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THE PLEISTOCENE DEPOSITS OF THE AREA AROUND CROFT IN SOUTH LEICESTERSHIRE

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CONTENTS

The Pleistocene sediments of an area of just over 100 km² in south Leicestershire have been mapped. The first half of the paper describes their lithology and stratigraphy in terms of the units earlier identified by Shotton, Rice and Douglas. The original extension of the Baginton–Lillington sand and gravel along the proto-Soar valley is confirmed, as is an early ice advance laying down the Thrussington till, which in the west consists mainly of Triassic debris but eastwards contains more and more Jurassic and Cretaceous material. The Bosworth clays and silts accumulating in Lake Harrison are thickly developed in the southwest of the study area but thin northeastwards to be replaced by the upper levels of the Thrussington till; no thick and continuous horizon has been found north of Broughton Astley. An important marker horizon is the Wolston sand and gravel, representing a sandur that drained southwestwards into a partially emptied Lake Harrison. The final event was an overriding of the whole area by the ice responsible for the Oadby till.

The second half is concerned with the post-depositional disruptions to which the sediments have been subject. Sections at Dunton Bassett and Sapcote illustrate two styles of glaciotectonic disturbance that are believed to characterize a broad tract of southern Leicestershire. The Dunton Bassett pit displays faults and folds affecting not only the Wolston sand and gravel but also the basal Oadby till; all the structures indicate compression from just east of north. Motorway sections at Sapcote show huge Keuper Marl masses, 15 m thick in places, thrust south–southwestwards over till and laminated clay. As at Dunton Bassett, the disruption probably occurred during an advance of the ice responsible for the Oadby till. The area under review also exhibits the effects of subglacial scouring. At a late stage furrows were scored through all the earlier sediments and into bedrock. The largest of these furrows, which is filled with both glacigenic and water-lain materials, runs along the southeastern edge of the south Leicestershire igneous outcrops.

1. INTRODUCTION

(a) *Outline of this and earlier investigations*

The description by Shotton (1953) of the glacial succession in the area between Coventry, Rugby and Leamington inaugurated a period of sustained research (Bishop (1958), Rice (1968) and Douglas (1980)), into the Pleistocene deposits filling what Shotton termed the proto-Soar valley. This paper reviews a further area of 117.5 km² where detailed mapping has been completed and which directly abuts the regions described earlier by Rice and Douglas (figure 1). Following brief prefatory accounts of the bedrock geology and the research methods employed, the main body of the present work is divided into three sections. The first describes the local representatives of the regional Pleistocene succession, employing with one minor modification the nomenclature suggested by Shotton (1976); the second section is a review of the regional relationships and the inferred conditions of sedimentation; the final section is an account of the post-depositional disturbances to which the previously described sediments have been subject.

(b) *Physique and geology of the area mapped*

The area lies within the catchment of the River Soar and is a region of subdued relief with heights that range from under 60 m O.D. in the north to over 135 m in the southeast near the watershed with the Avon. Bedrock outcrops over only 10% of the area, being concealed elsewhere beneath either glacial drift or later alluvial gravels (figure 2). The geological basement comprises three main units. By far the most extensive is the Keuper Marl, through which protrude 12 separate masses of pre-Triassic diorite. Individually none of these igneous outcrops is as much as half a square kilometre in extent, but together they constitute a distinctive zone stretching from Enderby in the north 8 km southwestwards to Sapcote. It is only the larger

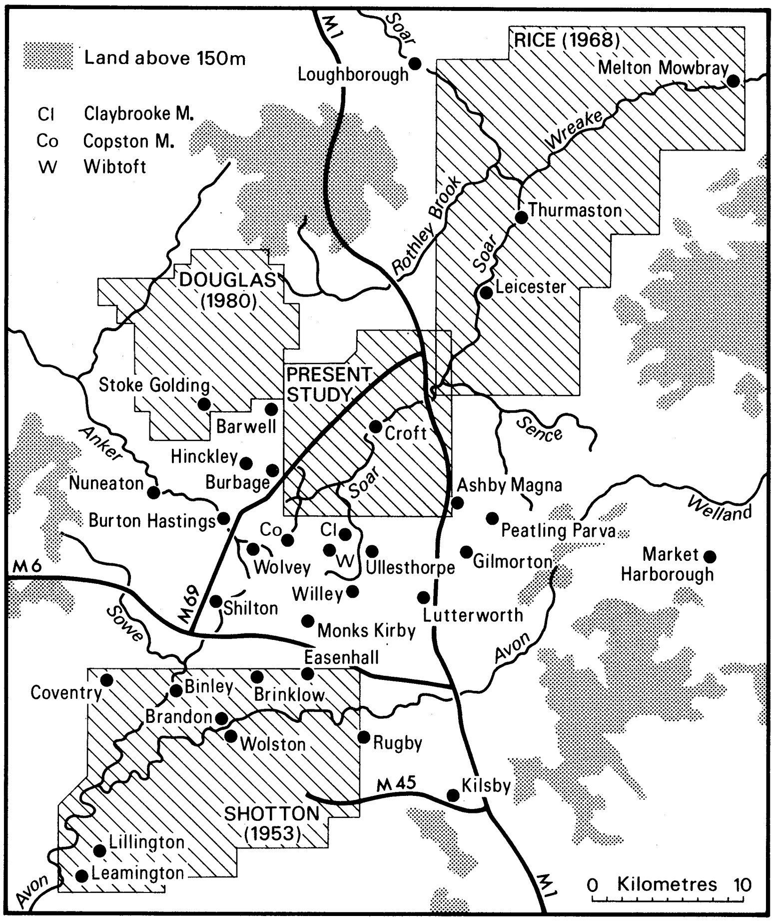

FIGURE 1. The location of the present study in relation to those of earlier authors. Also marked are the settlements referred to in the present paper.

outcrops such as those at Croft and Enderby that produce hills rising substantially above the surrounding land. The other variation in the bedrock floor occurs in the southeast where rockhead around Dunton Bassett is formed by the Rhaetic and Lower Lias strata.

(c) *Field and laboratory procedures*

Mapping was at the 1:10560 scale, with much of the information coming from use of a hand-operated bucket auger of 6 cm diameter. Over 2000 holes drilled with this instrument mean that there are few localities more than 200 m from what is believed to be a reliable data point. The field mapping was complemented by information from over 400 boreholes, but the distribution is so uneven that, particularly in the south, there remain districts where reliable information from this source is still very scanty.

Sediments for laboratory study were normally collected from exposures but in a few cases auger samples had to be used. Stone counts on gravels and tills were performed on samples of clasts held on a sieve with an aperture 9 mm square. Particle size analyses were made in accordance with British Standard 1377, the pipette method being used for particles smaller than 62 μm. Separation of heavy minerals was by bromoform and was normally performed on

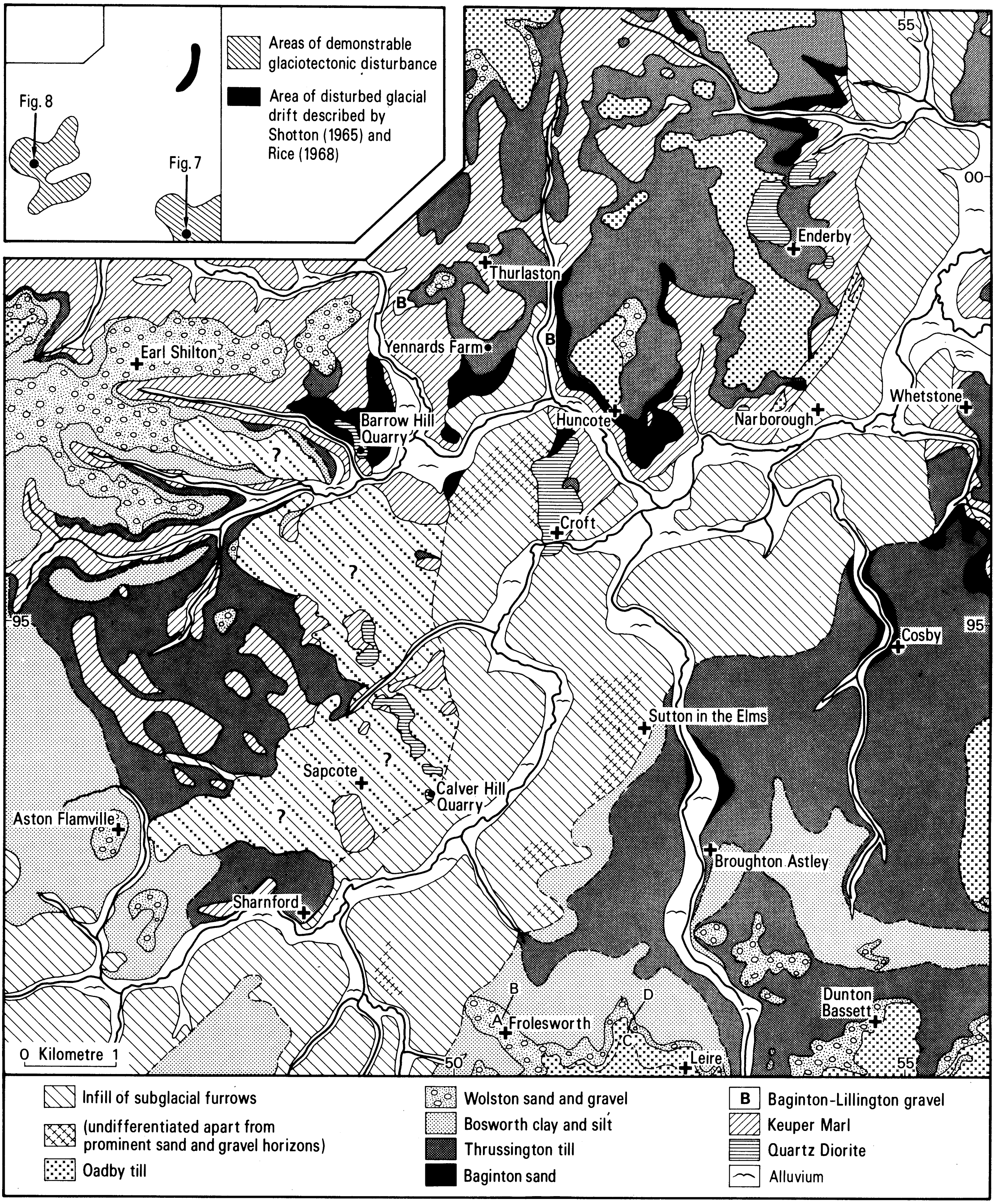

FIGURE 2. A map of the glacial deposits in the area around Croft. Glacial disturbance has locally been so severe that recourse has been had to basic lithological mapping. Thus no immediate distinction is drawn between bedrock and transported Keuper Marl, and for this reason a key at the top left indicates areas of demonstrable large-scale disturbances.

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the 212–300 μm fraction. The light residues were cleaned with oxalic acid before being examined microscopically for grain roundness and surface texture contrasts.

2. Local representatives of the regional Pleistocene succession

(a) *The Baginton–Lillington gravel*

This gravel, the oldest recognized drift member, is of very restricted occurrence, the main outcrop being confined to a small area near Huncote. Here a pit (513982) shows the gravel, up to 5 m thick, resting directly on Keuper Marl (figure 3) and consisting mainly of regularly bedded material with few of the stones exceeding 5 cm in diameter. The commonest constituents are Bunter pebbles, which, with locally derived material, compose almost 90% of the clasts (table 1). The absence of both flint and middle Jurassic debris differentiates the Baginton–Lillington gravel from other gravel deposits in the area.

Two concealed occurrences of the gravel are known. North of Enderby a deep borehole on the M69 revealed material that appears to be a direct continuation of that at Huncote, both deposits flooring a gentle-sided drift-filled valley trending from southwest to northeast. A second concealed occurrence lies southeast of Broughton Astley where a well encountered 5.2 m of gravelly sand resting on Keuper Marl at an almost identical elevation to that at Huncote; notes held by the Institute of Geological Sciences describe the pebbles as from ‘Carboniferous, Triassic, Liassic and older strata’. One possible further occurrence requires mention. In the Thurlaston Brook valley 2 km west of the Huncote pit, an isolated mass of gravel lies banked against rising slopes of Keuper Marl. A sample from a shallow hand-dug trench possesses a composition resembling the gravel at Huncote more closely than any other deposit (table 1); however, the implications of any such identification are referred to again in §3(*a*).

(b) *The Baginton sand*

The Baginton sand is best exposed in the pit at Huncote, where it consists of up to 6 m of cross-bedded sand, generally light reddish brown (2.5YR 6/4) but with occasional layers blackened by coal. In the terminology of Allen (1963) the bedding consists of omikron cross-stratification with local areas of pi cross-stratification. The numerous individual cross-stratified units average between 0.3 and 0.5 m in thickness. Measurements on 100 separate units (figure 3) indicate a dominant water flow from south to north. Throughout most of its thickness the sand has a low clay content, but within the top metre or so silt and clay layers become increasingly dominant and the cross-bedding correspondingly less prominent. Although the majority of the deposit is stone-free, occasional pebble stringers contain a higher proportion of Keuper debris than the underlying gravel (table 1). Many of the clasts are also appreciably larger; this is especially true of the locally derived Croft fragments, many of which are notably disc-shaped, presumably reflecting their greater transportability in the prevailing hydraulic conditions.

Several exposures of almost identical sand were examined during construction of the M69, and deep exploratory boreholes proved the sand to be continuous beneath the interfluve between Huncote and Enderby. On the right bank of the Soar the same bed is believed to outcrop at three separate localities. The most northerly, 1.5 km south of Whetstone, was formerly the site of at least two sandpits. Poole *et al.* (1968, p. 63) record one of these as displaying 3.7 m of pink, medium-grained, gently current-bedded sand, which later boreholes have proved to

Table 1. Composition of samples of clasts collected from various members of the drift succession

details of sampling site				details of sample (percentage composition)										
member of drift succession	location	grid ref.	nature of site	size	Bunter pebbles	skerry	Carboniferous limestone, sandstone and grit	coal	Bunter Keuper sandstone	lias	Middle Jurassic limestone	flint	chalk	others
Baginton–Lillington gravel	Huncote	513982	working pit	1913	77	9	5	2	3	1	—	—	—	3
?Baginton–Lillington gravel	Thurlaston	493987	shallow trench	430	78	10	5	—	3	—	—	—	—	4
Baginton sand	Huncote	512982	working pit	210	52	23	4	—	3	1	—	—	—	5
Thrussington till – brown Triassic facies	Huncote	513982	working pit	206	12	86	—	1	1	—	—	—	—	2
Thrussington till – red Triassic facies	Huncote	513982	working pit	271	15	83	1	1	—	1	—	—	—	1
Thrussington till – chalky facies	Dunton Bassett	541902	working pit	204	3	3	3	1	1	11	10	15	52	2
Wolston sand and gravel	Dunton Bassett	541902	working pit	763	35	4	16	—	4	8	23	7	1	3
Wolston sand and gravel	Earl Shilton	476982	temporary section	355	53	23	16	—	5	—	—	1	—	2
Oadby till (basal part)	Dunton Bassett	541902	working pit	217	24	22	22	—	—	15	11	4	1	2
?fill of subglacial furrow	Smockington	460903	old cutting	169	72	12	8	—	1	1	—	1	—	6
?fill of subglacial furrow	Smockington	460902	old cutting	285	25	9	2	—	2	18	18	19	—	7
?fill of subglacial furrow	Smockington	450901	temporary trench	158	14	9	10	—	—	15	13	31	8	1
?fill of subglacial furrow	Sapcote	485940	old pit	311	18	3	5	—	5	32	20	16	1	1

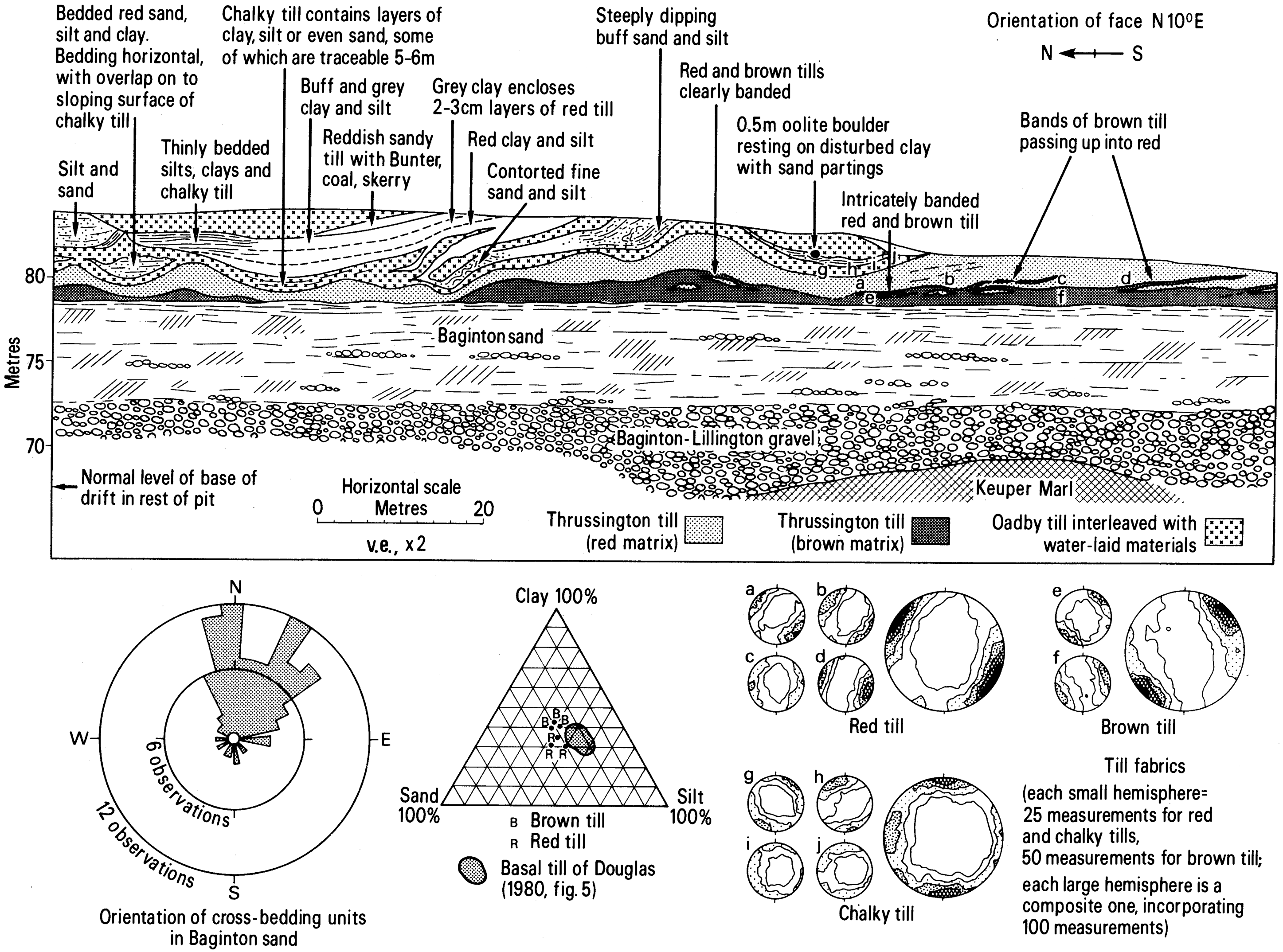

Figure 3. Huncote sand and gravel pit. Above, a characteristic part of the main working face. Below, from left to right, orientated units within the Baginton sand, particle size analyses compared with data from Douglas (1980), and measured fabrics at points specified on the main section above.

rest directly on Keuper Marl. The second locality is centred on Cosby, where borings have shown the alluvium to rest on a bed, up to 5.5 m thick, described as 'red brown, medium to fine sand with occasional fine gravel'. The third outcrop lies north of Broughton Astley where hand-augering proved pure red (2.5YR 5/6) medium to fine sand to exceed 2.75 m in thickness and to extend below local stream level. Further south the Baginton sand is concealed beneath later tills and clays. A well on the southeastern outskirts of Broughton Astley penetrated 13.4 m of clayey drift before entering 4.7 m of sand resting on Keuper Marl, while a borehole 2.2 km further southwest at Leire was sunk to 30.5 m before entering 4.3 m of sand and gravel, again lying directly on Keuper Marl.

(*c*) *The Thrussington till*

This term was introduced (Rice 1968) to describe the deposit that, north of Leicester, signals the first ice advance after accumulation of the Baginton sand. The commonest lithology (pp. 469–71) is a red, largely Trias-derived till with the local addition of bluish grey horizons rich in Liassic debris and sometimes containing chalk and middle Jurassic erratics. Similar variability characterizes the present area. If the Thrussington till be defined lithostratigraphically as the glacigenic material between the Baginton sand below and the Wolston sand and gravel above, then it can be shown to encompass a range of till types extending from a red till of almost purely Triassic derivation that dominates in the west to a grey till studded with chalk that reaches its fullest development in the east. While not the only two till types to occur, these nevertheless provide a convenient basis for description under the heads of the Triassic and Chalky facies respectively.

Triassic facies

The Baginton sand between Huncote and Enderby is normally succeeded by a red or reddish brown till with greenish grey mottling that boreholes have locally proved to exceed 19 m in thickness. The till passes laterally onto the surrounding bedrock slopes without change in composition, and further west occurs as a thin sheet, typically 1–3 m thick, draped across the undulating rockhead surface. This Triassic facies is well exposed in the pit at Huncote (figure 3). Here a twofold subdivision is clearly discernible, with the basal member having a dark reddish brown matrix (5YR 3/3) and the upper member a dark red matrix (2.5YR 3/6). The brown member does not exceed 2 m in thickness but persists with only minor breaks along the full 500 m length of the working face. Samples from the two variants showed that the clasts are of closely similar composition, with 98% consisting of Bunter pebbles and skerry (table 1); geochemical analyses of the matrices showed only minor differences, both apparently being Keuper Marl derivatives. That the dual coloration is an original feature and not the result of secondary chemical alteration is shown by the interleaving that characterizes the boundary between the two deposits. Fabric studies (figure 3) reveal significant contrasts in the arrangement of the clasts, suggesting either different modes of deposition or, possibly, temporary shifts in the direction of ice movement.

The differences between the brown and red variants are too subtle to be traced by means of a hand auger and it is not known how widespread the distinction may be. More readily detectable are certain regional changes in erratic content. The most obvious is an eastward increase in the proportion of Cretaceous debris, even within this largely Trias-derived deposit. Precise quantitative assessment is impracticable, but by making a note whenever chalk or flint was recovered with the auger a map was prepared on which each data point across the outcrop of the Triassic facies was classified as yielding or not yielding Cretaceous debris; west of the Soar some 10% of the data points are associated with identifiable Cretaceous material, whereas east of the Soar that figure rises to over 35%.

Chalky facies

Grey chalky till (7.5Y 4/1) unequivocally older than the Wolston sand and gravel occurs in a sandpit at Dunton Bassett (see figure 7). Over two-thirds of the till clasts are either chalk or flint (table 1). This occurrence cannot be dismissed as a localized lens since a borehole has proved the material to be at least 5.9 m thick, and augering has shown it to outcrop extensively on the nearby hillslopes. The transition north and northwestwards into the area dominated by the Triassic facies takes place through a zone of bewildering complexity. In the triangle bounded by Dunton Bassett, Broughton Astley and Cosby an intricate pattern of outcrops is virtually impossible to decipher without deep sections. In broad terms there must be numerous lenticular masses of grey chalky till set within a body of glacigenic sediments that comes primarily from Triassic sources yet not infrequently contains Cretaceous clasts.

(*d*) *The Bosworth clays and silts*

The term Bosworth clay (later amplified by Shotton (1976) to Bosworth clays and silts) was introduced by Douglas (1974) to refer to a fine-grained stoneless deposit that he traced to Barwell at the western edge of the present mapping area. In this locality the material approaches 20 m in thickness and is composed of purplish and bluish brown silty clay with thin bands of silt and fine sand. It also contains lenses of red till with clasts of skerry, coal and Bunter pebbles. Northeastwards the deposit thins and disappears by the old stone quarries at Barrow Hill. Southeastwards, by contrast, it outcrops over a very wide area and has been well displayed in two motorway borrow pits near Aston Flamville. The more southerly pit revealed up to 12 m of Pleistocene sediments overlying the Keuper Marl. The lower half of the sequence (figure 4) consisted of a mixture of red till and brown clay; the clasts in the main till horizon were predominantly of Triassic origin, but at least two pieces of oolite were recovered. The top half of the complete succession was never cleanly exposed but the brown clay evidently passed up into crudely stratified grey silts enclosing occasional clay and till horizons. Deformed bedding beneath a few of the pebbles was taken to indicate that some of the clasts are drop-stones. Rock fragments in the greyish till were predominantly of Liassic derivation, but there were also flints, chalk and oolite. The second borrow pit (462935) exhibited a basically similar sequence with the upward transition from reddish brown into grey clay and silt being accompanied by a corresponding change in the character of the till lenses.

Further east, on the right bank of the Soar, exposures proved so limited that two detailed auger traverses were run to investigate the stratigraphy of the deposit (figure 4). If anything, till is here less abundant than at Aston Flamville, with only 5% of an aggregate of 30 m classifiable as till. To the north near Broughton Astley temporary exposures revealed brown silty clay with red till passing up into purplish blue and brown clay and silt, an overall sequence closely resembling that in the borrow pits.

(*e*) *The Wolston sand and gravel*

The term Wolston sand was introduced by Shotton (1953) to describe a sand stratum of widespread occurrence between Rugby and Coventry. Occupying the same stratigraphical

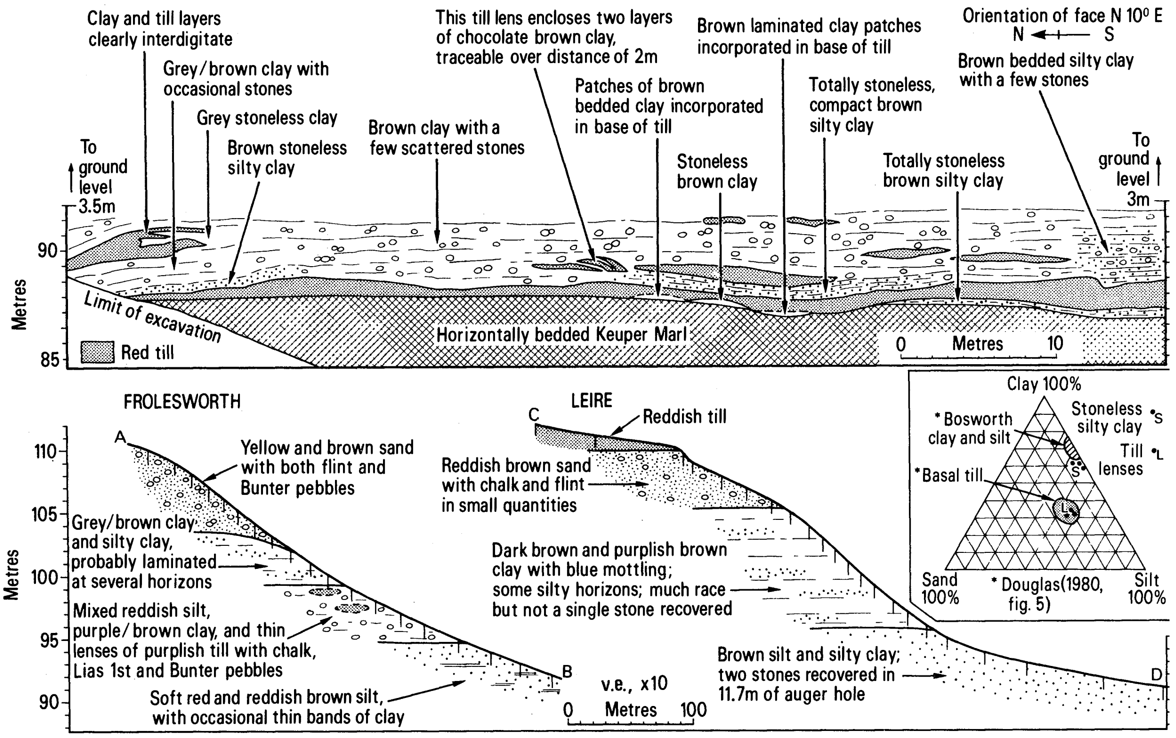

Figure 4. Aspects of the Bosworth clays and silts. Above, the basal part of the section in the Aston Flamville borrow pit at G.R. 455921; inset, a comparison of particle size data with those of Douglas (1980). Below, two auger traverses at Frolesworth and Leire; traverse lines indicated on figure 2.

position in the present area is a bed of sand and gravel that, over the years, has been worked at a number of separate sites. The sole active pit is at Dunton Bassett, where the chalky facies of the Thrussington till is capped by an impersistent layer of Bosworth clays and silts that in turn passes up into 8 m of yellow (10YR 7/6) sand and then into 5 m of medium–coarse gravel (figure 7). The highly calcareous sand is conspicuously false-bedded, with the structures falling mostly into the pi cross-stratification category of Allen (1963); 100 foreset wedges showed a statistically significant orientation in a direction of S 53° W. Over 35% of the clasts in the main gravel, which is moderately sorted and locally calcreted, come from Jurassic and Cretaceous sources (table 1). Material of similar composition is readily traceable in outcrops westwards through Leire to Frolesworth, where an old pit formerly displayed 3.7 m of sand and flinty gravel (Eastwood *et al.* 1923). Further to the west the bed is only represented around Aston Flamville and Earl Shilton. In the latter area several derelict workings attest to a sequence that again coarsens upwards from a cross-bedded sand to a moderately coarse gravel, the aggregate thickness probably amounting to some 10 m. A sample of the gravel (table 1) showed much less eastern material than at Dunton Bassett; yet the presence of flint is common to both areas and this property differentiates the material from the Baginton–Lillington gravel.

(*f*) *The Oadby till*

In central Leicestershire Rice (1968) found the till immediately above the equivalent of the Wolston sand to contain relatively few Cretaceous erratics compared with the locally derived Liassic and Triassic detritus; this passed up into a grey till with a majority of Cretaceous and middle Jurassic erratics. Within the area now mapped glacigenic sediments demonstrably younger than the Wolston sand and gravel are largely confined to the Dunton Bassett neighbourhood. In the pit at that village the water-laid strata are succeeded by a dull reddish brown till (5YR 4/4) whose composition (table 1) agrees well with that recorded from central Leicestershire. The same material can be traced westwards to Frolesworth, but augering indicates that it is a thin layer rapidly succeeded by grey chalky till. Although the sequence thus appears very similar, the outcrop area is rather small for judgement to be made whether the central Leicestershire division into lower and upper Oadby till would here be justified.

Further north and northwest, in the absence of the Wolston sand and gravel as a marker horizon, the onset of a widespread glacigenic horizon rich in chalk is taken to mark the transition to the Oadby till. Few good sections have been seen, the most important being that at the Huncote sandpit (figure 3). Here bluish grey chalky till first occurs as thin sheets separated by equally abundant layers of sand, silt and clay, often arranged in the form of small sedimentary basins. Fabric measurements on the earliest chalky till failed to reveal any strong orientation, in sharp contrast to the underlying Thrussington till. The assemblage attests to ice-marginal accumulation with flow tills and melt-out tills interlayered with sediments deposited in temporary pools. The sequence has suffered later disturbance, presumably owing to overriding by the ice bringing the full thickness of the Oadby till.

3. Regional correlations and inferred conditions of accumulation

(a) *The Baginton–Lillington gravel and the Baginton sand*

Shotton (1953) hypothesized that these two members were laid down by the proto-Soar river in a valley running northeastwards from Bredon Hill towards Leicester. Rice (1968) identified the Thurmaston sand and gravel as the correlative in the Leicester district, and it is now possible to review the evidence of sedimentation along the full length of the reconstructed valley.

Shotton showed that the gravel in Warwickshire changes from a high Jurassic content near Lillington to an almost total dominance of Bunter pebbles where the deposit disappears beneath later drift beyond Binley. On re-emerging 20 km to the north near Huncote it is still dominated by Bunter pebbles but now contains an admixture of rather more material from local Keuper Marl outcrops; there appears to be little further change in the next 15 km to Thurmaston (Rice 1968, p. 466). To examine the uniformity of the sand rather more closely than has previously been attempted, samples were collected from seven different outcrops between Wolston in the south and Thurmaston in the north. In all the properties that were measured (table 2) the specimens show only minor variations; the differences are generally very small by comparison with those that separate the Baginton sand from the Wolston sand.

Shotton argued that the Baginton–Lillington gravel and the overlying sand were both laid down by normal land streams deriving their sediments from erosion of an earlier drift cover, represented in Warwickshire by the sporadically occurring Bubbenhall clay. In Leicestershire no certain correlative of the Bubbenhall clay has been identified, although possible thin drift underlying the sand and gravel has been recorded in a number of boreholes. On the motorway 1200 m west–southwest of the Huncote pit 2 m of 'red marly boulder clay' are reputed to occur beneath the sand. This is a puzzling log since the borehole is the only one of seven within a

TABLE 2. SELECTED PROPERTIES OF SAND SAMPLES COLLECTED FROM THE BAGINTON SAND AND THE WOLSTON SAND AND GRAVEL

site	grid ref.	nature of site	particle size		sorting coefficient	percentage loss with HCl	percentage heavy minerals	colour	particle roundness: mean (s.d.)‡
			mean, ϕ†	mean µm					
Baginton sand									
Wolston	410476	old pit	2.03	245	0.50	2.2	0.41	5YR 6/6	5.08 (0.82)
Broughton Astley	529931	auger sample	2.11	232	0.52	1.7	0.24	2.5YR 5/6	5.10 (0.86)
Cosby	547951	temporary trench	1.77	292	0.44	1.4	0.09	5YR 5/8	5.15 (1.05)
Whetstone	554959	temporary trench	1.61	327	0.30	0.9	0.27	5YR 5/6	5.11 (0.90)
Huncote	513982	working pit	1.90	268	0.38	0.2	0.21	1.5YR 6/4	5.00 (1.07)
Lubbesthorpe	539014	auger sample	1.92	265	0.41	1.2	0.31	5YR 4/6	5.25 (1.01)
Thurmaston	615102	old pit	2.31	202	0.49	1.1	0.33	5YR 5/6	5.19 (1.04)
Wolston sand and gravel									
Smockington	461895	old pit	1.86	275	0.68	14.1	1.17	7.5YR 6/6	5.22 (1.21)
Dunton Bassett	541902	working pit	1.56	339	0.57	17.8	3.33	10YR 7/6	4.75 (1.24)
Frolesworth	507903	old pit	1.29	409	0.51	19.6	4.28	7.5YR 6/6	5.17 (1.01)
Earl Shilton	476982	old pit	1.76	295	0.45	1.5	0.73	2.5YR 4/6	4.95 (1.20)
Cadeby	443014	working pit	1.46	363	0.51	1.0	1.42	5YR 5/4	4.79 (1.02)

† The symbol ϕ stands for $\log_2$ (particle diameter/mm).
‡ Based upon visual comparison with a specially prepared scale from 1 (highly angular) to 9 (fully rounded).

radius of 50 m to encounter such a horizon; yet the material remains the most likely candidate for equation with the Bubbenhall clay. On the other hand, when the base of the sand was exposed near the site of the borehole, the sloping bedrock surface was seen to be covered with half a metre of broken skerry blocks set in a marly matrix. This layer, which is devoid of far-travelled erratics, is assumed to be a gelifluxion deposit that mantled the lower hillslopes before their burial by the aggrading river.

The implication of the above reference to gelifluxion, that at least part of the sedimentation took place under a cold climatic régime, receives support from several sources. Neither gravel nor sand in Leicestershire has yielded contemporaneous organic remains, but in Warwickshire such evidence points to a severe but not fully arctic climate during part of the accumulation (Shotton 1953, 1968; Kelly 1968; Osborne & Shotton 1968); in the same region cryoturbation structures attest to frost action during deposition of the gravel. Yet it is features within the Baginton sand that probably bear witness to the most severe climate. At Huncote several ice-wedge casts have been noted (see, for instance, the plate in *Teaching geography* **1** (1975) p. 71). They are normally narrow features, 2 m or more deep, mostly intraformational but terminating upwards at different levels. One example was seen to reach the top of the sand like the single wedge reported by Shotton (1968) from Warwickshire. Inasmuch as ice wedges are believed to denote conditions of great severity, the environmental evidence may signify refrigeration as the aggradation progressed.

The height of the top of the sand measured at 52 sites within the proto-Soar valley exhibits, apart from minor local irregularities, an extremely gentle northeasterly slope (figure 5). One measure of the regional slope is provided by comparing elevations from around Coventry with those from around Croft. In the former area eight data points yield a mean height of 83.8 m (s.d. = 2.2 m) and in the latter 35 data points yield a mean height of 77.1 m (s.d. = 1.8 m). Such an analysis indicates a decline of 6.7 m in 23 km or a slope of 1 in 3433. The alternative procedure illustrated in figure 5 gives a slope between Leamington and Leicester of 1 in 3409. Both values lie close to the 1 in 3300 calculated by Shotton (1953, p. 249) as the fall of the bedrock floor of the proto-Soar valley. By comparison with the modern rivers these slopes are very gentle (for example, the lowest reaches of the present-day Soar floodplain decline at 1 in 1365). Yet application of standard hydraulic formulae to test the range of conditions capable of generating sufficient tractive force to entrain the sediments suggests, at least as far as the Baginton sand is concerned, no need to invoke post-depositional tilting to explain the gentleness of the gradient. The Baginton–Lillington gravel, on the other hand, is much more problematical since, at the computed slope, it would appear to demand exceptionally high discharges for entrainment. One possibility, although difficult to prove, is that advance of the ice sheet responsible for the Thrussington till had already depressed the crust glacio-isostatically so that the currently observed gradients incorporate the effect of post-glacial recoil.

The lateral limits of the proto-Soar valley floor are not easy to define since, in the course of the aggradation, avulsion probably led to several different routes round the igneous outcrops of south Leicestershire; moreover, the evidence for some of the routes could well have been destroyed by the events to be described in §4. The presence of Liassic material in the gravel at Huncote implies that, for a time at least, the trunk river flowed to the northwest of the Enderby igneous outcrop. The position of one left bank tributary may be indicated by the gravel, mentioned in §2(*a*), that closely resembles the Baginton–Lillington gravel in composition and lies along part of the Thurlaston Brook valley. However, the elevation of the gravel at 91 m

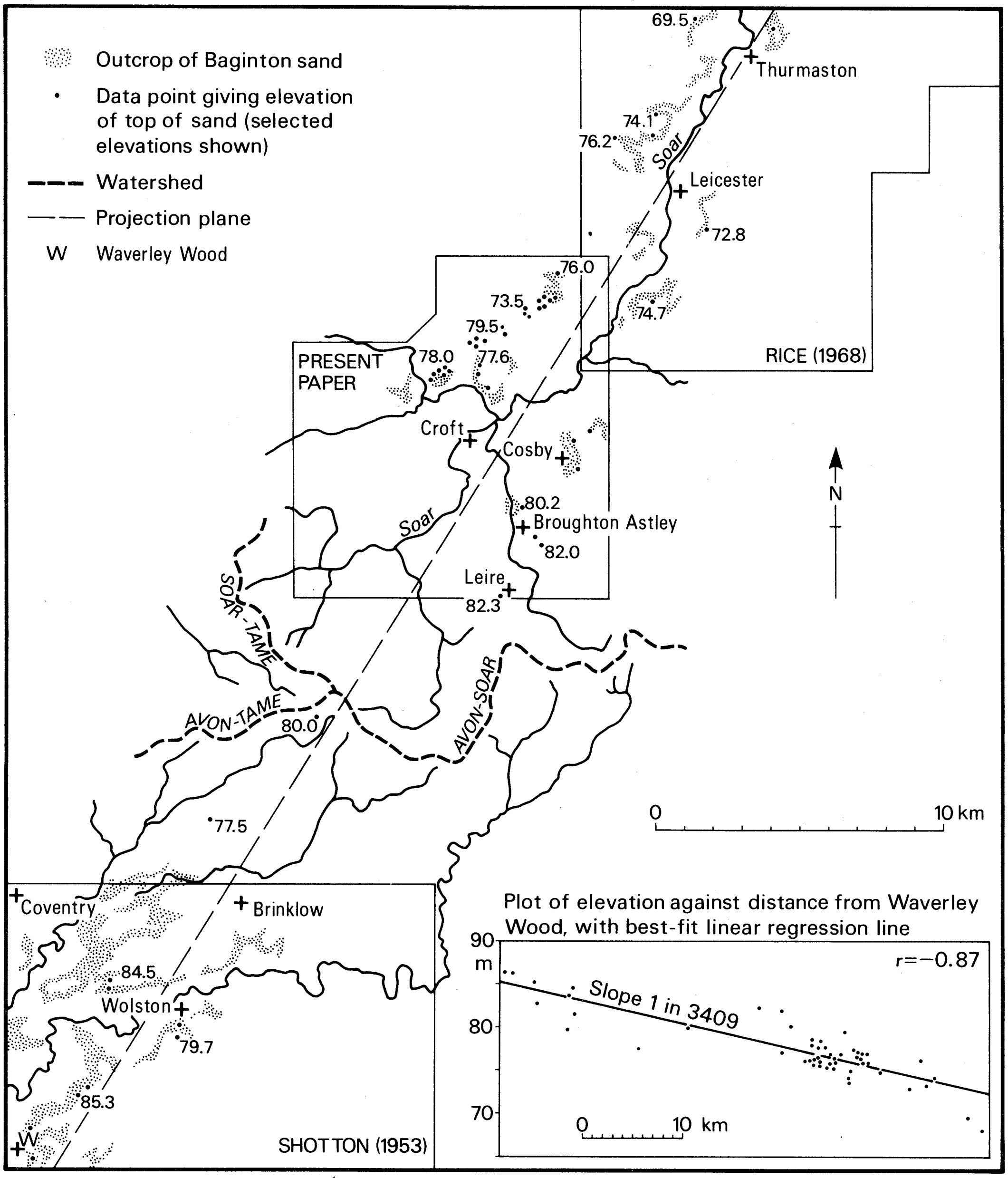

Figure 5. Baginton sand outcrops between Waverley Wood and Thurmaston. The inset shows the best-fit linear regression line for 52 points where the elevation of the top of the sand has been determined.

o.d. appears rather high for such an interpretation, and perhaps a more likely alternative is that the deposit represents localized outwash laid down in front of the advancing Thrussington till ice.

(*b*) *The Thrussington till*

The Thrussington till varies in both composition and thickness. Moreover, when traced southwestwards from a line through Barrow Hill quarry, Broughton Astley and Dunton Bassett, it interdigitates with, and ultimately is very largely replaced by, the Bosworth clays and silts. The zone of transition is most obvious around Broughton Astley, where, to the north of the village, the predominant material above the Baginton sand is till, while to the south it is a stoneless water-laid sediment. In the southernmost area till tends to be concentrated at or near the base of the succession. Although the Aston Flamville borrow pits showed an interleaving with water-laid sediment right to the bottom of the drift, elsewhere the till probably forms a basal stratum comparable to that in the Market Bosworth area (Douglas 1980). In boreholes along the southern section of the M69 the basal glacigenic sediments exceeded 11 m in thickness and, as Douglas has argued, the first event to follow deposition of the Baginton sand was advance of an ice sheet that, at its maximum, probably reached a line between Warwick and Stratford (Shotton 1976). The relationship of the till to the Bosworth clays and silts implies that it was withdrawal of this ice that permitted lacustrine sedimentation to extend back north as far as Broughton Astley.

Although borehole records suggest there may be local exceptions not yet adequately exposed, the normal contact between the till and underlying Baginton sand is sharp and undeformed. This is true even though the highest sands contain delicate structures that would seem to offer little resistance to deforming stresses. At Huncote occasional fine sand and silt partings pass as low-angle streaks into the basal few centimetres of the till, but other than that there is no obvious distortion. Since the presence of ice-wedge casts points to the establishment of permafrost, freezing might be invoked as a factor favouring the preservation of the structures. On the other hand, after the section illustrated in figure 3 had been drawn, further workings revealed a channel 1.25 m deep and 8 m broad, filled with coarse, crudely stratified gravel, that cut down into the top of the sand but was sealed above by the brown variant of the Thrussington till. The wet pro-glacial conditions implied by the channel suggests that the brown variant may be a flow till later overridden by the ice depositing the red till as a lodgement sediment. Admittedly the basal till exhibits few traits diagnostic of its origin, and one of its measurable properties, namely its fabric, reveals a stronger preferred orientation than is usually regarded as characteristic of flow tills. On the other hand, the basal layers of the red till are frequently charged with masses of Keuper Marl, some of which are several metres across and up to 2 m thick; these large transported blocks are regarded as marking the onset of undoubted lodgement processes.

The contrasting facies in the Thrussington till seem best explained as the result of ice movement from two distinct directions. During the earliest phase the dominant movement was from the north or northwest and carried with it debris of mainly Triassic and Carboniferous derivation. The resultant till mantles the bedrock west of the proto-Soar valley and, as at Huncote and Wolston, overlies the Baginton sand along the axis of that valley. The eastward limit of this initial ice advance is less clear, but the available evidence points to the whole of the present mapped area being first invaded by ice from the northwestern quadrant. For instance, boreholes along the M1 encountered substantial thicknesses of red till both south of Whetstone and in the vicinity of Lutterworth. Further south at Kilsby, Shotton (1963) recorded 5 m of red and green mottled Triassic till in the M45 cuttings. Close to the junction of the M1 and M6, on the other hand, boreholes proved such till to be absent, with grey chalky till coming to rest directly on bedrock; this patchy distribution may indicate that the limit of the Triassic facies is here being approached. At the regional scale but not always apparent in individual sections, there is an upward increase in the importance of northeastern debris. This is most marked in the east of the mapped area, whereas further west the limit reached by ice transporting Cretaceous material remains difficult to fix since the characteristic chalky till does not appear to form a continuous horizon, but rather a series of lenticular masses. Yet all workers who have undertaken detailed mapping of the East Midland drifts have recorded an early input of materials of northeastern provenance (Shotton 1953, p. 225; Bishop 1958, p. 266; Rice 1968, p. 469; Bridger 1975, p. 199; Douglas 1980, p. 280).

(*c*) *The Bosworth clays and silts*

It is not feasible to reconstruct in detail the configuration of Lake Harrison (Shotton 1953), in which the Bosworth clays and silts accumulated, since there is little doubt that many temporary fluctuations occurred. However, the area of major development of this member of the drift succession can now be charted. The thickest sequence of pure clay and silt lies in the west, near Stoke Golding, where Douglas (1980) records some 35 m of such material. Shotton (1953) mapped at least 15 m of comparable deposits in the Brinklow area, and in an interpretation of local boreholes implied that lake sediments may attain about 30 m near Ullesthorpe. During the present study an auger traverse at Leire proved a continuous succession of some 16.5 m of fine-grained stoneless sediments. Away from this triangle of fullest development between Stoke Golding, Leire and Brinklow, the Bosworth clays and silts rapidly become less prominent. To the west and north they die out against till-veneered bedrock slopes. To the northeast they are replaced by the Thrussington till along the axis of the proto-Soar valley. To the southeast they are also replaced by the Thrussington till, as around Dunton Bassett, but in this direction a contributory factor is the rising bedrock surface. Finally, to the southwest there seems to be a much slower thinning, although evidence here becomes sporadic owing to post-glacial erosion by the Avon and its tributaries; at Hutchins brickyard near Snitterfield (202589) augering has proved 12 m of stoneless plastic clay without any underlying Thrussington till (Tomlinson 1935; Shotton, personal communication).

From this regional pattern it is inferred that, once the ice sheet responsible for the early Thrussington till (which presumably had not reached Snitterfield) withdrew to a line near Broughton Astley, lacustrine sedimentation supervened over a very wide area to the southwest. The northeastward slope along the proto-Soar valley had not yet been reversed by glacial deposition and there consequently still existed a natural basin bounded on three sides by rising ground and on the fourth by the ice front. The frequent interleaving of till and water-laid sediments signifies a fluctuating position for the ice front, but at the moment it is possible to outline only the broadest pattern of change.

(*d*) *The Wolston sand and gravel*

Recognition of this bed as a widespread stratum suitable for use as a marker for purposes of dating is so crucial to studies of the East Midland drifts that the basis for correlation with the sand horizon mapped by Shotton (1953) from near Leamington in the south to beyond Easenhall in the north has been critically re-examined along two selected transects. The first runs between Frolesworth and Easenhall, and here the continuity of the bed can be demonstrated by tracing its outcrop southwards through abandoned pits in the parishes of Ullesthorpe, Willey and Monks Kirby. Only beneath the Soar–Avon watershed is the stratum concealed by later till, and even there its presence is attested by boreholes. In the old workings the gravel component contains a substantial proportion of flint, together with lower and middle Jurassic limestones; it also becomes appreciably finer in a southerly direction until, at Monks Kirby, most of the material is sand with just a few layers of medium fine gravel. Along the second transect, namely between Hinckley and Easenhall, the continuity of the bed is less complete. A substantial sand horizon around Hinckley is well attested by both boreholes and surface outcrops, and one old pit at Burbage is recorded as displaying 5.5 m of pebbly red and reddish yellow sand. According to the Geological Survey 1 inch sheet no. 169, this last-named site lies on a spread of sand and gravel that extends continuously southwards to Wolvey and Copston Magna. However, exploratory investigations for the M69 cast some doubt on this interpretation. Boreholes adjacent to the motorway south of Burbage did not encounter any consistently thick layer of sand, and re-examination of surface exposures makes it questionable whether there is now any direct physical continuity between the sand at Hinckley and that which undoubtedly exists around Wolvey and Copston Magna. This point will be discussed again below (§4 (*c*) (i)), but here it suffices to note that no doubt is being cast on the correlation of the sands at Wolvey and Hinckley since both appear to occupy the same stratigraphic position as a capping to the Bosworth clays and silts. Beyond Wolvey boreholes along the M69 proved the sand and gravel to extend continuously southwards to Shilton, whence, apart from short gaps due mainly to postglacial erosion, the bed can be traced eastwards along the M6 to Easenhall.

The above transects show that the Wolston sand and gravel clearly did once form a single widespread sheet of water-laid sediment. Contouring the top of the stratum (figure 6) reveals that, apart from a few irregularities, it declines in altitude from the outcrops in Leicestershire to the most southerly outcrops near Leamington. As Douglas (1980) suggests, the deposit appears to be part of a sandur laid down by meltwater flowing in a southwesterly direction, an interpretation supported by the progressive decrease in particle size and by the cross-bedding measurements at Dunton Bassett (figure 7). Cryoturbation structures in the gravel near Lutterworth (Poole *et al.* 1968, p. 50) indicate subaerial accumulation and it seems that over a wide area fluvial sedimentation had replaced lacustrine. By this stage relatively rapid sedimentation close to the ice front had reversed the original northeastward slope of the proto-Soar valley, and a fall in the level of Lake Harrison had restricted the ponded water to a relatively small area in the southwest. Here interbedding of clays and sands suggests a fluctuating water level that was as much as 30 m below the culminating height when the Bosworth clays and silts around Hinckley were accumulating. The potential overflow cols across the Jurassic scarplands to the southeast are all too high to have functioned as spillways when the Wolston sand and gravel was being laid down, and water was probably escaping along the face of the Cotswold scarp owing to a partial withdrawal of Welsh ice from that position.

The fragmentary distribution of the Wolston sand and gravel to the northeast of the outcrops at Hinckley and Frolesworth is in part ascribable to post-depositional factors such as glaciotectonics (see §4 (*b*)) and dissection by the Soar and its tributaries. Yet there are sound reasons for believing there may never have been a continuous sand and gravel sheet analogous to that further to the southwest. In describing the Wigston sand and gravel of central Leicestershire, a bed equated with the Wolston sand of Shotton, Rice (1968) stressed the discontinuity of the material with the phrase ‘rarely can an outcrop be traced for more than a mile or so’ (p. 485). Moreover, the elevation of the Wigston sand and gravel is commonly below that of the Wolston sand and gravel as now mapped around Frolesworth and Hinckley. This seems to preclude the materials in central Leicestershire being a simple northward extension of the sandur, and they are interpreted either as debris deposited in subglacial tunnels or as slightly earlier glacifluvial sediments laid down during a temporary phase of ice stagnation and melting. For the present,

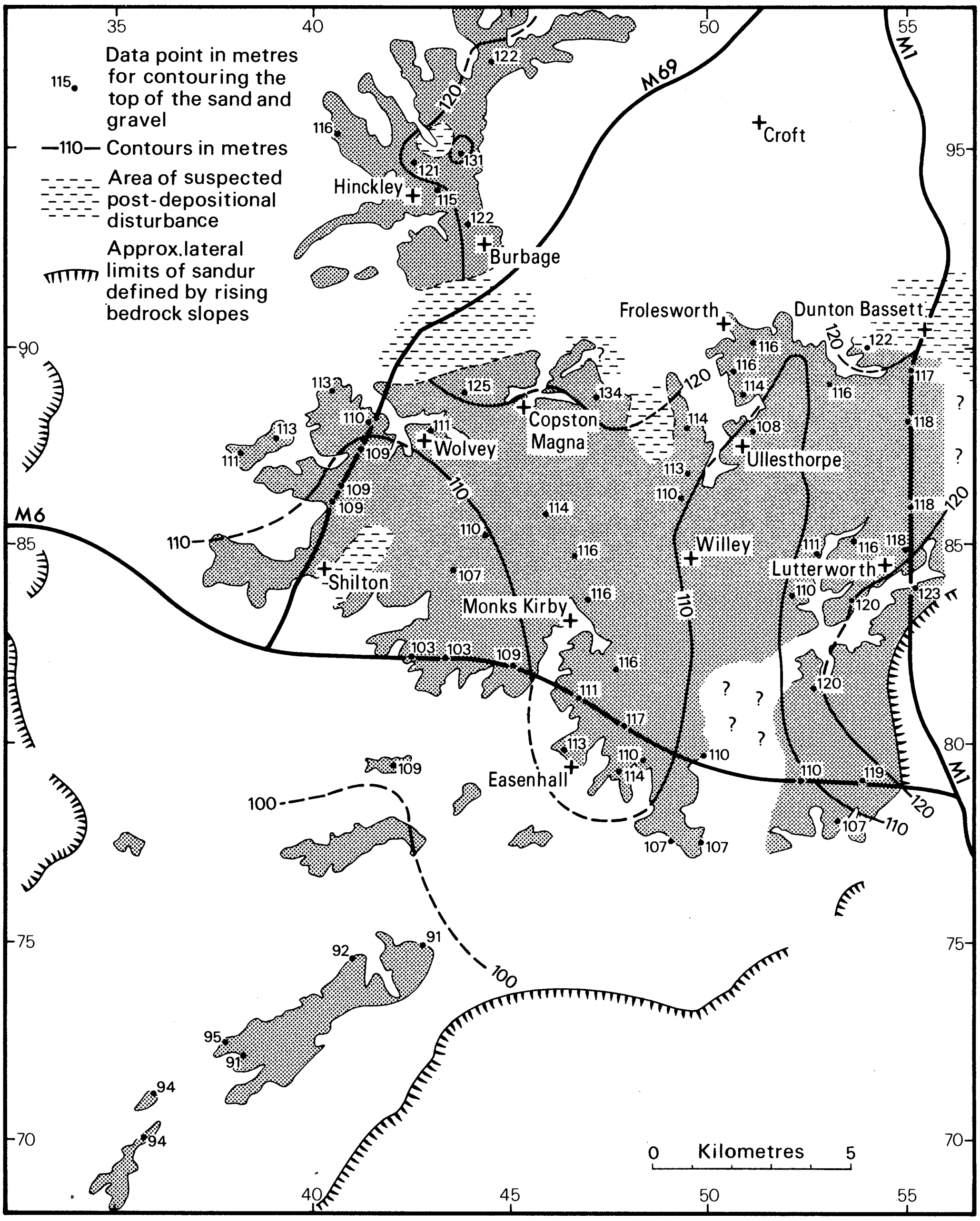

FIGURE 6. The present distribution of the Wolston sand and gravel. Contours on the top of the bed are shown, as are areas of probable post-depositional disturbance.

owing to the different conditions of accumulation, it seems wise to retain the term Wigston sand and gravel for the central Leicestershire deposits while acknowledging that they are the approximate time-equivalent of the Wolston sand and gravel.

(*e*) *The Oadby till*

The concept of ice stagnation and temporary melting extending to the north of the present mapped area is supported by the marginal sedimentation features at Huncote (figure 3). The ice that readvanced across this complex assemblage carried much debris of northeastern provenance, although the first till above the Wolston sand and gravel at Dunton Bassett contains an almost equal amount of northwestern debris. Despite an intervening layer of laminated silts up to 0.5 m thick at Dunton Bassett, there is no substantial element of lacustrine sedimentation at this stratigraphic level within the present mapped area. Since Shotton (1953) recorded the material above the Wolston sand in the Coventry area as predominantly stoneless clay there must be a significant transition in the intervening region, and, while it is not yet possible to identify details, its position as indicated by evidence from the M6 and M69 motorways must lie close to the area mapped by Shotton. The implication is that the low level of Lake Harrison persisted for some time after the ice carrying the Oadby till had started to readvance southwards. Eventually, as Bishop (1958) showed, the lake must have regained its former level before being overwhelmed by the sustained advance that carried the ice margin to Moreton-in-the-Marsh.

4. Glacial disturbance of the Pleistocene succession

(a) *Introduction*

It has been assumed thus far that sedimentation in the proto-Soar valley occurred as a virtually continuous process under the varying influence of streams, ponded water, meltwater discharge and fluctuating ice sheets. Despite lateral variations in lithology, the basic postulate is that much of the accumulation occurred in identifiable, approximately horizontal sheets that can be mapped over wide areas. However, it has become increasingly clear that by itself this conceptual framework is inadequate to account for many individual observations. Evidence is now at hand that the Pleistocene sediments described in §§2 and 3 above have been disrupted by at least two pene-contemporaneous processes, namely glaciotectonics and the scouring of subglacial furrows. Features associated with each of these processes will first be described, then their ages and possible interrelationships discussed.

(b) *Glaciotectonics*

Glaciotectonics may be defined as the production, through the passage of an ice mass, of large-scale structures involving the transport without disaggregation of either bedrock or previously deposited superficial sediments. After an initial review of sections at Dunton Bassett and Sapcote that illustrate the nature of the occurrences within the present mapping area, attention will be directed to possible additional cases, with the aim of establishing the areal extent of glaciotectonic disturbances.

(i) *The section at Dunton Bassett sandpit* (figure 7)

It has been argued above that the Wolston sand and gravel accumulated in the form of a smooth sandur, but in this particular exposure the bed has patently been disrupted by later faulting and folding. In general the degree of compression represented by individual structures increases from south to north. The most southerly disturbance of note is a prominent thrust fault (A on figure 7) that displays with unusual clarity the associated drag structures. Workings near the fault never properly exposed the contact at the base of the sand, so that the downward continuation of the thrust had to be inferred from shallow hand augering. This disclosed a very irregular junction between the sand and underlying till, with the Bosworth clays and silts

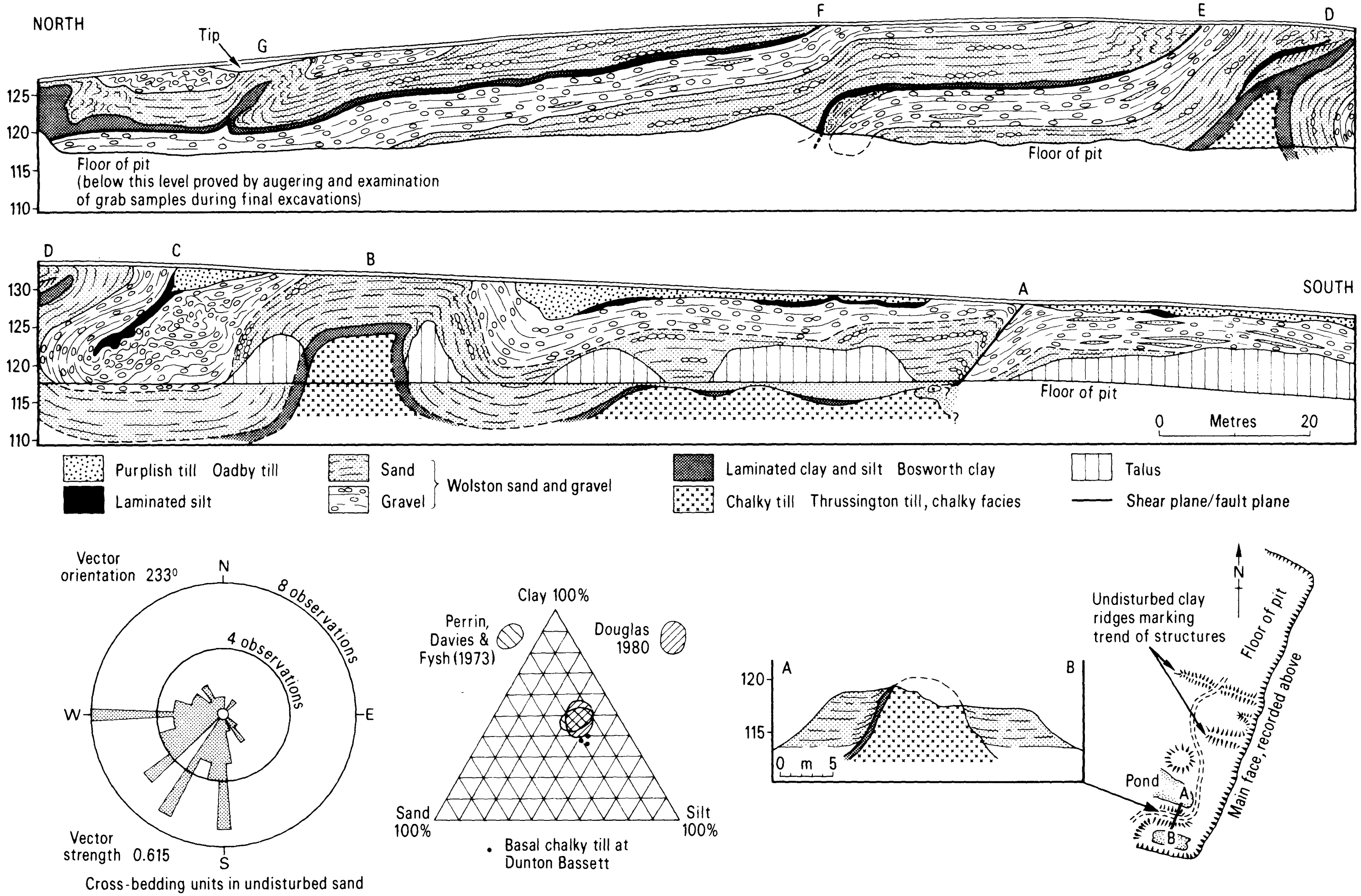

FIGURE 7. Dunton Bassett sand and gravel pit. Above, structures on the main working face. Below, from left to right, orientation of bedding units in the sand, composition of the basal till compared with the chalky tills of Douglas (1980) and Perrin *et al.* (1973), and a measured section through an apparently diapiric structure.

totally absent over a distance of ten metres or more; the fault angle may also decline rapidly with depth if thin till lenses encountered in the course of augering are streaks of such material dragged up along the line of disturbance.

Northwards from the thrust fault augering showed the Bosworth clays and silts at first to be intermittently developed and then to thicken to 1.25 m in the limbs of the first major fold (B). The vertical southern limb of this asymmetric structure is noteworthy for its clear demonstration of the involvement of the Oadby till in the glaciotectonic folding; crude bedding in the till at this point conforms almost precisely to the attitude of the adjacent contact with the gravel. In the core of the next downfold to the north (C), the Oadby till again reaches several metres in thickness but exhibits no discernible bedding. Part of the axial plane of this particular structure is occupied by highly contorted silts and clays that, in undisturbed form elsewhere, can be seen to lie between the gravel and the till. This marker horizon shows that there has been substantial attenuation of the gravel on the inverted limb, with thickening on the other limb accompanied by intricate structural convolutions.

The overfold (D), with a small secondary thrust on its northern limb, is characterized by severe deformation of the Bosworth clays and silts. Thickening to 1.5 m, this stratum has been squeezed along the core of the fold and in hand specimens is seen to consist of a myriad of broken pieces of laminated sediment. The next two structures (E and F) are best described as huge compressional slides in which virtually undeformed masses of sand and gravel have ridden southwards on a continuous sheet of silt and clay whose thickness varies from under 10 cm to almost a metre. Although the commercial workings never afforded a totally clean face for examination, it appears that a large overturned ruck (G), possibly with some thrust faulting, had developed in the higher of these transported sand and gravel masses. At the northernmost limit of the section further disturbances were becoming apparent but were never adequately revealed to permit identification; nearby workings did, however, show that the Bosworth clays and silts here thicken to over 2.5 m.

All the structures indicate compression from the north–northeast, the direction from which ice transporting the Oadby till is believed to have moved. The presence of folded Oadby till implies that this ice had already advanced across the area before most of the displacement occurred. The compressional shortening of the Wolston sand and gravel in this one section is estimated as 220 m, i.e. from just over 550 to 332 m. Almost half this figure is represented by the two large translocations at the northern end of the face. Here décollement took place within the Bosworth clays and silts, but further south the upper horizons of the Thrussington till were incorporated in all the main folds; the differences in structural style along the section may well be related to the local southward thinning of the Bosworth clays and silts.

The literature on glaciotectonics is beset with uncertainty about the extent and thickness of frozen ground at the time of deformation. In the present case independent evidence of cryoturbation structures in the Wolston sand and gravel suggests that that stratum may have been partially frozen. However, the primary factor promoting glaciotectonics is believed to have been high pore-water pressure developing within either the Bosworth clays and silts or, where that bed was missing, the Thrussington till. The former unit would be especially weak under such circumstances, and the long low-angle dislocations are assigned to this cause. Where the clays and silts were either missing or very thin the upper layers of the Thrussington till were mobilized by the same mechanism. Here, however, there was no clear décollement horizon, and that diapirism may have played a part in initiating some of the disturbances is suggested

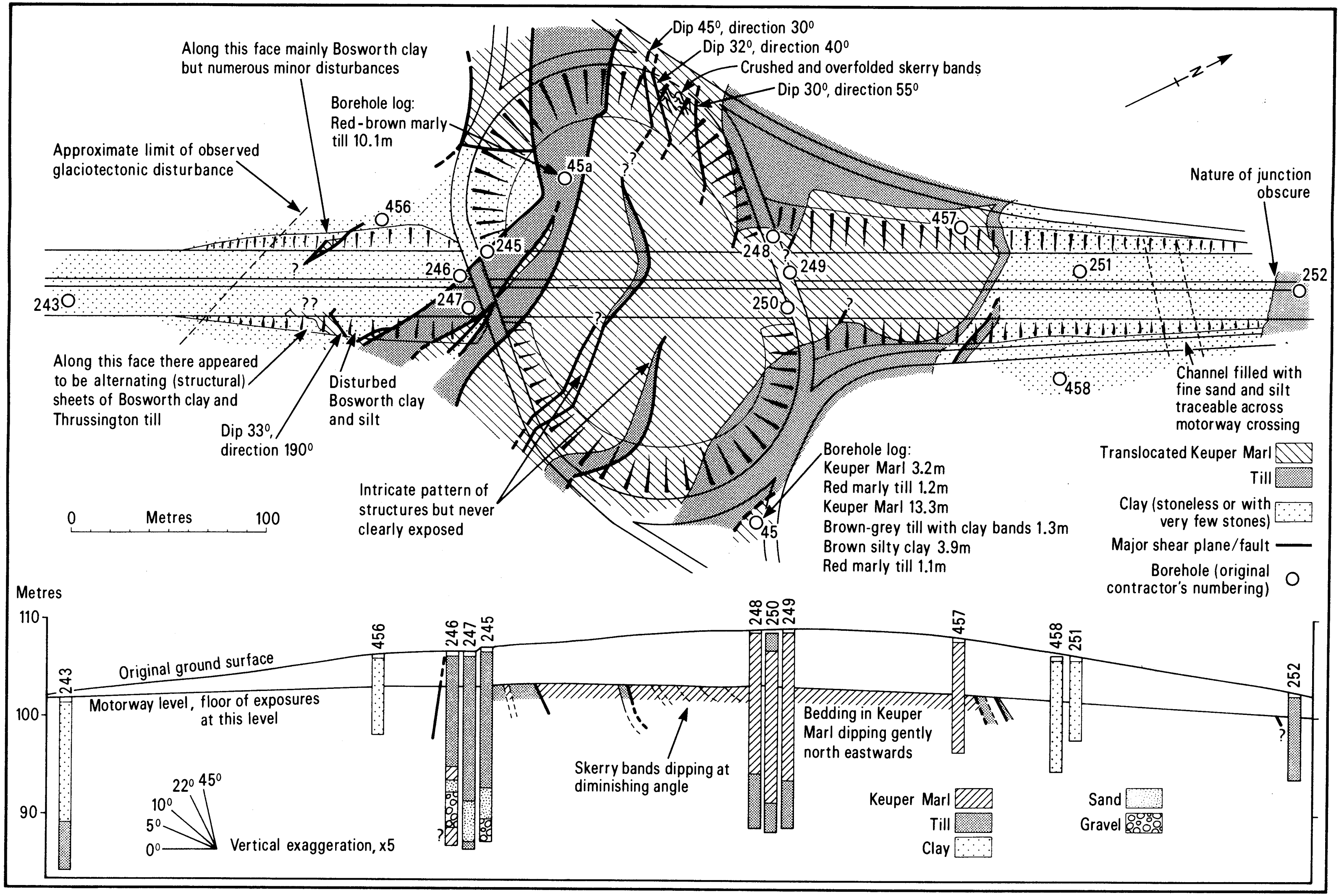

FIGURE 8. The glacial drifts at the A5070 access to the M69 west of Sapcote. The plan (above) depicts the major structures observed in the course of several months of recording, while the section (below) illustrates the evidence provided by boreholes.

by an almost vertical-sided plug of Thrussington till projecting some 7 m into the sand immediately southwest of the thrust fault (A); this plug seems to be of a true piercement nature with undisturbed bedding in the sand extending to within less than a metre of the till contact.

(ii) *The motorway section at Sapcote* (figure 8)

The very first trench dug during construction of the access road to the M69 from the A5070 west of Sapcote revealed a slab-like mass of Keuper Marl overlying slices of Thrussington till and Bosworth clays and silts. As further work was undertaken on the large bowl-shaped excavation illustrated in figure 8 it soon became clear that the engineering works were sited in an area of huge transported masses of Keuper Marl. Exploratory boreholes had proved the marl to be at least 14.95 m thick in places and to overlie till that was penetrated to 5.4 m without being bottomed. In practice the area of the bowl may be divided into two main parts. To the northwest lies a section dominated by translocated Keuper Marl. However, instead of a single monolithic block of such material the exposures revealed a series of massive slices separated by high-angle thrusts. The exact source of the Keuper Marl remains unknown, but one conspicuous aspect of the observed slices was their contrasting lithologies, some consisting of 'marbled' red and green sediment, others of clearly bedded mudstone and skerry. The thrusts must therefore represent substantial dislocations, not mere minor adjustments within a single originally homogeneous mass. The line of one of the most prominent thrusts is continued southeastwards by a sheet of red till that is traceable over a distance of at least 90 m but nowhere exceeds 5 m in thickness.

The southeastern part of the bowl is dominated by an extremely mixed assemblage of till, clay and displaced Keuper Marl. Much of the glacigenic sediment appears identical to the Triassic facies of the Thrussington till and occurs as a series of sheets bounded by steeply dipping thrusts, some of which carry obvious slickensides. There are also several sheets of reddish brown till containing occasional clasts of chalk. The clay assumes a number of different forms. Some horizons are chocolate brown in colour and, being interleaved with red till, are virtually indistinguishable from the lower part of the Bosworth clays and silts as exposed in the Aston Flamville borrow pits. Another type of clay is bluish brown, silty in texture and contains a variable number of stones of diverse provenance. On cursory examination the deposit appears to be almost structureless, but at a few points indistinct planes traversing the materials are discernible and some of these are found to be associated with thin slivers of Keuper Marl, up to 3 m long. This bluish brown clay is interpreted as a dislocated and sheared upper part of the Bosworth clays and silts. Together with thicker but still discontinuous northward-dipping sheets of Keuper Marl, this whole assemblage constitutes what is best described as a complex Schuppen zone.

A short distance along the motorway southwest of the bowl a major change in the orientation of the structures is observed, with shear planes now dipping in a south–southwesterly direction. Beyond a further zone displaying dislocated sheets of till and silty clay, there is finally a transition near the southern limit of the cuttings into what appears to be undisturbed Bosworth clays and silts. Along the motorway to the northeast of the main bowl the cuttings soon become too low to yield much further detail regarding the glaciotectonics. The translocated masses of Keuper Marl first give place to a narrow belt of reddish brown till and then to blue-brown clay. Much of the latter shows little sign of internal deformation but any idea that the limit of the

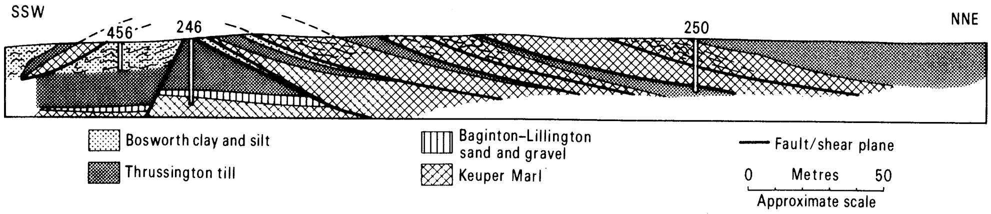

Figure 9. The inferred structural relationships at the A5070 access to the M69. Position of schematic section indicated by boreholes numbered as in figure 8.

glaciotectonics has been reached in this direction is dispelled by sections 1.4 km further along the motorway that display a whole series of low-angled thrusts.

Figure 9 depicts in diagrammatic fashion the major structures in the vicinity of the bowl. Successive irregular sheets of Keuper Marl, together with a little Thrussington till and Bosworth clay and silt, have been thrust over each other by compressive stresses directed from between north and northeast. The strata penetrated by borehole 246 can be interpreted as the regional drift succession overlying Keuper Marl, and this block appears to be bounded on its southwestern side by a steeply dipping normal fault. The sheets of Keuper Marl that dip south–southwestwards beyond borehole 456 are taken to represent the frontal downturned edges of one or more of the thrust masses observed in the main bowl. Since the Bosworth clays and silts have not been encountered northeast of Barrow Hill quarry, incorporation of this stratum in the structures implies that the translocated masses have not travelled any great distance. Although the same sediments are also the youngest member of the drift succession recognized in the actual bowl, augering a short distance away disclosed sufficient chalk and flint in some of the glacigenic deposits to suggest very strongly that the Oadby till was involved in the disturbances.

(iii) *Other areas of probable glaciotectonic disturbance*

Although the complexity of potential sedimentation processes must cause hesitation before glaciotectonics is invoked to explain irregularities in drift successions, the proven structures at both Dunton Bassett and Sapcote lend support to the belief that glaciotectonic features are more widespread than has hitherto been realized. The following observations lead the writer to conclude that the occurrences at Dunton Bassett sandpit are part of a disturbed zone traceable at least from abandoned pits beside the old railway line at Broughton Astley (534917) to well beyond the eastern edge of the present mapped area. Overgrown sections in the pits at Broughton Astley disclose not only an extremely uneven base to the local gravel outcrop but also sharply contorted structures. When that section of the M1 east of Dunton Bassett was being built, Poole *et al.* (1968, p. 56) recorded deformed beds that included both sand and gravel and also till and laminated clay. Rather strangely the Geological Survey 1 inch sheet no. 170 portrays little sand and gravel in this general vicinity although numerous shallow sections, old pits and boreholes bear witness to substantial quantities of water-laid sediment now lying in attitudes that would be most unlikely as original depositional forms and for which glaciotectonic disruption appears by far the most feasible explanation. Only 2.75 km further southeast, between Gilmorton and Peatling Parva, an abandoned pit (581886), formerly worked by the same company as that now operating at Dunton Bassett, is reported by the management to have displayed analogous structural dislocations. A recent small excavation in sharply contorted gravels near Peatling Parva (592893) strengthens the belief that the zone of glaciotectonics extends at least this far eastwards.

In tracing the glaciotectonic disturbances away from the motorway cuttings at Sapcote it has to be assumed that the form of the proto-Soar valley is sufficiently well established for transported masses of Keuper Marl to be differentiated from *in situ* bedrock; often any residual uncertainty could only be dispelled by drilling boreholes to depths of 20 m or more. In practice the first indication that the Sapcote area might contain anomalous drift structures came before the motorway investigations were even started when routine augering just south of the village disclosed a mass of Keuper Marl within a region shown on the Geological Survey 1 inch sheet no. 169 as covered entirely with drift and at a height some 7 m above the local rockhead elevation as postulated by Shotton (1953, fig. 11). Later work showed this to be but one of a whole series of Keuper Marl masses scattered across an area of 11 km^2 between Sharnford in the south and Barrow Hill quarry in the north. Although the distribution of these masses would be extremely difficult to explain as the product of conventional bedrock outcrops, few deep sections other than along the M69 have been seen to prove their glaciotectonic origin. Augering has identified disturbed drift stratigraphy along the western edge of the present mapped area near the Leicester–Nuneaton railway line, and only 2 km further west Eastwood *et al.* (1923, p. 110) described a pit on the northern outskirts of Hinckley as displaying sand and gravel buckled into two large anticlines 'probably by a fresh advance of the ice'.

To complete this review of possible local glaciotectonics, reference must be made to 11 boreholes sunk close to the A5–M69 crossing, some 1.5 km beyond the southwestern corner of the present mapped area. All encountered Keuper Marl at depths of less than 10 m, and the deepest penetrated 13.25 m of such material. There is no direct evidence that this is not *in situ* bedrock, but, by the criterion of the established form of the proto-Soar valley, a bedrock outcrop in this position would represent a discrepancy in elevation of no less than 25 m. The size of the disparity arises from the site lying close to the axis of the buried 'Hinckley valley', a major left-bank tributary of the proto-Soar valley. If the proven Keuper Marl is true bedrock, the only feasible alternative course for the lower Hinckley valley appears to be a sinuous route south–southwestwards towards Burton Hastings. This necessitates a curious, obtuse-angled confluence with the main valley and, on current evidence, it seems more likely that the Keuper Marl encountered in the boreholes consists of translocated masses similar to those at Sapcote.

(*c*) *Subglacial furrows*

The term subglacial furrow is used to denote an enclosed, drift-filled depression of linear form that can confidently be assigned a subglacial origin. It has been preferred to such alternatives as 'tunnel valley' or 'iceway' since these have a more precise genetic connotation that it is desired to avoid. Two subglacial furrows have been identified. The larger Narborough furrow runs along the southeastern edge of the igneous outcrops extending from Enderby to Sapcote; near Croft it is joined from the north by the shorter Thurlaston furrow.

(i) *The Narborough furrow*

The first clear evidence of this drift-filled trough came with exploratory work for the M1 in the early 1960s (see Rice 1968, pp. 486–493). Additional data collected during the intervening

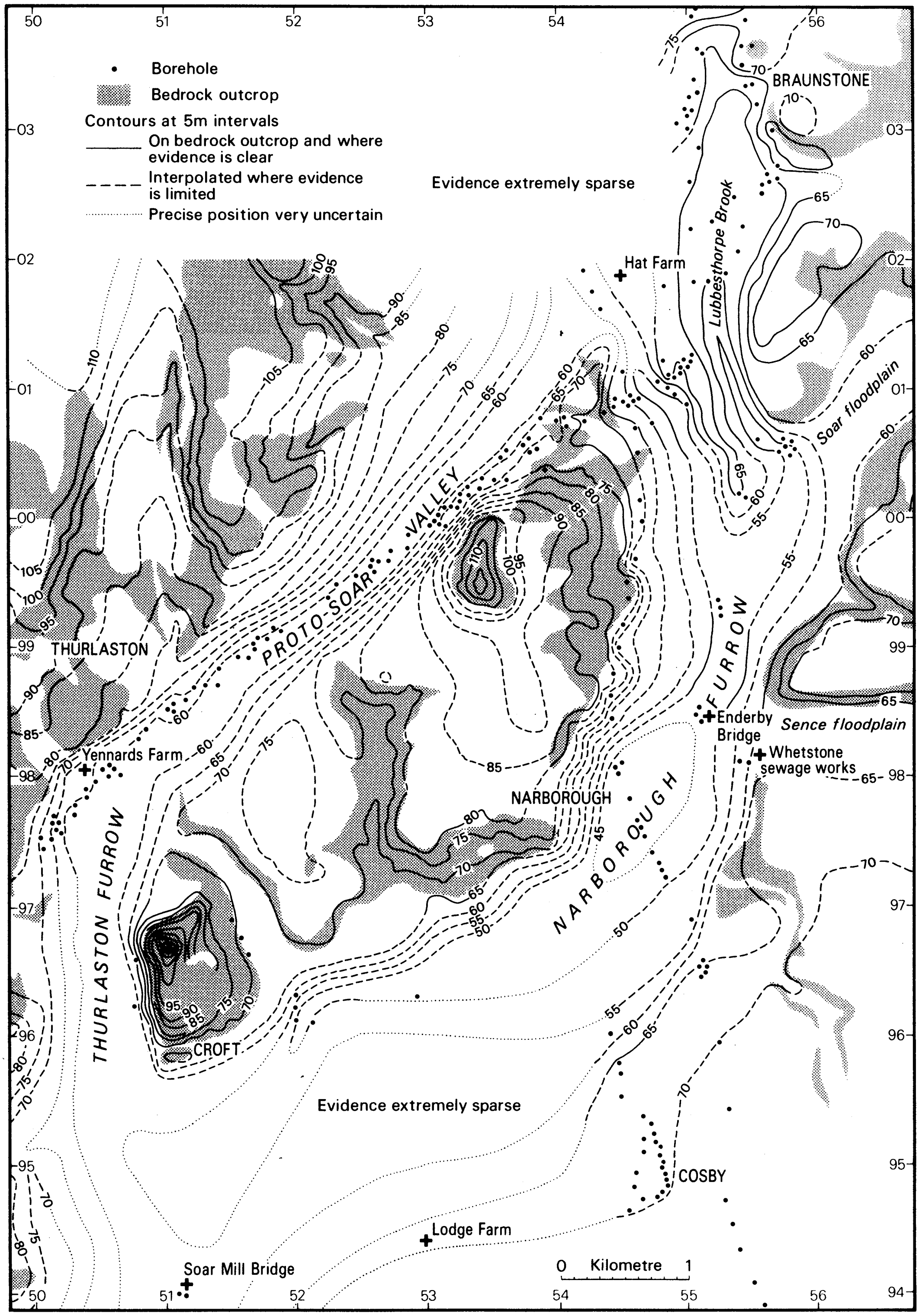

FIGURE 10. Contours on the bedrock surface around and northeast of Croft. The depression marked 'proto-Soar valley' is floored by the Baginton–Lillington gravel, whereas those marked 'Thurlaston furrow' and 'Narborough furrow' are filled to their base with a mélange of predominantly chalky sediments.

years now permit a much clearer definition of at least the northern part of the feature. Description will commence with this northern part so that the basic characteristics of the furrow and its filling can be established; only then will attention be turned to the southern area, where subsurface information remains sparse and precise delimitation of the feature much more difficult.

The configuration between Braunstone and Soar Mill Bridge (figure 10). The northern limit of the furrow is marked by two shallow drift-filled cols that notch the low watershed between Lubbesthorpe and Braunstone Brooks. Southwards along Lubbesthorpe Brook the depression deepens, although a recurrent problem is the limited number of boreholes that actually reach bedrock; the maximum recorded thickness of drift in this area is 20 m without the base being bottomed. Along the lower reaches of Lubbesthorpe Brook recent drilling has done much to confirm the validity of an earlier resistivity survey which was interpreted as showing a narrow-topped ridge of Keuper Marl separating two steep-sided depressions. It is the easterly depression that appears to continue the line of the furrow beneath Lubbesthorpe Brook, while the westerly depression remains as a feature of very indeterminate form with few records by which any northward extension can be plotted. A borehole at Hat Farm is reputed to have met, at a depth of 0.6 m, 'dark red marl' which is 28.2 m thick and rests upon 'red marl and stone beds' proved to a further 16.7 m. If the upper marl is true bedrock, this log virtually precludes any northward extension. On the other hand, boreholes along the nearby M1 were sunk to depths of 12.2 and 10.7 m without reaching rockhead and it seems possible that the Hat Farm record actually refers to 28.2 m of till resting on bedrock, an interpretation which could mean that the westerly depression is at least of the same general size as that underlying Lubbesthorpe Brook.

The original boreholes where the M1 crosses the River Soar still provide one of the most informative transects of the Narborough furrow. They illustrate that the feature is markedly asymmetrical, with its axis some 250 m west of the floodplain margin and average gradients to east and west of 1.3 and 5.2° respectively. More recent sections and drillings allow the eastern edge of the depression to be fixed with considerable precision at Whetstone sewage works and near Cosby, but further south reliance has to be placed on augering, which seems to indicate the edge as crossing Broughton Brook valley in the general vicinity of Lodge Farm. Meanwhile the western margin of the furrow has been closely defined southwest of Narborough by excavations to explore the reserves of ballast beneath the Soar floodplain. Nearer Croft a series of boreholes close to the confluence of Thurlaston Brook has picked up the same margin sloping at an apparent angle of 6.5°; the maximum thickness of drift encountered was 16 m and there is reason to believe that this particular borehole may have been sunk along the asymmetrically placed axis of the furrow.

The deposits between Braunstone and Soar Mill Bridge. Since only a few sample materials from within the furrow have been available for study, reliance has often had to be placed upon the descriptions given in borehole logs. The latter were generally prepared by organizations well versed in the recording of drift successions, and table 3 presents an analysis of the descriptions accorded to an aggregate of 599 m of material; it assigns to ten categories over 94 % of the glacial sediments logged in recent boreholes. Till or till-like material is the most abundant deposit, composing some 53 % of the total. Several different till types are present, the most common being grey and chalk-bearing. Brown sand and grey clay together compose a further 30 % of the total, illustrating the importance of water in the accumulation of the drift infill. One further point about table 3 requires mention. Since core samples show that some of

TABLE 3. AN ANALYSIS OF THE LOGS OF BOREHOLES PENETRATING THE NARBOROUGH FURROW BETWEEN BRAUNSTONE AND SOAR MILL BRIDGE

(The table gives figures in metres; the values in parentheses refer to the thicknesses specifically recorded as containing chalk and/or flint.)

location	number of boreholes	aggregate thickness† m	till			silt and/or clay			sand			sand and gravel	other‡
			red/ brown	brown	brown grey	grey/ blue	brown	grey/ blue	reddish	brown	grey		
north of Lubbesthorpe Brook–Soar confluence	42	351.35	95.48	46.90	11.89	129.56	5.17	46.93	0.30	7.90	4.45	—	2.77
			(29.32)	(12.23)	(—)	(90.46)	(—)	(20.23)	(—)	(—)	(—)	(—)	
from Lubbesthorpe Brook confluence to Enderby bridge	14	103.01	0.90	4.04	—	9.14	2.88	51.07	0.38	6.78	9.82	12.62	5.38
			(—)	(—)	(—)	(9.14)	(—)	(—)	(—)	(—)	(—)	(—)	
south of Enderby Bridge	16	144.75	0.70	10.33	—	7.40	—	53.40	21.02	22.99	3.96	—	24.95
			(—)	(8.23)	(—)	(7.40)	(—)	(9.49)	(—)	(13.60)	(—)	(—)	
total	72	599.11	97.08	61.27	11.89	146.10	8.05	151.40	21.70	37.67	18.23	12.62	33.10
			(29.32)	(20.46)	(—)	(107.00)	(—)	(29.72)	(—)	(13.60)	(—)	(—)	

† Excluding soil, alluvium, bedrock.

‡ Mainly material described as 'reworked Keuper Marl'.

the material described as grey chalky till is in fact a bedded silty deposit with numerous very small chalk specks, there can be little doubt that the table tends to exaggerate the proportion of true till.

Although no wholly consistent stratigraphy is apparent in the infill, certain trends and patterns are discernible. Till tends to be relatively more abundant in the north than in the south, this being especially true of the reddish brown and brown varieties. In places these last two form a virtual lining to the furrow, and at several sites the borehole logs imply a gradation through red till with erratics into red 'till' composed entirely of broken Keuper Marl fragments, and only then into undisturbed bedrock. Another noteworthy characteristic is the irregular distribution of thick sequences of silt, sand and gravel. Such sequences can occur in areas where the infill is predominantly till, a relationship suggesting that the water-laid sediments may occupy channels of much smaller dimension than the furrow as a whole.

Probable continuation south of Soar Mill Bridge. In the 5.5 km from Soar Mill Bridge to the edge of the mapped area the primary criterion for tracing the furrow has been augering into grey chalky glacigenic and glacifluvial sediments at elevations where other members of the drift succession might be expected. As far as Sharnford the western margin is defined by the Calver Hill igneous outcrop and by glaciotectonically displaced Keuper Marl, but the eastern margin is less clear. The ridge running southwestwards from Sutton in the Elms is composed on the west of grey chalky sediments and on the east of Bosworth clays and silts overlying Thrussington till, but the actual line of contact is concealed beneath a widespread capping of sand. Eastwood *et al.* (1923, p. 114) held this sand to be an outlier of the deposits mapped in the present study only a kilometre away at Frolesworth as the Wolston sand and gravel. However, such an interpretation poses formidable problems since in places the sand undoubtedly overlies part of the furrow infill, and yet evidence elsewhere, even if not conclusive, strongly suggests that the furrow is younger than the Wolston sand and gravel. Therefore, although the precise field relations remain obscure, the sand is provisionally mapped as part of the infill rather than as an outlier of the Wolston sand and gravel.

South of Sharnford the furrow margins appear to diverge and the depression to split into two branches. Augering in the valley leading south to Wibtoft encountered chalk-bearing grey and purplish brown till with much interleaved sand, silt and clay that has tentatively been mapped as part of the fill in the eastern branch of the furrow. Further west near Wigston Parva a return to the regional stratigraphy of Wolston sand and gravel over Bosworth clays and silts is supported by a borehole in the latter stratum which proved 3.6 m of yellowish and grey silt passing down into 3.3 m of smooth red clay with odd stones. Although elevation and sequence accord almost precisely with those at the Aston Flamville borrow pits 2.7 km to the north, between runs a zone of low-lying chalky sediments interpreted as the western branch of the subglacial furrow. This view is based upon augering and also upon an old excavation near stream level just north of Smockington Hollow (461903). A 50 m long face displays a northeasterly dipping succession consisting of gravel at the base, followed in turn by brown sand, chalky till, grey silt and a red gritty sand and gravel. Most of the lower gravel comes from northeasterly sources (table 1), whereas the upper gravel, apart from an occasional flint, closely resembles the Baginton–Lillington gravel in composition; provenance thus affords very ambiguous guidance to stratigraphical position. The disturbed bedding, with dips of 20° at one point, might suggest that the exposure lies within the region of glaciotectonics, yet the regional outcrop pattern appears to favour ascription to the furrow infill. Roadworks on the A5 at the southwestern corner of the mapped area displayed a crudely bedded gravel with two-thirds of the clasts from Cretaceous and Jurassic sources (table 1). The elevation is consistent with a Wolston sand and gravel outcrop, but the composition is unusually flinty for that member of the succession. It cannot be denied that the stratigraphy in the whole southwestern corner of the mapped area remains uncertain, but on available evidence the surface deposits seem most likely to represent the western continuation of the Narborough subglacial furrow.

Given the reservations just expressed, it would be premature to attempt to delineate any continuation of the furrow beyond the present mapping limits. Yet two observations are worth recording. The first concerns the identification of an easterly branch running south towards Wibtoft. This idea receives support from the Geological Survey officers, who note the Wibtoft region as, in their view, the one breach in the continuity of the Wolston sand and gravel outcrop, and who specifically mention that, on the eastern side of the breach, brown clay has been seen banked against the edge of the sand and gravel (Eastwood *et al* 1923, p. 115). The second observation concerns the possible extension of the western branch towards Burton Hastings. Here, as pointed out in §3 (*d*), the investigations along the M69 recorded a local absence of the Wolston sand and gravel; although the matter requires further study, it could well result from transection by the subglacial furrow.

(ii) *The Thurlaston furrow*

Although the existence of this feature was suspected early in the present work, proof only came with construction of the M69. Cuttings at Yennards Farm then showed that the Baginton sand is abruptly cut out, for a distance of some 900 m, by chalky till mixed with abundant silt and laminated clay. Two sections were particularly informative in elucidating the nature of the furrow margin and the character of the infill. The first displayed the actual contact between the Baginton sand and furrow infill. Striking in a direction of 215°, approximately parallel to the axis of the furrow, this junction sloped at an angle of 30°. The sedimentary structures in the sand were undisturbed only a few centimetres from the junction, while the adjacent till, red and reddish brown in colour, was clearly banded parallel to the contact; this till was 1.5 m thick and contained skerry, coal and Bunter pebbles. It was replaced above a sharp boundary by grey chalky till and then by grey silts and laminated clays. The second section, near the axis of the furrow, exhibited a complex succession of tills, clays, silts and sands. The commonest till was very chalky in composition, and several of the sand and silt horizons were heavily charged with small chalk particles. Yet the most striking aspect of the 5 m deep section was its demonstration of at least two separate phases of disturbance. The earliest silt and clay had been both folded and eroded before deposition of a cover of fine water-laid sediment, interbedded with thin till horizons, that had itself then been deformed with local dips in excess of 10°. Strong compressive forces were not necessarily involved, and the structures could conceivably be attributed to collapse over masses of stagnant ice. Only the upper part of the full drift sequence at this site was exposed since a borehole had earlier proved 20 m of deposits without reaching rockhead at 59 m O.D.

As a deep feature the Thurlaston furrow cannot extend far north of the motorway, but southwards its course can be traced round the western flank of Croft Hill, where two boreholes, sunk to depths of 14.3 and 15.2 m, failed to reach bedrock. The logs refer almost exclusively to grey clay; some is studded with fragments of chalk, flint and quartzite pebbles and is probably till, but much is sandy or silty in texture and contains innumerable small chalk pellets; from the description the latter closely resembles the water-laid material found in the Narborough furrow on the other side of Croft Hill. Southwest of Croft a pipeline trench across the Thurlaston furrow emphasized the discordance between modern relief and rockhead relief; Keuper Marl was proved to outcrop up the northwestern slope of the interfluve between the Soar and Thurlaston Brook virtually to the summit of the ridge, whereas the southeastern slope was seen to be composed of chalky till interbedded with grey laminated clay. Although no detailed evidence is available, it is presumed that the Thurlaston and Narborough furrows converge near Soar Mill Bridge.

(iii) *Other possible related features*

Reference to figure 2 will show that there remains one district about which discussion has been deferred owing to the uncertainty that still shrouds its correct interpretation. This region lies between Sharnford in the south and Barrow Hill Quarry in the north, and extends westwards from the line of igneous outcrops centred about Stoney Stanton to the zone of glaciotectonics revealed by the M69 excavations. Hand augering shows that the surface materials almost invariably consist of chalky glacigenic and water-laid sediments, with the latter ranging from bedded silts to coarse gravel. A borehole some 1200 m southwest of Barrow Hill Quarry (G.R. 484960, with full log in I.G.S. Report 76/10) encountered 10.97 m chalky till overlying a varied succession that includes lacustrine deposits, sand and gravel, a till of Triassic derivation and more chalky till, the whole amounting to 18.29 m and still not being bottomed at 67 m O.D.; being about 8 m below the expected level of the Baginton sand, this elevation carries the implication of some erosion having occurred. The only deep exposure is found in an abandoned gravel pit 1 km northwest of Sapcote (485940). This oval-shaped excavation has 8.5 m high walls that descend below the level of the adjacent brook and show the material to consist of a coarse, crudely stratified gravel with horizons of cobble-sized clasts that include flint, Lias limestone, Lincolnshire limestone, Carboniferous limestone and Millstone grit. The gravel exhibits a similarly diverse provenance (table 1), a noteworthy component in this case being heavily weathered local igneous rocks. It is extremely difficult to relate this outcrop of flinty gravel, which is at most 400 m by 200 m in extent, to its immediate surroundings. Augering shows the pit to be bounded on the west by a huge mass of transported marl, on the north and east by red Trias-derived till, and on the south by interbedded chalky till and silt.

In attempting to explain both the occurrence of the gravel at Sapcote and also the relationships over the whole area now under review, two hypotheses merit consideration. The first is that there are several parallel subglacial furrows, analogous to those described above but of much shorter length. In favour of this hypothesis is the high proportion of silty and even sandy material that augering shows accompanies the chalky till; on this interpretation the Sapcote gravel might be regarded as an exceptionally coarse representative of a water-laid furrow infill. The second hypothesis regards the chalky deposits as primarily Oadby till with an unusual admixture of water-laid sediment. The area might then be viewed as part of the glaciotectonic zone that has not yet been sufficiently dissected to reveal the structures below the level of the Oadby till. The I.G.S. borehole could be interpreted as having penetrated through the Oadby till into a zone of sheared sediments beneath. The gravel at Sapcote abuts, on the west, translocated Keuper Marl and is therefore at the very least contiguous with the glaciotectonic zone. Yet the deposit itself cannot be unequivocally referred to any single member of the drift succession. The most likely equation on grounds of composition is with the Wolston sand and gravel, but the base of the Sapcote deposit is some 20 m lower than the expectable base of that stratum when undisturbed. The isolation and low elevation may indicate a better correlation with the Wigston sand and gravel (see discussion above, §3 (*d*)), although until more is known about the relationships at depth no firm conclusion can be drawn.

(*d*) *General discussion*

In considering the origin of the subglacial furrows it should first be stressed that they cannot be fitted into any pattern of confluent northward-draining valleys with dimensions even remotely resembling those of the present-day Soar and its tributaries, and it can safely be assumed that the furrows are enclosed depressions, probably with irregular long profiles. The literature on such features suggests two possible origins, localized scouring by ice to produce iceways (Gresswell 1964), and excavation by subglacial streams to produce buried tunnel valleys (Woodland 1970). Although the abundance of water-laid sediments among the fill of both the Narborough and Thurlaston furrows argues for the involvement of meltwater, many of the borehole logs and the solitary section in a furrow margin show that the depressions are often lined with till and that it may be only an inner core that is of aqueous origin. The sequence is reminiscent of that recorded in the central Edinburgh area by Sissons (1971), who argued that subglacial meltwater streams utilized depressions scoured earlier in the same glaciation by ice; a further parallel with the Edinburgh features is the way that the Narborough furrow in particular sweeps round the edge of the igneous bosses between Enderby and Sapcote. Yet it must be remembered that the character of deposits resting on an eroded surface does not necessarily indicate the nature of the eroding agent. Thus, it is possible to envisage local scouring by meltwater being followed by glacial deposition as a subglacial stream shifts and deepens its course. Thereafter, with partial melting of the ice sheet, predominantly aqueous sedimentation may supervene to fill what remains of the furrow. At the same time dirty basal ice collapsing into the hollow would yield discontinuous horizons of glacigenic sediment and, on melting, would also induce contortions in any overlying beds. Such a history would serve to explain both the lack of stratigraphic consistency and the presence of contorted strata.

The furrows appear to date from the time of deposition of the Oadby till; not only is the fill normally rich in northeastern material, but the depressions appear to be eroded through all members of the drift succession up to and including the Wolston sand and gravel. The glaciotectonic disturbances are of approximately the same age. This is most obvious from the pit at Dunton Bassett but may also be inferred from observations elsewhere. For example, although no highly chalky till was seen in the motorway sections at Sapcote, augering nearby did establish the local involvement of such material. Owing to the extreme variability of the Thrussington till such an occurrence is not entirely diagnostic, but the balance overwhelmingly favours disruption by a late-stage ice advance from east of north. Despite the fact that both the glaciotectonics and the furrows are apparently attributable to the same glacial advance, the way in which the Narborough furrow around Sharnford cuts uninterrupted across the main zone of glaciotectonics suggests that it is the younger feature. Such a conclusion is also consistent with the tendency of the modern streams to follow the alignment of the furrows; the latter, if incompletely filled at the end of the glaciation, could well have guided the development of the newly instituted drainage system. This argument appears more soundly based than any that attempts to relate the modern stream network to the detailed course of the proto-Soar as represented by the remnants of the Baginton sand.

Finally, reference must be made to disturbed drift deposits that were formerly exposed in the M1 cutting at Narborough. Two accounts of this section have been published (Shotton 1965; Poole 1968), differing in important points of detail. The present writer, who also examined the cutting while engineering work was in progress, is convinced that Shotton was correct to recognize a widespread series of dislocations outlining a pattern of horst and graben blocks. Shotton ascribed the dislocations to faulting triggered by glacio-isostatic recovery, whereas Poole attributed them to a powerful ice-push from the northeast. The presence of glaciotectonics only a few kilometres away strengthens Poole's contention that glacially induced forces were involved, although few of the major displacements at Narborough were compressional, a fundamental difference from those at Dunton Bassett and Sapcote. One possibility is that the normal faults are relief structures following removal of the glacial compression so clearly attested elsewhere, another that they are connected with collapse of the steep western side of the Narborough furrow which runs immediately alongside. The matter needs further investigation but practical opportunities are now limited by the spread of suburban housing.

5. Conclusions

The present work is believed to sustain the following main conclusions.

(*a*) No unequivocal correlative of the Bubbenhall clay in Warwickshire can yet be recognized in south Leicestershire.

(*b*) The thesis advanced by Shotton (1953) and supported by Rice (1968) of a water-laid stratum of sand and gravel stretching the length of the proto-Soar valley from Stretton on Fosse to Leicester is further confirmed. Yet the precise conditions of accumulation still pose certain problems owing to the extremely low downvalley gradient of the deposit.

(*c*) Within the area around Croft the Baginton sand is normally succeeded by the Thrussington till. The intervening Glen Parva clay recognized by Rice (1968) in the vicinity of Leicester now appears to be a local development that cannot be directly correlated with the Wolston clay of Shotton (1953).

(*d*) The occurrence of till resting directly on the Baginton sand at such widely separated sites as Thurmaston, Huncote and Wolston implies an early ice advance over the East Midlands before the main impounding of Lake Harrison. However, the absence of corresponding till beneath lacustrine sediments at Snitterfield may indicate an early more localized ponding in that vicinity.

(*e*) Lacustrine clays overlying the Thrussington till are thickly developed in an area between Stoke Golding in the west, Leire in the east and Wolston in the south. Northwards from this area the clays thin rapidly and are replaced by till so that any extension of Lake Harrison beyond Broughton Astley was presumably very short-lived.

(*f*) Glacial readvance across the site of Lake Harrison was preceded by deposition of a sandur that formed a virtually continuous sheet of sand and gravel from Hinckley and Dunton Bassett in the north to the vicinity of Leamington in the south.

(*g*) Severe disruption occurred beneath the newly advancing ice. Not only were the earlier drift deposits affected, but substantial thicknesses of Keuper Marl were translocated and distorted by the powerful compressive stresses that developed.

(*h*) Slightly later, but still in the course of the same ice advance, subglacial erosion scoured a series of elongated furrows that locally cut through all the earlier drift and penetrated deep into the underlying bedrock. These furrows were subsequently filled with an intimate mixture of glacigenic and water-laid sediments.

(*i*) Together the glaciotectonics and subglacial scouring occupy over 43% of the mapped area. This figure must be regarded as a minimum since, in the absence of good exposures, it would undoubtedly be difficult to identify glaciotectonics affecting only earlier tills.

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REFERENCES

Allen, J. R. L. 1963 The classification of cross-stratified units, with notes on their origin. *Sedimentology* **2**, 93–114.

Bishop, W. W. 1958 The Pleistocene geology and geomorphology of three gaps in the Midland Jurassic escarpment. *Phil. Trans. R. Soc. Lond.* B **241**, 255–306.

Bridger, J. F. D. 1975 The Pleistocene succession in the southern part of Charnwood Forest, Leicestershire. *Mercian Geologist* **5** (3), 189–203.

Douglas, T. D. 1974 The Pleistocene beds exposed at Cadeby, Leicestershire. *Trans. Leicester lit. phil. Soc.* **68**, 57–63.

Douglas, T. D. 1980 The Quaternary deposits of western Leicestershire. *Phil. Trans. R. Soc. Lond.* B **288**, 259–286.

Eastwood, T., Gibson, W., Cantrill, T. C. & Whitehead, T. H. 1923 Geology of the country around Coventry. *Mem. geol. Surv. U.K.*

Gresswell, R. K. 1964 The origin of the Mersey and Dee estuaries. *Geol. J.* **4**, 77–86.

Kelly, M. R. 1968 Floras of Middle and Upper Pleistocene age from Brandon, Warwickshire. *Phil. Trans. R. Soc. Lond.* B **254**, 401–415.

Osborne, P. J. & Shotton, F. W. 1968 The fauna of the channel deposit of early Saalian age at Brandon, Warwickshire. *Phil. Trans. R. Soc. Lond.* B **254**, 417–424.

Perrin, R. M. S., Davies, H. & Fysh, M. D. 1973 Lithology of the chalky boulder clay. *Nature, phys. Sci.* **245**, 101–104.

Poole, E. G. 1968 Some temporary sections seen during the construction of the M1 motorway between Enderby and Shepshed, Leicestershire. *Bull. geol. Surv. Gt Br.* **28**, 137–151.

Poole, E. G., Williams, B. J. & Hains, B. A. 1968 Geology of the country around Market Harborough. *Mem. geol. Surv. U.K.*

Rice, R. J. 1968 The Quaternary deposits of central Leicestershire. *Phil. Trans. R. Soc. Lond.* A **262**, 459–509.

Shotton, F. W. 1953 Pleistocene deposits of the area between Coventry, Rugby, Leamington and their bearing upon the topographic development of the Midlands. *Phil. Trans. R. Soc. Lond.* B **237**, 209–260.

Shotton, F. W. 1963 Middle Pleistocene sections in the M45 motor road. *Proc. Coventry nat. Hist. scient. Soc.* **3**(7), 183–188.

Shotton, F. W. 1965 Normal faulting in British Pleistocene deposits. *Q. Jl geol. Soc. Lond.* **121**, 419–435.

Shotton, F. W. 1968 The Pleistocene succession around Brandon, Warwickshire. *Phil. Trans. R. Soc. Lond.* B **254**, 387–400.

Shotton, F. W. 1976 Amplification of the Wolstonian stage of the British Pleistocene. *Geol. Mag.* **113**, 241–250.

Sissons, J. B. 1971 The geomorphology of central Edinburgh. *Scott. geogr. Mag.* **87**, 185–196.

Tomlinson, M. E. 1935 The superficial deposits of the country north of Stratford on Avon. *Q. Jl geol. Soc. Lond.* **91**, 423–462.

Woodland, A. W. 1970 The buried tunnel-valleys of East Anglia. *Proc. Yorks. geol. Soc.* **37**, 521–578.