolstonian deposits have been removed by dissection is evident from the outcrop pattern of the drift formations. Large inliers of bedrock south of Market Bosworth and Sutton Cheney are surrounded by the outcrops of Basal Till and Bosworth Clay suggestive of a once continuous spread of drift whose preservation or erosion has been largely a function of distance from stream channels. Thus the most complete record



of drifts coincides with the present watershed between the Anker and Soar basins, although drift thickness relates to the intersection of the sub-drift and contemporary land surfaces (fig 2.3). The remnants of the Cadeby sandur (fig 7.1) are indicative of those areas of higher ground which have survived dissection. The chronology of this postglacial evolution must remain rather vague within western Leicestershire. Unlike the Avon and Soar valleys considered by Shotton (1953) and Rice (1963) respectively, the record of river terraces in western Leicestershire is meagre. Within the study area, the Sence and Sence Brook attain no great size and only one low terrace above the floodplain has been mapped by the author. Further westwards near Sheepy Parva, it is possible to recognize two terraces and the Anker below Atherstone has terrace remnants at more than one level.

The pattern of postglacial landform development is an extraordinarily complex one which has resulted in some seeming anomalies which are difficult to reconcile. At the village of Croft, southwest of Leicester, Rice (pers. comm.) has noted that the Soar has cut a steep-sided slot into the outcrop of the dioritic intrusion. It would appear that the gorge is the product of superimposition from a drift cover which must have extended across the area and that the Soar has made an incision of at least 10m into extremely resistant bedrock since the Wolstonian. Similarly, in Charnwood Forest, Bridger (1971) has recorded several examples of streams which cut across rocks of the Precambrian basement the courses of which seem explicable only in terms of superimposition from a drift cover. At the other extreme, the preservation of relatively delicate features argues that elsewhere in the Midlands postglacial erosion has been almost nil. Most



notably, the Lake Harrison bench recognized by Dury (1951) has remained remarkably intact (fig 6.2). An erosional feature, frequently cut across soft clays, the bench can still be traced over much of its length and on slopes immediately adjacent to those more recently recognized by Dury (1972) to be undergoing 'pedimentation'. On the surveyed profile at Edge Hill, Dury showed that a constant slope was cut across periglacial head referable to the Devensian and acknowledged that not only did the slope undergo solifluction during the last glaciation but slope development has proceeded subsequent to periglaciation.

Within the study area, even allowing for the effect of compaction, the streams have incised by as much as 50m into the inferred surface represented by an extrapolation of the Chalky Till and Flinty Gravel horizons. A large proportion of this dissection may have taken place immediately upon the withdrawal of the ice from the area. The large volumes of water supplied by the melting of stagnant ice would have been particularly efficacious in this respect (Rice, 1972).

The lack of glacial drift in the Anker valley frustrates attempts to reconstruct the sub-drift surface there, but beyond the western flanks of the Hinckley valley, the Anker may be a survival of the preglacial pattern of drainage, following the eastern edge of the Hartshill range, an area that may never have belonged to the proto-Soar catchment. The upper courses of the Sence and other right bank tributaries of the Anker are entirely postglacial streams trending at right angles to the line of the Hinckley valley.



Mention has already been made that the Cadeby Sand and Gravel is a scarp former. Above the steeper slopes developed at the edge of this formation, the interfluvial crests are often flat-topped, especially where the overlying till cover has been stripped. Striking examples of these plateaux occur at Newbold Verdon and at Kirkby Lodge. Below the outcrops of sands and gravels, aprons of colluvial material mantle the slopes in many places thickening to well over a metre downslope. Active mass movement is evidenced by fresh slump scars and rotational slips involving sands and gravel (plate 4). The toes of these slipped masses extend downslope into the spreads of colluvial material consisting of a melange of sandy wash and clay.

Qualitative assessment of valley side slopes would indicate that the north and northwest facing slopes tend to be rather steeper than those with a southerly or southeasterly aspect. The relationship is well shown by the tributary of the Sence which has cut through the drifts between Nailstone and Barlestone. On the northwest facing slopes the Cadeby Sand and Gravel gives rise to a prominent scarp with slope facets of up to 12 degrees, whereas on the opposite slopes the same horizon has not produced any notable features and the gentle slopes of 2-4 degrees are mantled with a thick spread of sandy colluvium. Although both slopes are clearly still evolving, the valley asymmetry may be an inheritance from periglacial conditions when aspect exerted an important control on solifluction. The extent to which the spreads of colluvium are remnants of a once more continuous mantle of head must remain a problem.

Shotton (1968) in the Avon valley and Morgan (1973) for the area between Wolverhampton and Stafford have recognized



# PERIGLACIAL INVOLUTIONS EXPOSED AT CADEBY

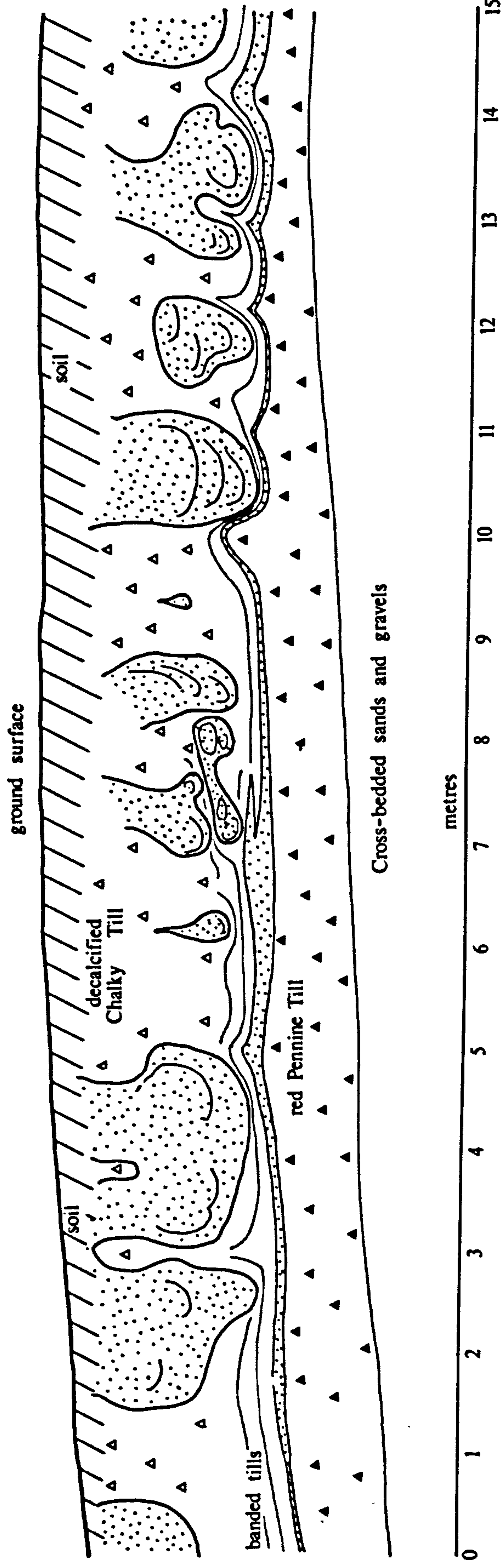


FIG 91



several phases during the Devensian when ice wedges were developing and cryoturbation took place. Within western Leicestershire pockets of sand are relatively frequent and at Cadeby most faces of the sand and gravel pit show that the upper layers of till have been disturbed (fig 4.2). One face showed a particularly fine series of involutions which have developed to a maximum depth of 2.5m below the present ground surface (fig 9.1). The base of the involutions coincides with a layer of fine sand which separates the Chalky and banded tills from the Pennine Till, the latter being almost unaffected by the disturbances. Decalcified Chalky Till has been drawn up in a series of plumes around "frost kettles" which contain well-sorted but unbedded sands. The junction between sand and till is sharp and the relationship suggests that a layer of sand has been involuted into the till. The Flinty Gravel which caps the till succession locally contains some sand and could be a possible source of the filling in the involution cores (frost kettles) but as these and similar pockets of sand seem to be related to the present land surface rather than to any 'sub-Flinty Gravel' plane, another source is indicated. Perrin et al. (1974) show from an examination of surface soil texture in eastern and southern Britain that a province of cover sands once extended over much of East Anglia and the East Midlands, possibly as an extension of the belt of cover sands in the Netherlands and Belgium (although the validity of this stratigraphical correlation has not been demonstrated). Such a sheet of aeolian deposits would provide the material which was subsequently incorporated in the involutions and thus the period of aeolian deposition must have preceded the periglacial disturbance. In the absence of any direct dating evidence for the period or

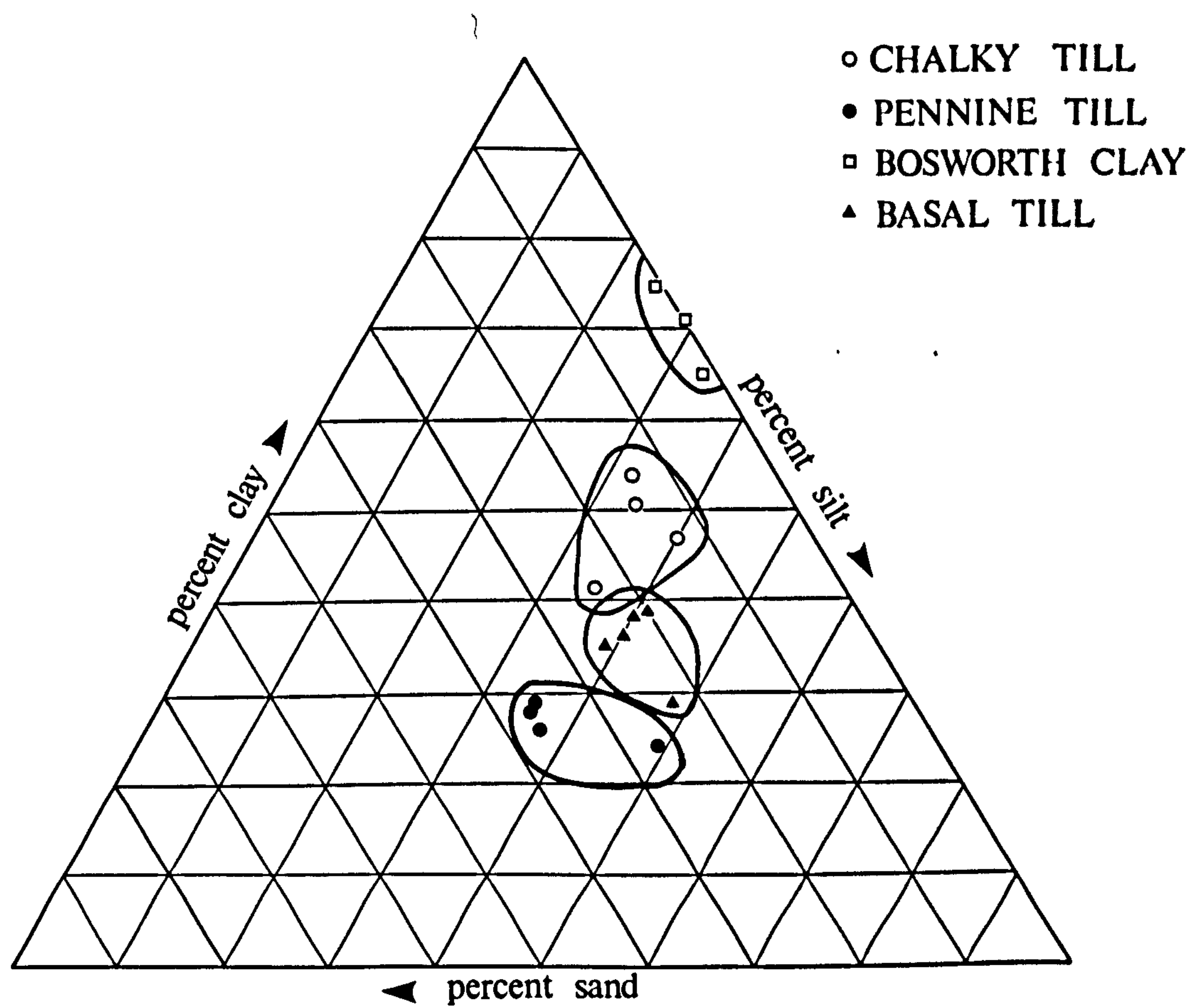


periods of periglacial activity, it can only be contended that a Devensian date seems certain as the involutions are related to the present land surface rather than any Wolstonian one.



# Appendices





APPENDIX I



APPENDIX 2

The listings which follow are for the programs used in the till macrofabric analysis presented in this volume. They have been slightly modified from the listings provided by the programs' authors and both run on the Leicester University Cyber.



```

C
C
C
C
5
PROGRAM TILFAB (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)

TILL FABRIC ANALYSIS (ANDREWS)
THIS PROGRAM MODIFIED TO RUN ON CYBER (T.D. DOUGLAS, 1975)

C
C
C
C
10
DIMENSION IDRE(100)
DIMENSION AZ(100),PL(100),TITLE(6)
COMMON/HEAD/TITLE,NPAGE
SL = 3.  * CI = 1.
SL AND CI ARE SIGNIFICANCE LEVEL (IN STANDARD DEVIATIONS) AND
C
C
C
C
15
CONTOUR INTERVAL, PARAMETERS FOR SUBROUTINE FABRIC
READ(5,300) TITLE
NOTE THAT A CARD WITH UP TO 60 HOLLERITH CHARACTERS
MUST PRECEDE THE DATA
NPAGE=1
INDEX=0
READ(5,100) ID,ND,ORT,DIP
7 ID=ID
NDR=ND
SUMA=0.
SUMB=0.
SUMC=0.
LINE=0
N=0
GO TO 651
1 N=N+1
IF(DIP) 20,20,25
20 AZ(N) = ORT
PL(N) = -DIP
GO TO 30
25 AZ(N) = AMOD(ORT+180.,360.)
PL(N) = DIP
30 DIP=DIP*..17453292
ORT=ORT*..17453292
COSD=COS(DIP)
A=COSD*SIN(ORT)
B=COSD*COS(ORT)
C=SIN(DIP)
SUMA=SUMA+A
SUMB=SUMB+B
40

```



```

SUMC=SUMC+C
READ (5,100) ID,ND,OPT,OIP
IF(ID-IDR)2,651,2
2 R=SUMA*SUMA+SUMB*SUMB+SUMC*SUMC
45 R=SQRT(R)
ORTN=ATAN(SUMA/SUMB)*57.29577951
IORTN=ORTN
IF(SUMB) 13,5,5
5 IF(ORTN) 12,50,50
12 IORTN=360+IORTN
50 GO TO 51
13 IORTN=180+IORTN
50 CP=SUMC/R
PTRAL=ATAN(CP/SQRT(1.-CP**2))*57.29577951
IPTBAL=PTRAL
55 IF(SUMC) 8,6,6
6 A=N
X=20.**(1./(A-1.))-1.
COSTHTA=1.-(A-R)*X/R
SINTHTA=SQRT(1.-COSTHTA**2)
THETA=ATAN(SINTHTA/COSTHTA)
CDEG=THETA*57.29577951
Y=(A-1.)/(A-R)
WRITE (6,602)
WRITE (6,610) NPAGE
NPAGE=NPAGE+1
DO 3 INDEXDO=1,5
3 WRITE (6,603)
WRITE (6,604) IDR
WRITE (6,605) NDR
WRITE (6,606) IORTN
WRITE (6,607) IPTBAL
WRITE (6,608) R
WRITE (6,609) CDEG
WRITE (6,615) Y
CALL FABRIC(N,SL,CI,PL,AZ)
IF(ID.NE.1) GO TO 7
1001 WRITE(6,612)
IF(INDEX) 1002,1000
1002 WRITE (6,601)

```



```

85 WRITE(6,603)
   DO 1003 I=1,INDEX
1003 WRITE (6,614) IDRE(I)
      WRITE(6,603)
1000 WRITE (6,200)
      CALL EXIT
      8 INDEX=INDEX+1
      IDRE(INDEX)=IDR
      GO TO 6
90 SUBROUTINE PRINT
   C
   C TILL FABRIC ANALYSIS
651 IF(LTNE) 800,652,*00
652 WRITE (6,602)
      WRITE (5,610) NPAGE
      NPAGE=NPAGE+1
      WRITE (6,603)
      WRITE(6,611)
      WRITE (6,612)
      WRITE (6,603)
800 WRITE (6,614) IDR, NDR, ORT, DIP
      LINE=LINE+1
701 IF(LINE.GT.45) 701, 1
      LINE=0
      GO TO 1
105 C
      END OF SUBROUTINE
120 FORMAT(I3,1X,I3,3X,2F3.3)
601 FORMAT(34H DIP IN FOLLOWING SAMPLES NEGATIVE)
602 FORMAT(1H1)
603 FORMAT(//)
604 FORMAT(16X,15H IDENTIFICATION,12X,I5)
605 FORMAT(16X,15H NATURE OF DATA,12X,I5)
606 FORMAT(16X,15H ORIENTATION ,12X,I5)
607 FORMAT(16X,17H POINT OF BALANCE,10X,I5)
608 FORMAT(16X,11H RESULTANT,12X,F10.3)
15 609 FORMAT (16X,21H CIRCLE OF CONFIDENCE,1X,F10.3)
610 FORMAT(48X,94 PAGE NO.,I5)
611 FORMAT(13X,9H IDENT.,7H NATURE,7X,7H ORIEN-,6H DIP)
612 FORMAT(22X,8H OF DATA,3X,7H TATION)
614 FORMAT(13X,I7,I5,F12.0,F7.3)
615 FORMAT(16X,20H PRECISION PARAMETER,2X,F10.3)
200 FORMAT(20H PROCESSING COMPLETE)
301 FORMAT(6A10)
      END
20

```



```

5      SUBROUTINE FABRIC (N,G,H,P,T)
        DIMENSION P(N),T(N),O(17,17),R(17,17),S(17,17),LI(241),LJ(241),
1      4P(30,48),IC(17,17),NA(5),TITLE(6)
        COMMON/HEAD/TITLE,NPAGE
        DATA NA,NP/1HX,1H*,1HC,1H/,1H-,1H /
10     FORMAT(1H1,I4,7H POINTS,5X,6A10/1H ,16HCOUNTING AREA = F6.3/1H ,
1      1 18HEXPECTED NUMBER = F5.2/1H ,29HSTANDARD DEVIATION (SIGMA) =
2      2 F5.2,23H = (EXPECTED NUMBER) / F3.1,30X,8HPAGE NO. I5)
101    FORMAT(1H /1HC,21X,7I5)
102    FORMAT(1H /1H0,11X,11I5)
103    FORMAT(1H /1H0,6X,13I5)
104    FORMAT(1H /1H0,1X,15I5)
150    FORMAT(1H ,66HORDER OF SYMBOLS IS -, X, *, ', /, -, ... WITH CONTO
1      1UR INTERVAL = F3.1,6H SIGMA/1H3,42X,1H1/1H )
201    FORMAT(1H ,3X,79A1)
202    FORMAT(2H W,2X,39A1,1H+,39A1,2X,1HE)
203    FORMAT (1HC,42X,1HS)
        A = G**2/(N+G**2)
        R = 1. - A
        E = N*A
        SIG = E/G
        F = SIG*H
        M = 0
25      DO 10 I=1,17
        X=(I-9)/7.874
        DO 10 J=1,17
        Y=(9-J)/7.874
        IC(I,J) = -1
        W = X**2 + Y**2
30      IF(W.GT.1.22) GO TO 10
        M=M+1
        IC(I,J)=0
        LI(M)=I
        LJ(M)=J
        SH=SQRT(2. - W)
35      O(I,J) = 1. - W
        R(I,J)=Y*SW
        S(I,J)=X*SW
10      CONTINUE
        DO 20 K=1,N

```



```

45 PHI = (90. - P(K))*0.017453293
THE = T(K)*0.017453293
ST = SIN(THE)
CT = COS(THE)
SP = SIN(PHI)
QQ = COS(PHI)
RR = SP*CT
SS = SP*ST
50 DO 20 M=1,241
I = LI(M)
J = LJ(M)
IF(ABS(QQ*Q(I,J)+RR*P(I,J)+SS*S(I,J)).GE.B) IC(I,J) = IC(I,J) + 1
20 CONTINUE
WRITE (6,100) N,ITITLE,A,E,SIG,G,NPAGE
NPAGE = NPAGE + 1
WRITE (6,101) (IC(I,2),I=6,12)
WRITE (6,102) (IC(I,3),I=4,14)
WRITE (6,103) ((IC(I,J),I=3,15),J=4,5)
60 WRITE (6,104) ((IC(I,J),I=2,16),J=6,12)
WRITE (6,103) ((IC(I,J),I=3,15),J=13,14)
WRITE (6,102) (IC(I,15),I=4,14)
WRITE (6,101) (IC(I,16),I=6,12)
DO 50 I=1,16
70 DO 50 J=1,16
IT=-1
65 IF(IC(I,J).LT.0) IT = IT+1
IF(IC(I+1,J).LT.0) IT=IT+1
IF(IC(I,J+1).LT.0) IT=IT+1
IF(IC(I+1,J+1).LT.0) IT=IT+1
70 IF(IT) 25,25,50
25 IN=5*I-4
JN=3*J-2
7A = IC(I,J)
ZB = IC(I+1,J)
ZC= IC(I,J+1)
ZD = IC(I+1,J+1)
ZE = ZD - ZB - ZC + ZA
ZF = ZB - ZA
75 ZG = ZC - ZA
80 40 IX=1,5

```



```

85      XX = (IX-1)/5.
      LX = IN + IX -1
      ZEX = ZF*XX
      ZFX = ZF*XX
      ZFA = (ZFX+ZA)/F
      ZGX = (ZEX+ZG)/F
      DO 40 IY=1,3
      LY = JN + IY - 1
      MM = ((IY-1)/3.)*ZGX + ZFA
      MO = MOD(MM,5)
      IF(MO.EQ.0) MO=5
      MP(LX,LY) = NA(MO)
      40 CONTINUE
      50 CONTINUE

90      DO 80 J=2,21
      MJ = 50-J
      V = ((J-25)/3.)**2
      DO 70 I=2,32
      MI = 82-I
      IF((((I-41)/5.))**2+V).LT.62.) GO TO 90
      MP(I,J) = NB
      MP(MI,J) = NB
      MP(I,MJ) = NB
      70 MP(MI,MJ) = NB
      80 CONTINUE

105     WRITE (6,100) N,TITLE,A,E,SIG,G,NPAGE
      NPAGE = NPAGE + 1
      WRITE (6,200) H
      WRITE (6,201) ((MP(I,J),I=2,80),J=2,24)
      WRITE (6,202) (MP(I,25),I=2,39),(MP(I,25),I=41,80)
      WRITE (6,203) ((MP(I,J),I=2,80),J=26,48)
      WRITE (6,203)
      RETURN
      END

110

```



```

5      C      PROGRAM TILFAB (INPUT, OUTPUT, TAPE7=INPUT, TAPE2=OUTPUT)
6      C      ANALYSIS OF AXIAL ORIENTATION DATA
7      C      DATA FORMAT: SAME AS ANDREWS AND SHIMIZU (1966), MARK (1971)
8      C      COL. 1 - 3: SAMPLE IDENTIFICATION. MUST BE NON-ZERO, THE SAME
9      C      THROUGHOUT A SAMPLE, $ DIFFERENT FOR SUCCESSIVE SAMPLES
10     C      COL. 5 - 7: OBSERVATION NO, NOT USED BY PROGRAM;
11     C      COL. 9 : #TYPE OF DATA CODE# CAN BE LEFT BLANK
12     C      COL. 11-13: ORIENTATION, IN DEGREES CLOCKWISE FROM NORTH;
13     C      COL. 15-16: DIP, IN DEGREES BELOW THE HORIZONTAL PLANE.
14     C      LAST DATA CARD MUST BE FOLLOWED BY BLANK CARD.
15     C      DIMENSION A(3,3),RT(3,3),R(3,3),IORT(3),S(3),THTA(3),
16     C      IQ(3,3),AT(3,3)
17     C      WRITE(2,500)
18     C      500 FORMAT(1#,24X,#LARGEST#,25X,#INTERMEDIATE#,25X,#SMALLEST#,//# ID
19     C      1 N #,3(5X,# ORT DIP #,5X,#S#,7X,#THETA#,2X),//)
20     C      RAD=.017453292
21     C      EPSI=.00001
22     C      READ(7,100) ID,0,D
23     C      100 FORMAT(I3,7X,2F3.0)
24     C      9 IDR=ID
25     C      N=0
26     C      A11=0.0
27     C      A12=0.0
28     C      A13=0.0
29     C      A22=0.0
30     C      A23=0.0
31     C      A33=0.0
32     C      8 N=N+1
33     C      O=O*PI
34     C      D=D*PI
35     C      CD=CD(0)
36     C      X=SIN(O)*CD
37     C      Y=COS(O)*CD
38     C      Z=SIN(D)
39     C      A11=A11+X*X
40     C      A12=A12+X*Y
41     C      A13=A13+X*Z

```



```

40      A22=A22+Y*Y
      A23=A23+Y*Z
      A33=A33+Z*Z
      READ(7,100) ID,0,D
      IF(ID.EQ.IDR) GO TO 8
      A(1,1)=A11
      A(1,2)=A12
      A(1,3)=A13
      A(2,1)=A12
      A(2,2)=A22
      A(2,3)=A23
      A(3,1)=A13
      A(3,2)=A23
      A(3,3)=A33
      DO 7 IQ=1,3
      DO 7 JQ=1,3
      Q(IQ,JQ)=0.0
      IF(IQ.EQ.JQ) Q(IQ,JQ)=1.0
7      CONTINUE
      DO 1 KK=1,50
      DO 4 I=1,2
      JJ=I+1
      DO 4 J=JJ,3
      IF(ABS(A(I,J)).LE.EPSI) GO TO 3
      DO 2 IR=1,3
      DO 2 JR=1,3
      R(IR,JR)=0.0
      IF(IR.EQ.JR) R(IR,JR)=1.0
2      CONTINUE
      BETA=(A(I,I)-A(J,J))/2.
      ALPHA=SQRT((A(I,J)**2+BETA**2))
      CHTA=SQRT((ALPHA+ABS(BETA))/(2.*ALPHA))
      IF(BETA)20,21,22
20      BETA=-1.
      GO TO 21
22      BETA=1.
21      SHTA=(-1.)*BETA*A(I,J)/((2.)*ALPHA*CHTA)

```



```

75      STHIA1=(-1.)*STHTA
      R(I,I)=CTHTA
      R(J,J)=CTHTA
      R(I,J)=STHTA
      R(J,I)=STHTA1
      CALL TRANSP(R,RT,3,3)
      CALL MULT (RT,A,AT,3,3)
      CALL MULT (AT,R,A,3,3)
      CALL MULT (Q,R,AT,3,3)
      DO 6 IQ=1,3
      DO 6 JQ=1,3
85      6 Q(IQ,JQ)=AT(IQ,JQ)
      3 IF(A3S(A(1,2)).LT.EPSI.AND.ABS(A(1,3)).LT.EPSI.AND.ABS(A(2,3)).LT.
1EPSI) GO TO 5
      4 CONTINUE
      1 CONTINUE
90      WRITE(2,202) IDR
202  FORMAT(= NOTE: SPECIFIED LEVEL OF ACCURACY FOR SAMPLE#,I4,= NOT RE
1ACHED AFTER 50 JACOBI SWEEPS#)
      5 CONTINUE
      A11=A(1,1)
      A22=A(2,2)
      A33=A(3,3)
      IF(A11.GE.A22.AND.A11.GE.A33) GO TO 10
      I=2
100     IF(A33.GT.A22) I=3
      DO 11 J=1,3
      STORE=Q(J,I)
      Q(J,I)=Q(J,1)
      Q(J,1)=STORE
105     11 CONTINUE
      STORE=A(I,I)
      A(I,I)=A(1,1)
      A(1,1)=STORE
      10 CONTINUE
      IF(A(2,2).GE.A(3,3)) GO TO 12
      DO 13 J=1,3
      STORE=Q(J,2)
110     Q(J,2)=Q(J,3)
      Q(J,3)=STORE

```



```

115      13 CONTINUE
        STORE=A(2,2)
        A(2,2)=A(3,3)
        A(3,3)=STORE
120      12 CONTINUE
        DO 23 J=1,3
        IF(Q(3,J).GE.0.0) GO TO 23
        DO 24 I=1,3
        Q(I,J)=-Q(I,J)
        24 CONTINUE
125      23 CONTINUE
        DO 14 I=1,3
        IF(Q(2,I).NE.0.0) GO TO 25
        IORT(I)=90
        IF(Q(1,I).LT.0.0) IORT(I)=270
        GO TO 19
130      25 IORT(I)=ATAN(Q(1,I)/Q(2,I))/RAD+0.5
        IF(IORT(I)) 15,16,16
        16 IF(Q(2,I)) 17,19,19
        15 IF(Q(2,I)) 17,18,18
        18 IORT(I)=IORT(I)+180
        17 IORT(I)=IORT(I)+180
        19 IDIP(I)=ASIN(Q(3,I))/RAD+0.5
        S(I)=A(I,I)/FLOAT(N)
        THTA(I)=ASIN(SQRT(1-S(I)))/RAD
140      14 CONTINUE
        IF(ABS(S(1)+S(2)+S(3)-1.0).LE.EPSI) GO TO 26
        WRITE(2,201) IDR
        201 FORMAT(= THE SUM OF THE S(I) IN SAMPLE#,I4,= IS NOT 1.?)
        26 CONTINUE
        145      WRITE(2,200) IDR,N,(IORT(I),IDIP(I),S(I),THTA(I),I=1,3)
        200 FORMAT(1H,2I5,3(5X,2I5,2F10.5))
        IF(ID.NE.0) GO TO 9
        STOP
        END

```



```

SUBROUTINE MULT (A,B,C,M,N)
DIMENSION A(M,M),B(M,M),C(N,N)
DO 30 I=1,M
DO 20 J=1,M
SUM=0.0
DO 10 K=1,M
SUM=SUM+A(I,K)*B(K,J)
10 CONTINUE
C(I,J)=SUM
20 CONTINUE
30 CONTINUE
RETURN
END

```

```

SUBROUTINE TRANSP (A,B,M,N)
DIMENSION A(M,N),B(N,M)
DO 20 I=1,N
DO 10 J=1,M
B(I,J)=A(J,I)
10 CONTINUE
20 CONTINUE
RETURN
END

```



APPENDIX 3

Significance of the largest and smallest (S1, S3)  
eigenvalues for till macrofabric samples 1-11.

	N = 25		N = 20		N = 15			
	S1	S3	S1	S3	S1	S3		
1	***	***	***	***	***	***		
2	***	**	***	**	***	***	Key:	
3	***	*	**		**			
4	***	**	***	***	***	***	***	99%
5	*	***	*	**		***	**	95%
6	***	***	***	***	***	*	*	90%
7	*	***		***		**		
8	***	***	***	***	***	***		
9	***	*			**	***		
10		***		***		**		
11	***	***	***	***	***	***		

Explanation

In order to test the effect of the pebble a/b axis ratio on the strength of the preferred orientation, the significance of the eigenvector statistics were calculated after removing from each sample five pebbles with the lowest a/b ratios to give a sample of 20 and subsequently a further five pebbles to give a sample of 15. The percentage points for the significance levels were adjusted for the resulting smaller sample size (Park, 1973, 1974; Anderson and Stevens, 1971). The original sample statistics (N = 25) from Table 5.4 appear in the first column for comparison. The significance measured here is whether the preferred orientation (largest eigenvector) and pole to the preferred plane (smallest eigenvector) are significantly different from the values expected for a random sample drawn from a uniform population.

The results suggest that the exclusion of those pebbles with the poorest a/b ratios (usually less than 3:2) does not materially affect the strength of the eigenvectors as given by the measure of significance. (See page 70).



APPENDIX 4Addendum

Whilst this thesis was in the final stages of completion, a borrow pit was excavated near Aston Flamville during the course of the construction of the M69 motorway. The sections in the pit not only provided the best exposures of lacustrine material in the area but also corroborated much of the analysis presented in this research.

The deepest part of the pit had been excavated some 10m below ground level. Two distinct lithologies were revealed: a series of brown, laminated silts and clays resting on a till. The silts and clays contained isolated bands of sand. The laminations were best developed in the brown silts and on a small scale showed a number of slump structures. This lacustrine sequence contained discrete, but not infrequent very small inclusions of a reddish till probably dropped from floating bergs. The underlying till had a reddish-brown matrix and contained no Jurassic or Cretaceous erratics. The junction between the till and the lake clays was a sharp, near horizontal one, but interfingering of the till and bedded material convincingly demonstrated that no length of time elapsed between the deposition of the two, i.e. the lake was established on the withdrawal/stagnation of the ice which was responsible for the till (see 6.2).

Comparison of this section with the borehole evidence from the motorway and the correlations between that and the study area leave no room for doubt that the laminated silts and clays are the equivalent of the Bosworth Clay and the till, the equivalent of the Basal Till.



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## PLATE 1

Looking northwards towards Market Bosworth church from Ambion Hill. The steeper slopes in the foreground have been developed below a capping of Cadeby Gravel. Bosworth Clays outcrop on the lower slopes although stream incision has exposed an inlier of Keuper Marl in the centre of the valley.







## PLATE 2

Wellsborough Hill from Kingshill Spinney, Coton. The rising ground in the distance is capped by Cadeby Sand and Gravel which overlies the less competent Eosworth Clay. A borehole sunk in the field in the foreground recorded over 30m of drift.







## PLATE 3

Calcreted gravels, Cadeby. Parts of the Cadeby Gravel have been cemented with a calcareous cement probably derived through the leaching of the overlying Chalky Till. Blocks such as these represent a hazard to the quarrying operation.







## PLATE 4

Gravel scarp, Market Bosworth. The outcrop of the Cadeby Sand and Gravel has given rise to slightly steeper slopes. The small slump scar in the foreground is within the gravel horizon.







## PLATE 5

Ice-wedge cast, Huncote. The growth of the ice-wedge was contemporaneous with the deposition of the cross-bedded sands (syngenetic). The sands belong to the Thurmaston Sand and Gravel series (Rice, 1963) and the overlying till is correlated with the Basal Till of west Leicestershire.







## PLATE 6

Banded tills, Cadeby. The alternating light (Chalky) and dark (Pennine) bands of till dip gently to the right of the photograph (north). Each band reveals distinct matrix types and erratic content. Note that a small fault runs at an angle towards the bottom left from the junction of hammer head and haft, throwing the bands some 2cm downwards to the south.







## PLATE 7

The till sequence at Cadeby. The top of the Cadeby Gravel is exposed in the bottom centre of the photograph. It is overlain by almost a metre of Pennine Till, then the banded sequence (within which the hammer has been placed). The upper part of the exposure consists of Chalky Till showing some weathered joint faces near the surface.







