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Onshore Geology Series

TECHNICAL REPORT WA/89/9

Geology of the Radcliffe on Trent District

1:10 000 sheet SK63NW
Part of 1:50 000 Sheet 126 (Nottingham)
and 142 (Melton Mowbray)

D J LOWE

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1 INTRODUCTION

This report describes the geology of 1:10 000 sheet SK63NW (Radcliffe on Trent), which is included in 1:50 000 Geological sheets 126 (Nottingham) and 142 (Melton Mowbray). The original geological survey of the region was part of Old Series One-inch sheets 71NE, surveyed by W T Aveline, E Hull and T R Polwhele in 1858, with amendments by W T Aveline in 1878, and 71SE, surveyed by E Hull in 1855, with amendments by W T Aveline in 1878, both published in 1879. An account of the geology is given by Aveline (1862, 1880). The Radcliffe on Trent district (hereafter referred to as the 'district') was geologically surveyed at 1:10 560 scale by R L Sherlock and W B Wright in 1904 to 1906, and published on Nottinghamshire County Series sheets 42 and 43. The One-inch to one-mile Geological sheet 126 (Nottingham) was published in 1908, with an accompanying memoir (Lamplugh and others, 1908). An account of the concealed coalfield was later written by Edwards (1951). Geological sheet 126 was reprinted in 1959, and published on the 1:50 000 scale in 1972, with amendments to the Carboniferous. One-inch to one-mile Geological sheet 142 (Melton Mowbray) was published in 1909, with an accompanying memoir (Lamplugh and others, 1909). The sheet was reprinted in 1959 and 1969 and published on the 1:50 000 scale in 1976.

An area centred on the village of Cotgrave, in the south-east of the district, was partially revised by R A Eden in 1954 at 1:10560 scale, but the results of this survey were not published.

The district was re-surveyed by D J Lowe at 1:10 000 scale in 1987 to 1988, under the direction of T J Charsley (Team Leader) and A J Wadge (Programme Manager). This work constitutes part of the Nottingham Geological Mapping Project, and was jointly funded by the BGS and the Department of the Environment.

The district lies in the county of Nottinghamshire and is largely south of the River Trent (Figure 1). It is cut by the south-west to north-east flowing River Trent in the north of the sheet area. Much of the northern part of the district is occupied by the broad alluvial flood plain and associated terraces of the River Trent, mainly lying below 30m AOD. Steep river cliffs are present north of the river in the north-west of the district and on the south side of the river in the north-east. The small area north-west of the flood plain comprises deeply incised rounded slopes, falling south-eastwards and the south-eastern part of the district, beyond the flood plain, is almost everywhere gently undulating, with an overall rise towards the south-east. The western side of the district includes the edge of the urban area of West Bridgford, a suburb which forms the south-eastern outskirts of Nottingham; other heavily built-up areas are Radcliffe on Trent in the north-east and Cotgrave in the south-east.

Solid strata of the Triassic Mercia Mudstone Group occupy almost the entire district, the only exception being a small area of Triassic Sherwood Sandstone Group rocks conjectured to lie beneath superficial deposits in the north-west. The Triassic rocks are extensively covered by alluvial deposits, mainly of the River Trent, in the northern half of the district and by lacustrine deposits to the south of the flood plain. Much of the Trent flood plain has been worked as a source of sand and gravel, with extraction still continuing. Former workings have been subject to extensive landscaping to produce a variety of leisure facilities or are currently derelict, partly flooded, and awaiting restoration.

Coal Measures, comprising part of the Nottinghamshire Coalfield, lie concealed beneath the cover of Permo-Triassic rocks and much of the district has been

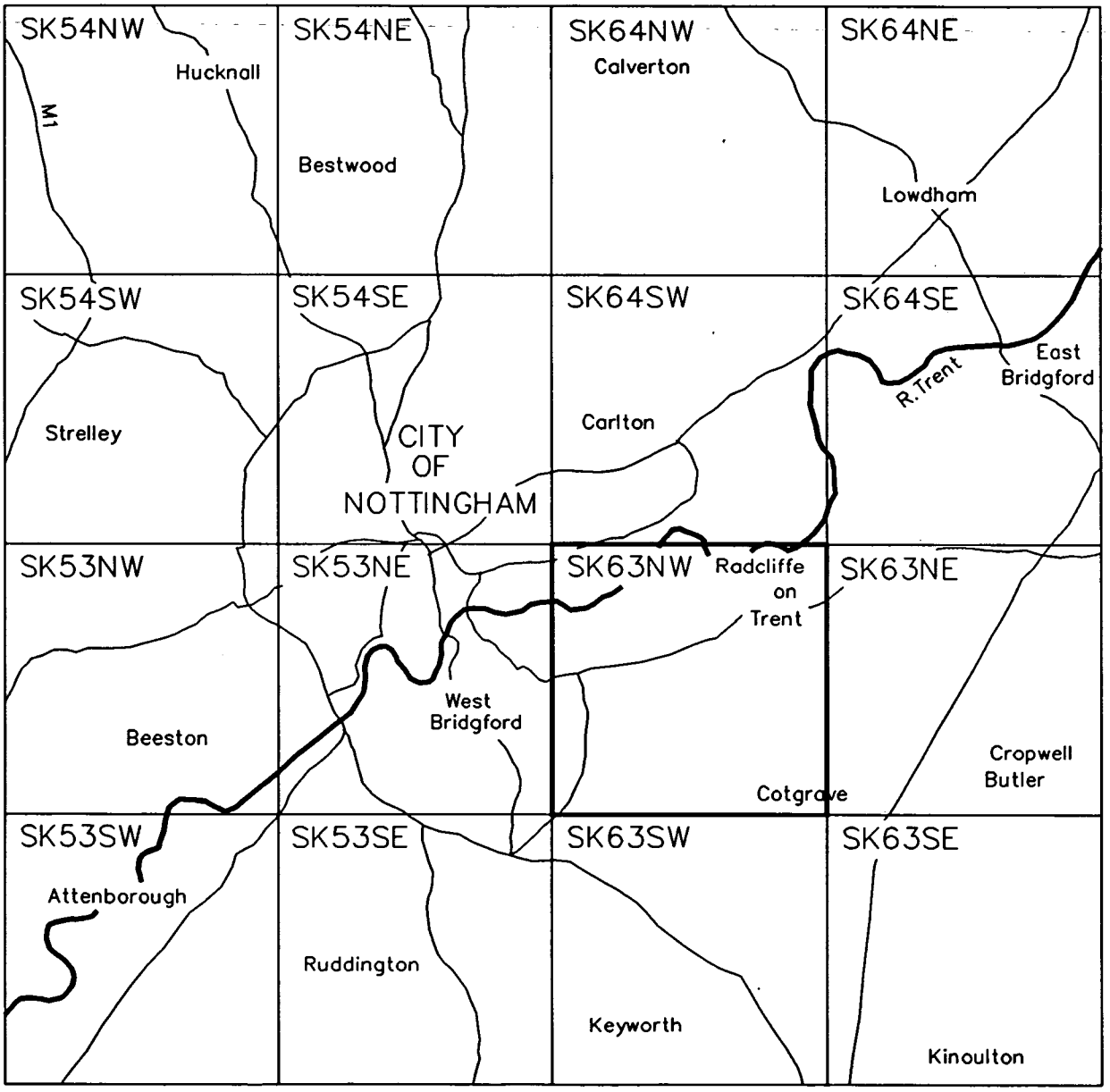


Figure 1. Location map of district (shown with bold outline), in relation to entire Nottingham Project.

undermined. Workings enter the area from the now abandoned Clifton Colliery to the west and from Cotgrave Colliery, with its shafts just east of the district, which is still operative. Large colliery spoil heaps, now partially landscaped and returned to agriculture, dominate the area north of Cotgrave village in the south-east of the district.

British Coal and, to a lesser degree, Tarmac Roadstone Limited, together with light industrial complexes on the southern fringes of Netherfield and Colwick to the north of the district, provide considerable local employment. The district is, however, predominantly agricultural and also includes the small, originally farming, communities of Bassingfield and parts of Tollerton and Gamston. Farming is nowadays mostly arable, but areas of pasture still remain.

Corresponding reports covering contiguous 1:10 000 sheets are:-

SK64SW (Carlton)	Rathbone (1989)
SK53NE (West Bridgford)	Charsley (1989)
SK63NE (Cropwell Butler)	Lowe (1989)
SK63SW (Keyworth)	Crofts (1989)

2 GEOLOGICAL SEQUENCE

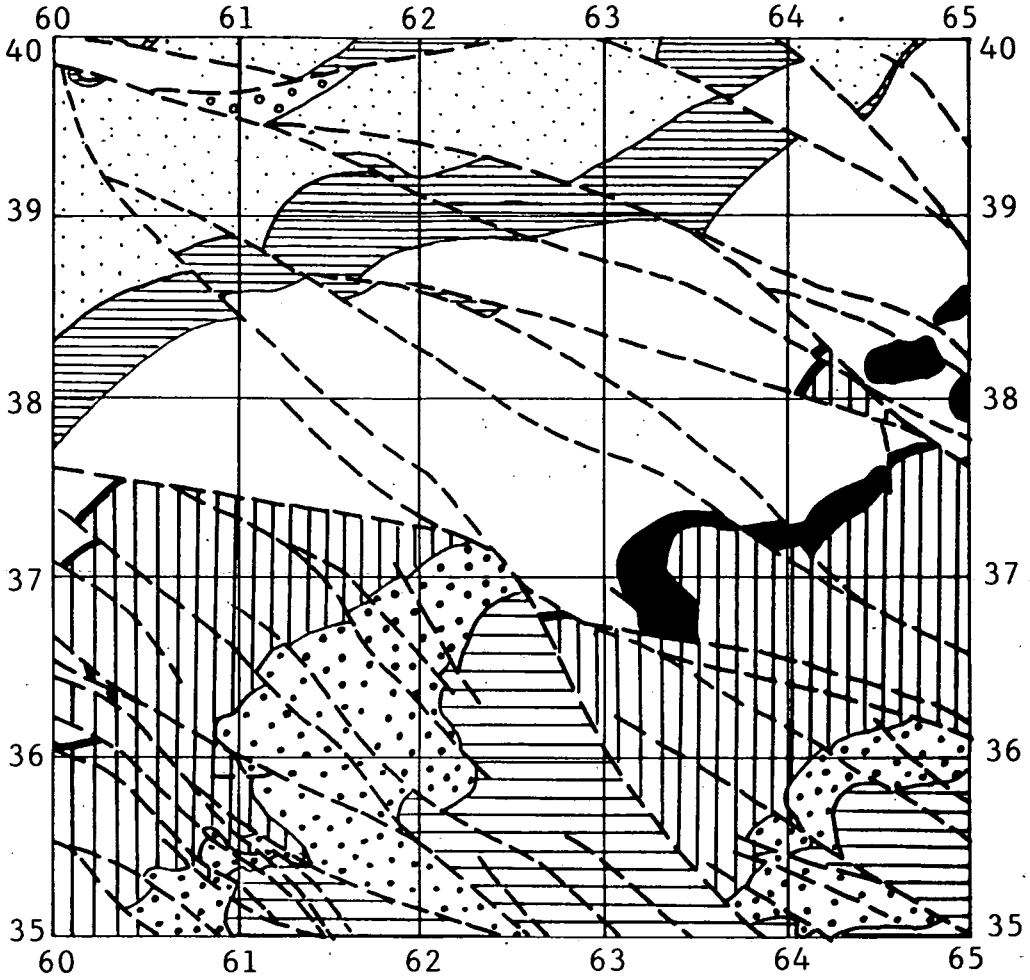
The geological sequence proved, both at outcrop and at depth within the district, is summarised below. Each lithostratigraphical subdivision is described in the following chapters and the generalized disposition of the solid rocks at outcrop is shown in Figure 2.

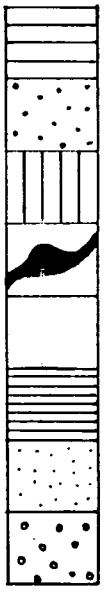
DRIFT

QUATERNARY	Head	
	Alluvium	
	Holme Pierrepont Sand and Gravel	
	Bassingfield Sand and Gravel	
	Lacustrine deposits	
	Sandy till and other undifferentiated complex drift deposits	

SOLID

TRIASSIC	Mercia Mudstone Group	
	Cropwell Bishop Formation	
	Edwalton Formation	
	Hollygate Sandstone Member	
	Undifferentiated	
	Cotgrave Sandstone Member	
	Gunthorpe Formation	
	Radcliffe Formation	
	Sneinton Formation	
PERMO-TRIASSIC	Sherwood Sandstone Group	)
	Nottingham Castle Sandstone Formation	)
	Lenton Sandstone Formation	)
		) proved
PERMIAN	Edlington Formation	)
	Cadeby Formation	) only in
	Permian Basal Breccia	)
		) boreholes
CARBONIFEROUS	Coal Measures	)
	Middle Coal Measures	)
	Lower Coal Measures	)
	Millstone Grit	)
	Igneous Rocks	)





Cropwell Bishop Formation

Hollygate Sandstone Member

Edwalton Formation

Cotgrave Sandstone Member

Gunthorpe Formation

Radcliffe Formation

Sneinton Formation

Nottingham Castle Sandstone Formation

Fault

Figure 2. Sketch map of the solid geology of the Radcliffe on Trent district

3 CARBONIFEROUS

The Carboniferous rocks proved at depth beneath the sub-Permian unconformity range in age from Marsdenian to Westphalian C (Bolsovian), and belong to the Millstone Grit, Lower Coal Measures and Middle Coal Measures. The stratigraphical classification of the Millstone Grit and Coal Measures in the Nottingham area, along with a generalized vertical section showing the main coal seams and marine bands, is simplified in Figure 3. Relationships between standard and local names of the biostratigraphical subdivisions of the Westphalian in the Nottinghamshire area are illustrated in Table 1.

The Carboniferous rocks of the district are known from several deep boreholes, some of which remain confidential, and the account that follows is only a summary of the data available. Details of former coal workings and the confidential boreholes drilled for coal are held by British Coal.

Non-confidential borehole logs can be examined at the BGS.

No palaeontological collecting and only minor re-examination of earlier collections has been undertaken. Readers should refer to the work of Clift and Trueman (1929), Edwards and Stubblefield (1948), Edwards (1951), Eden (1954), Calver (1968) and Ramsbottom and others (1978) for further details.

Little has been written about the Millstone Grit of the district since only limited borehole information has been available. Brief accounts of the strata encountered in the Nottingham area as a whole were provided by Lamplugh and Gibson (1910), Edwards (1951) and Eden (1954). Lamplugh and others (1908) give an early summary of the Coal Measures beneath the district; more detailed accounts of the concealed coalfield were provided by Edwards (1951) and Eden (1954).

Only two boreholes have penetrated into the Millstone Grit and in neither case was the Subcrenatum Marine Band, marking the base of the Coal Measures, recorded, though the horizon of the band is closely controlled by distinctive lithologies above and below. The limited data available show the Millstone Grit to comprise a mainly sandstone sequence. The Rough Rock, a persistent sandstone which elsewhere is found directly underlying the Subcrenatum Marine Band, is separated from a lower major sandstone unit, the Chatsworth Grit, by a thin, predominantly mudstone sequence which includes bands of marine or near- marine fossils. The Chatsworth Grit is underlain by siltstone to the limit of current provings.

The Coal Measures consist predominantly of grey mudstone, siltstone and sandstone, with subordinate coal, seatearth and ironstone, deposited in cyclic sequences. The sandstones are mainly thin, impersistent, fine-grained sheets. Two thicker, more persistent sandstone units have been proved, the Crawshaw Sandstone and the Wingfield Flags. Some thirty-nine named, as well as numerous thin un-named coal seams have been proved, but to date workings in only three seams have extended beneath the district. In the south-west of the area one small panel in the Piper Seam enters from the now abandoned Clifton Colliery which had its shafts on sheet SK53NE to the west (Charsley, 1989a). From the same colliery and at a slightly higher level there are two worked panels within the Deep Hard Seam. Much of the ground between Cotgrave village and Radcliffe on Trent is undermined by Deep Hard Coal workings from Cotgrave Colliery, its shafts on the Cropwell Butler sheet to the east (Lowe, 1989). At the time of survey one panel extending north-westwards towards Nottingham (Tollerton) Airport was the only active working in the district. Two panels worked westwards from Cotgrave Colliery in the Deep Soft Seam penetrate beneath the eastern side of the district.

SERIES	STAGE NAMES		MARINE BAND NAMES	
	STANDARD	FORMER	STANDARD	FORMER
WESTPHALIAN	Bolsovian	Westphalian C	Cambriense Shafton Edmondia	Top Shafton Edmondia
	-M-M-M-M-M-M-M-M-M-M-M-M-M-M-M-M-		Aegiranum	Mansfield
	Duckmantian	Westphalian B	Sutton Haughton Clown Maltby	Sutton Haughton Clown Two-Foot
	-M-M-M-M-M-M-M-M-M-M-M-M-M-M-M-M-		Vanderbeckei	Clay Cross
	Langsettian	Westphalian A	Burton Joyce Langley Amaliae Meadow Farm Parkhouse Listeri Springwood Holbrook	Burton Joyce Upper Band Norton Forty Yard Parkhouse Alton Second Smalley Holbrook
	-M-M-M-M-M-M-M-M-M-M-M-M-M-M-M-M-		Subcrenatum	Pot Clay
NAMURIAN	Yeadonian	Namurian C	Cumbriense	
	-M-M-M-M-M-M-M-M-M-M-M-M-M-M-M-M-		Cancellatum	
	Marsdenian			

Table 1 - Relationships between standard and former names of the biostratigraphical subdivisions of the Westphalian and part of the Namurian in the Nottingham area.

The coals generally cap upward-coarsening sedimentary cycles, and are underlain by gleyed palaeosols ('seatearths'). The sequence is predominantly non-marine, but eight marine or near-marine (*Lingula*) bands, including the Listeri (Alton), Meadow Farm (Forty Yard) Amaliae (Norton), Vanderbeckei (Clay Cross), Maltby (Two Foot), Aegiranum (Mansfield) and Edmondia bands, have been proved (Figure 3). Many non-marine bivalve horizons, together with the (?)Main "Estheria" (*Euestheria*) Band and fish remains have also been proved. Non-marine bivalve horizons are most abundant in Westphalian B (Duckmantian) strata, below the Aegiranum (Mansfield) Marine Band (Table 1); whilst "Estheria" (*Euestheria*) and fish debris are most common in Westphalian A (Langsettian) and Westphalian C (Bolsovian) strata. Plant debris is common throughout the grey measures. Primary red beds, proved in the higher part of the Upper Coal Measures in other parts of the Nottingham area, are not preserved within the district, but the sub-Permian unconformity with associated red staining extends down to the horizon of the Cinderhill Main Coal in the west of the area. Igneous intrusions have been recorded in the Lower Coal Measures, but to date there has been little detailed study of their petrography and morphology.

The depositional sedimentary environments of the Coal Measures have been interpreted as shallow-water delta/lower delta plain during early Westphalian A passing gradationally into upper delta plain conditions in late Westphalian A and continuing as such throughout the majority of Westphalian B (Guion and Fielding, 1988). A reversion to lower delta plain conditions probably began in late Westphalian B, and continued throughout much of early Westphalian C.

In general, sedimentation kept pace with active subsidence of the Pennine Basin, with major faults playing a periodically important role. Marine influence was minimal except when the deltaic environment was periodically drowned by major marine transgressions and more local marine incursions. Coal Measure sedimentology has been the subject of numerous studies, most recently in the Pennine Basin by Guion (1978, 1987) and Guion and Fielding (1988), and is not discussed in detail here.

3.1 MILLSTONE GRIT

A limited thickness of Millstone Grit strata has been proved in the district by two deep boreholes, but the interpretation is complicated and the base of the overlying Lower Coal Measures, conventionally taken at the base of the Subcrenatum Marine Band, is not recorded. In the Cotgrave Bridge Boring (SK63NW/39)[6384 3669] the junction between the Lower Coal Measures and Millstone Grit is possibly faulted, within a predominantly sandstone sequence, at a depth of about 846m. The highest preserved Millstone Grit strata are medium- and coarse-grained sandstones with pebbly layers in the lower part, considered to represent the Rough Rock (Eden, 1954). The upper part of this widespread unit is possibly faulted out, together with an unknown thickness of higher beds including the Subcrenatum Marine Band. Evidence from adjacent areas implies a maximum throw of about 30m for the fault, but the situation revealed in the later Holme Pierrepont Borehole (see below) presents another possibility for the continuous sandstone sequence, in which case a much smaller fault would be probable. The identity of the Rough Rock is fairly certain due to the presence below it of two bands of marine fossils and an underlying Lingula band. The higher marine band, in dark grey mudstone overlying a coal smut and ganisteroid seatearth, includes *Orbiculoidea*, *Lingula*, goniatites and marine bivalves as well as fish remains and is identified as the Cumbriense Marine Band. Only about 3m below, in dark grey mudstone overlying a coaly sandstone and ganisteroid seatearth, *Lingula*,

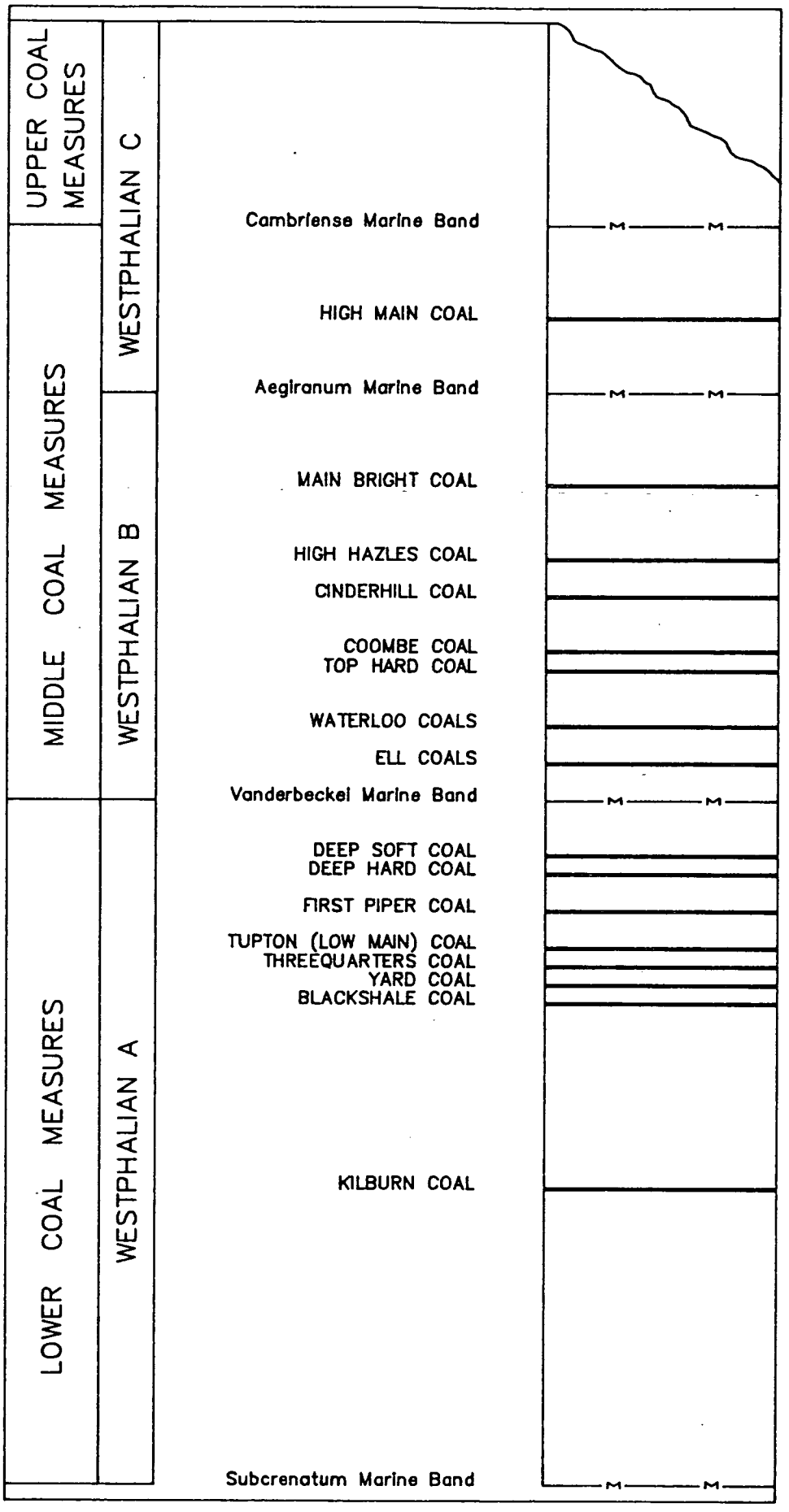


Figure 3. Stratigraphical classification of the Coal Measures of the Nottingham area, along with a generalised vertical section showing the main coal seams and marine bands.

goniatites, bivalves, gastropods and fish remains are probably an impoverished Cancellatum Marine Band fauna. Grey mudstone and siltstone about 4m lower in the core contain *Lingula* and rare fish fragments. Below the *Lingula* band described above, the sequence is essentially arenaceous, comprising predominantly fine-grained sandstone which, by its position relative to the higher marine beds, is identified as the Chatsworth Grit. The base of the Chatsworth Grit is marked by a gradual passage into coarse and then fine siltstone and the lowest beds proved in the borehole are of this latter lithology. The Cancellatum Marine Band marks the division between beds of Yeadonian and Marsdenian age and the oldest rocks in the borehole probably belong to the latter stage, whilst the Yeadonian sequence below the Rough Rock is condensed in comparison to provings farther north and west in the Nottingham area.

In the Holme Pierrepont Borehole (SK63NW/28)[6306 3932] a similar sequence was proved. As at Cotgrave Bridge the Subcrenatum Marine Band marking the base of the Coal Measures is not recorded but here no evidence of a fault was noted in the cores. The original interpretation was that the Subcrenatum horizon and adjacent strata were washed-out within the essentially arenaceous sequence. A marine fauna below the coarse-grained and locally pebbly lower part of this sandstone unit, including *Dunbarella*, *Orbiculoidea*, *Lingula*, goniatites and fish remains, is probably the Cancellatum Marine Band and confirms that the sandstone above is, in part, the Rough Rock. This generally coarse-grained sandstone unit, about 35m in thickness, is overlain by finer beds, mainly of silt grade but with some fine-grained sandstone, assumed to be the basal part of the Coal Measures. Below the Rough Rock, but above the Cancellatum band fauna, are other marine fossils which belong to the Cumbriense Marine Band, as reported for the Cotgrave Bridge Borehole. A bed of dark grey, pyritous siltstone with abundant large *Lingula* and rare gastropods, at a slightly lower level, may indicate an earlier episode of brackish to marine deposition or the earliest sign of the Cancellatum incursion. Whichever of these is the case, the remaining beds proved in the borehole, about 8m of fine-grained sandstone, must be of Marsdenian age and are considered to be part of the Chatsworth Grit. As in the Cotgrave Bridge Borehole, the argillaceous sequence between the Chatsworth Grit and the Rough Rock is probably condensed in comparison to the succession proven in areas to the west.

The similarity of the strata adjacent to the Coal Measures/Millstone Grit boundary, as revealed in the two boreholes discussed above, must leave some doubt regarding the original assumption of a major fault between the Crawshaw Sandstone and the Rough Rock in the Cotgrave Bridge Boring and a non-sequence of some description seems more likely, possibly with a minor fault detected in the cores. Whether this non-sequence is a wash-out of local extent or indicates the edge of a south-easterly failure of the Subcrenatum marine transgression is uncertain. In view of the limited thickness of Millstone Grit proved by the two boreholes considered above, the uncertainty as to the precise nature of the Coal Measures/Millstone Grit junction and the possibility that the nomenclature used in logging the holes almost 40 years ago might be mis- interpreted, it is considered inappropriate to speculate further upon the palaeogeography and depositional environments pertaining in the district during Marsdenian and Yeadonian (late Namurian) times.

3.2 LOWER COAL MEASURES

Despite the uncertainty regarding the precise nature of the Coal Measures/ Millstone Grit contact, as outlined above, it is reasonable to say that the entire Lower Coal Measures succession has been proved in the district. An unbroken sequence of 320m was recorded in the Holme Pierrepont Borehole [6306 3932], but consideration of other incomplete provings indicates that a total

COAL SEAM	MINIMUM THICKNESS(m)	MAXIMUM THICKNESS(m)	MEAN THICKNESS(m) OF INTER-SEAM MEASURES
Vanderbeckei Marine Band overlies Joan/Brown Rake Coal			
Joan	0.1	0.3	)if both recorded, they
Brown Rake	0.1	0.3	)are less than 1m apart
			6.0
Black Rake	0	0.5	
			10.0
Roof Soft	0.2	0.5	
			9.5
Deep Soft	0.7	1.1	
			11.0
Deep Hard	0.9	1.7	
			22.0
First Piper	0.3	0.9	
			9.0
Second Piper	0	0.6	
			16.5
Tupton	0	1.0	
			2.0
Threequarters	0	0.7	
			20.0
Yard	0.3	0.6	
			13.0
Blackshale	0.3	1.0	
			6.0
Ashgate	0.9	1.8	

[Blackshale + Ashgate combined to		2.4]	
			28.0
Mickley Thin	0	0.5	
			24.0
?Morley Muck	0	0.6	
			22.0
Kilburn	0.1	0.2	
			86.0
Norton	0.5	0.6	
			6.0
Forty Yard	0	0.1	
			14.0
Alton	0	0.5	
			13.0
Belperlawn	0	0.5	

Table 2 - Coal seam and mean inter-seam thicknesses.

maximum thickness of 350m is locally present. The base of the Vanderbeckei (Clay Cross) Marine Band marks the top of the Lower Coal Measures; it is a marine band of considerable lateral extent (Ramsbottom and others, 1978).

The cyclical depositional sedimentary environment of the beds has been the subject of many studies; early work and modern studies are well summarised by Guion and Fielding (1988), and this will not be repeated here. Known variations in coal seam thicknesses are given in Table 2, along with the mean inter-seam thicknesses. Up to twenty of the named Nottinghamshire Coalfield seams have been proved within the district, but not all are continuously present across the area. Below the Vanderbeckei Marine Band two thin seams, the Joan and Brown Rake coals, are locally developed, but elsewhere only one coal is recorded and, lacking criteria to differentiate, these are shown as Joan/Brown Rake on the Generalized Vertical Section of the geological map. Two seams, the Blackshale and Ashgate, are locally combined. In the past workings in the (First) Piper Coal and the Deep Hard Coal extended beneath the district from the now abandoned Clifton Colliery to the west. More recently the Deep Soft and Deep Hard coals have been worked from panels extending from Cotgrave Colliery to the east of the district. Only one panel in the Deep Hard Seam was active at the time of the survey.

Four marine or near-marine bands have been proved, the Amaliae (Norton) *Lingula* Band, the Meadow Farm (Forty Yard) *Lingula* Band, the Listeri (Alton) Marine Band and (?)Holbrook *Lingula* Band (Eden, 1954). The Amaliae and Meadow Farm *Lingula* bands contain *Lingula* and micro-fossils. Both bands probably represent only brackish to near-marine conditions. However, the Listeri Marine Band is of regional significance and contains *Lingula*, *Dunbarella*, other marine bivalves, goniatites and fish scales. The next lower band contains only *Lingula* and was considered to represent the Holbrook Marine Band by Eden (1954).

Only two substantial sandstones of regional importance are proved, the Crawshaw Sandstone and the Wingfield Flags. In deep borings at Cotgrave Bridge [6384 3669] and Holme Pierrepont [6306 3932], the Crawshaw Sandstone lies very close to, or in contact with, the Rough Rock, indicating either faulting or a non- sequence (cf Millstone Grit, above). The Crawshaw Sandstone was also proved by a deep borehole at Leahurst Road, West Bridgford (SK63NW/48)[6002 3640] on the western margin of the district, but its base was not reached. A maximum thickness of about 8m is recorded, but this is in a possibly faulted sequence and a greater thickness may be present locally. It consists of white and greyish white, fine- and medium-grained, cross-bedded, generally micaceous sandstone with subordinate layers of grey siltstone.

The Wingfield Flags, somewhat higher in the sequence, have been recognised in the West Bridgford (Leahurst Road), Holme Pierrepont and Cotgrave Bridge boreholes. At West Bridgford about 49m of greenish white, fine-grained, locally conglomeratic sandstone with subordinate siltstone layers is recorded. To the east and south-east there is appreciable thinning however, such that at Holme Pierrepont only about 8m of sandstone overlying 37m of siltstone is recorded and at Cotgrave Bridge a total thickness of 26m of beds which are considered to represent the Wingfield Flags comprise mainly sandy mudstone and muddy sandstone. This south-eastward thinning is confirmed by provings on adjacent sheets.

Higher in the Lower Coal Measures a less widespread sandstone is present close to the level of the Tupton (Low Main) Coal. Up to 26m of arenaceous beds are recorded and the Second Piper, Tupton and Threequarters seams may be locally washed-out. Where at its maximum development this sandstone sequence is probably the equivalent of the Tupton Rock of areas farther north and west.

3.3 MIDDLE COAL MEASURES

An incomplete Middle Coal Measures sequence has been proved by boreholes in the district. The Cambriense Marine Band, which marks the base of the Upper Coal Measures is not recorded, being everwhere cut out by the sub-Permian uncon- formity, but thicknesses between about 150m and 220m of Middle Coal Measures strata are recorded. Erosion of the relatively steeply dipping and locally faulted Coal Measures prior to the deposition of the overlying rocks has produced an overstep situation with the Permian Basal Breccia overlying progressively younger Coal Measure rocks towards the east. The plane of the unconformity lies at stratigraphic levels from just below the Cinderhill Main Coal to just above the Edmondia Marine Band (Figure 3).

The base of the Middle Coal Measures is defined by the Vanderbeckei (Clay Cross) Marine Band (Figure 3). The Vanderbeckei Marine Band contains a goniatite-pectinoid fauna indicating saline conditions, and represents a marine transgression across the delta plain (Edwards and Stubblefield, 1948; Calver, 1968a,b; Ramsbottom and others, 1978; Guion and Fielding, 1988). The Aegiranum (Mansfield) Marine Band has been proved throughout the district except where cut out by the sub-Permian unconformity; it defines the base of Westphalian C (Bolsovian) and represents another major, possibly eustatic, marine trans- gression (Ramsbottom and others, 1978).

The upper delta plain depositional sedimentary environment of the majority of the Westphalian B (Duckmantian) beds is fully discussed by Guion and Fielding (1988), and will not be repeated here. The Vanderbeckei Marine Band represents the only major marine incursion into the upper delta plain. The Maltby (Two Foot) Marine Band, which lies just below the Main Bright Coal, generally contains *Lingula* in the Nottingham area (Edwards, 1951; Edwards and Stubblefield, 1948), suggesting that fully marine conditions were not developed at this horizon (Calver, 1968a,b). Westphalian B faunas between these marine bands are dominated by non-marine bivalves, including *Anthracosia*, *Anthraconaia* and *Naiadites* (Edwards, 1951; Calver, 1968b), indicating fresh to low salinity water conditions. Peat accumulation, ultimately forming workable coal seams, was favoured in this upper delta plain, predominantly fresh water environment (cf Frazier and Osanik, 1969).

A reversion to lower delta plain depositional conditions probably began above the Main Bright Coal, and continued into lower Westphalian C (Bolsovian) age beds, following the return to marine conditions marked by the Aegiranum Marine Band. Slightly higher in the sequence an upward, but diachronous facies change from a deltaic environment to a dominantly alluvial environment with associated coal began above the High Main Coal. This type of alluvial facies association has been fully described by Besley and Fielding (1988), and Besley (1988). The beds above the High Main Coal are characterised by a mainly fresh-water fauna of non-marine bivalves, branchiopods (*Euestheria*), and fish remains.

The periodic return of near-marine or marine conditions is marked in this district by the Edmondia Marine Band and a slightly higher band which contains *Euestheria*. This band is tentatively identified as the Main Estheria Band, but a possibility remains that it is the Shafton Marine Band, which has been identified in areas to the north with an impoverished fauna of *Lingula* and *Euestheria*. Whatever the identity of this higher band, its fauna and that of the Edmondia Marine Band below indicate that fully marine conditions had not developed.

COAL SEAM	MINIMUM THICKNESS(m)	MAXIMUM THICKNESS(m)	MEAN THICKNESS(m) OF INTER-SEAM MEASURES
Edmondia	0	0.7	
			5.0
High Main	0.1	1.2	
			40.0
Main Bright	0.1	1.4	
			6.0
Two Foot	0	0.4	
			16.0
Low Bright	0	0.4	
			12.0
Low Bright Floor	0.5	0.6	
			1.5
Brinsley (upper)	0.4	0.7	
			1.5
Brinsley (lower)	0	0.7	

[above 3 seams locally combined to		2.0]	
			15.0
High Hazles	0.8	1.1	
			13.0
Cinderhill Main	0.2	1.1	
			22.0
Main Smut	0.1	0.3	
			15.0
Coombe	0	0.1	
			3.0
Top Hard (upper)	0.5	1.1	
			1.0
Top Hard (lower)	0.4	0.7	

[above 3 seams locally combined to		2.0]	
			8.0
Blidworth	0	0.3	
			8.0
Dunsil	0.3	0.8	
			9.0
First Waterloo	0	1.2	
			8.0
Second Waterloo	0.6	1.3	
			12.5
Third Waterloo	0.1	0.4	
			20.0
Fourth Waterloo	0	0.6	
			3.5
First Ell	0	0.8	
			16.0
Second Ell	0	0.4	
Second Ell Coal about 15m above Vanderbeckei Marine Band			

Table 3 - coal seam and mean inter-seam thickness

Known variations in coal seam thicknesses are given in Table 3, along with the mean inter-seam thicknesses.

Twenty-one of the named Nottinghamshire Coalfield seams have been proved, some of which are split into an upper and lower leaf, or are themselves a complex of more than one seam. No coal working has been carried out in the Middle Coal Measures beneath the district.

3.4 IGNEOUS ROCKS

Intrusive olivine dolerite sills have been encountered at two horizons in the Lower Coal Measures. No detailed petrography has been carried out on samples recovered within the district, but descriptions provided by Dunham, in Edwards (1951, p.79), of dolerites encountered in the Burton Joyce Borehole on sheet SK64SW, may be applicable (see below).

Two sills were proved by the Cotgrave Bridge Borehole [6384 3669]. The base of the higher intrusion is above the Kilburn Coal, which is itself identified by closely overlying the Wingfield Flags sequence. 39m of green, generally medium-grained 'igneous rock' with sporadic phenocrysts is recorded, the upper and lower margins being fine-grained due to chilling. Mudstone above and below the intrusion is noticeably baked adjacent to the contacts.

The lower sill in the Cotgrave Bridge Borehole is intruded directly below the Alton Coal, the identity of the latter confirmed by the overlying Listeri (Alton) Marine Band. 18m of pale green 'igneous rock' with carbonate veins and included mudstone fragments is proved and, as with the higher intrusion, the margins are chilled and more fine-grained than the central section. A sill, also 18m thick, was proved at the same horizon in the West Bridgford (Leahurst Road) Borehole [6002 3640]. Here the lithology is described only as 'igneous rock', but it is also noted that the Alton Coal has been replaced and coal fragments are present in the upper 2m of the intrusion.

A possible third intrusion, proved to a thickness of 42m in a confidential borehole, is reported as lying below a thin coal seam which is either the Kilburn or the local equivalent of the Morley Muck. The rock is described as green fine-grained dolerite, locally amygdaloidal, with chloritic and carbonate veins. Baked mudstone is recorded above and below the dolerite. Although this intrusion would lie at a different stratigraphic level to those described above if it were below the Kilburn Coal, it is here assumed that it underlies the Morley Muck horizon. The somewhat limited evidence for this assumption is the correspondence of thickness between this sill and the upper sill at Cotgrave Bridge and the fact that the Wingfield Flags sequence is not recorded beneath the thin coal, as would be expected in this area if it were the Kilburn.

The current interpretation is, therefore, that two sills underlie the district, one above the Kilburn Coal and one below the Alton Coal. The lower, sub-Alton, sill is present across the southern half of the district, as confirmed by the West Bridgford and Cotgrave Bridge boreholes, but is not recorded by boreholes in the north. The sill above the Kilburn Coal is present in the south-east, but does not extend as far west as the West Bridgford boring nor as far north as the Holme Pierrepont Borehole [6306 3932], though it is recorded in one confidential borehole between these proven limits.

Dunham (op. cit.) reported two types of olivine dolerite intrusion in the Carboniferous rocks of Nottinghamshire:- an analcite-rich variety allied to teschenite, and a normal type with no alkaline residium. Both types were encountered in the Burton Joyce Borehole in the district to the north (SK64SW)

and the two sills described occupy horizons close, but not identical, to those recorded beneath this district. The upper sill, about 32m thick lies close below a coal seam which is uncertainly identified as the Kilburn (cf the higher sill described above) and is of the teschenitic type. The lower sill at Burton Joyce, about 21m thick, is directly above the Alton Marine Band (cf the sub- Alton sill described above) and is described as a normal olivine dolerite. The similarity of thickness and horizon of the sills proved at Burton Joyce and beneath this district may be coincidental, but if ramifications of the same intrusive bodies are present in both districts, perhaps derived from a magma source situated some distance to the east, an area between the two sets of provings has not been affected. Why this should be the case is uncertain and might imply the presence of a significant contemporary structural barrier to magma movement.

Radiometric K-Ar age dating of two specimens of a similar sill in the Harlequin No.1 Borehole (Francis and- others, 1968), sited to the east of this district, gave ages of 296+/- 15 Ma and 302+/- 20 Ma. Burgess (1982) provided a recent account of the igneous rocks within the Nottinghamshire Coalfield and reported that the balance of available evidence suggests that the sills are of late Carboniferous age.

4 PERMO-TRIASSIC

A phase of deformation (the Variscan Orogeny) followed deposition of the Carboniferous strata, during which the Carboniferous basin sequence was inverted and the Pennines were formed. A long period of erosion took place before significant sediment deposition began again in the late Permian. The Permian Basal Breccia was deposited under continental conditions as a piedmont breccia by in-situ weathering and intermittent fluviatile activity, thus containing fragments derived from distant as well as local sources (Frost and Smart, 1979). The Permian rocks rest with profound unconformity and progressive overlap on a Carboniferous land surface of moderate to low relief.

The overlying Permian rocks in the district appear to represent one major transgressive-regressive depositional cycle. Regionally, the Cadeby Formation strata are considered to be the first transgressive deposits laid down on the western margin of the Zechstein Sea (Cycle EZ1 of Smith and others, 1987), with the overlying Edlington Formation belonging to the succeeding cycle (EZ2 of Smith and others, 1987). However, in this district there appears to be little evidence for a regressive phase within the Cadeby Formation prior to the deposition of the Edlington Formation (Permian Middle Marls). It is possible that only partial EZ1 and EZ2 cycles are present in the district; further regional studies are required to clarify the situation. The Permian rocks above the Basal Breccia are regarded as Upper Permian in age on the basis of miospore taxa from the 'Lower Permian Marl' (Cadeby Formation) (Clarke, 1965).

Aeolian and fluvial deposition of the Sherwood Sandstone Group sediments followed under continuing arid conditions. A further increase in aridity during deposition of the Mercia Mudstone Group strata brought about a change in environments, from fluvial, through fluvio-lacustrine, to arid coastal flats subject to periodic flooding and marine inundation. Gypsum was formed in an environment similar to modern-day continental sabkhas (Aljubouri, 1972).

4.1 PERMIAN BASAL BRECCIA

Basal breccias, possibly ranging in age from early to late Permian, represent the local accumulation of the proximal and distal products of erosion of the post-Carboniferous land surface; they are termed the Permian Basal Breccia. The Basal Breccia is not exposed, but the base of the Permian sequence has been penetrated in some twelve boreholes, three of which are confidential, and the Basal Breccia has been recorded in most of these. Generally it has been poorly described, but the limited data indicate marked variation of lithology and thickness across the district. Locally the breccia may be lacking or unrecognised at the base of a sandstone sequence, but elsewhere it has been recorded as having a sandstone, marly sandstone, silty mudstone or crystalline dolomitic matrix and including angular to subangular fragments and pebbles of Coal Measures 'shales', sandstone, siltstone and mudstone of unspecified age, ?Charnian rocks, quartz, granite and fine-grained igneous material. The colour of the breccia is equally variable and ranges from greenish white and greenish grey, through red-green mottled, to red-brown.

As stated above, the Basal Breccia may be absent locally, but where present thicknesses ranging from 0.1 to about 2m are recorded. An additional record of 4.8m of 'sandstone breccia' in a confidential borehole might be indicative of a somewhat smaller thickness of Basal Breccia overlain by sandy beds or of an aberrantly large thickness of Basal Breccia reflecting a relatively localised build-up of debris.

4.2 CADEBY FORMATION

The Cadeby Formation (Smith and others, 1987) includes rocks formerly assigned to the 'Lower Magnesian Limestone' and 'Lower Permian Marl'. The formation normally includes a predominantly carbonate facies and a predominantly mudstone facies, which are broadly equivalent to the two obsolete lithostratigraphical divisions.

In adjacent areas, the mudstone facies consists of grey, red-brown and yellow, thinly bedded mudstone and siltstone with rare plant remains (Charsley and others, in press). The carbonate facies comprises yellow to reddish brown, sandy dolomite or dolomitic sandstone with subordinate mudstone. Evidence for sporadic episodes of terrestrial deposition exists throughout the formation (Charsley and others, in press).

The formation is not exposed in the district, but the horizon has been penetrated by up to twelve boreholes. Its lithology has been moderately well described in most borehole logs but considerable variation is apparent and it is not possible to identify with certainty the limits of the carbonate and mudstone facies. Nor is it possible in every case to place a boundary between the carbonate facies, which is locally sandy, silty or muddy, and the overlying Edlington Formation on the basis of details recorded in the logs. It is suspected that beds of the latter formation are included with those of the Cadeby Formation in some of the interpretations decribed below.

The lower, mudstone, facies is locally inseparable from the underlying Basal Breccia, as the latter passes upwards into rock types similar to the matrix of the unit below. The lithology most commonly decribed is reddish brown or greenish grey silty mudstone or siltstone, termed 'marl' in older records. At some localities thin layers of dolomite or sandstone, which may be calcareous or dolomitic, are recorded. Fossils including brachiopods, bivalves and plant debris are relatively common. Where identifiable with certainty the mudstone facies is about 1m to 10m in thickness with an apparent increase from south to north across the district. Elsewhere it is uncertain whether the mudstone facies is absent or unrecognised among the beds above and below.

Recognition of the so-called carbonate facies in borehole logs is not everywhere straightforward since locally the rock is, or resembles, a sandstone or coarse siltstone rather than limestone. It is variously described as dolomite, dolomitic sandstone, sandstone or calcareous mudstone and siltstone and in detail all of these lithological elements can be present within this part of the formation. In broad terms a true dolomitic limestone, varying in colour from yellow-brown to pinkish red is present in the north and west of the district and this passes southwards and eastwards into sandstones, siltstones and mudstones with varying amounts of calcareous or dolomitic cement and dolomitic limestone laminae. The purer carbonates are stylolitic and in some cases 'marl' is preserved as an insoluble residue along the stylolitic planes. Poorly preserved fossils, especially brachiopods, are locally common. Although the range of lithologies encountered imposes a degree of uncertainty on placing the top and base of the carbonate facies in some of the boreholes, thicknesses of 4m to 12m may be present, but this upper limit is possibly too great and Edlington Formation strata may be included in the totals.

4.3 EDLINGTON FORMATION

The Edlington Formation (Smith and others, 1987) comprises strata formerly referred to as 'Middle Permian Marl'. Regionally it consists of interbedded red-brown, purple-brown and yellow, silty mudstone and sandstone with subordinate sandy dolomite.

The formation is not exposed in the district. Its horizon has been penetrated by twelve boreholes, but strata which are referrable to the formation are rarely recorded. Only one non-confidential borehole proves the formation with any degree of certainty. About 1.8m of red and grey 'marlstone' was logged in the Cotgrave Bridge Borehole [6384 3669] overlying Cadeby Formation strata, but here, as elsewhere in the district, it cannot be adaquately demonstrated that these beds are not a terrigenous component of the Cadeby Formation. Other boreholes prove siltstone with mudstone layers, sandstone with 'marly' streaks and dolomitic sandstone overlying definite Cadeby Formation strata, but it remains uncertain to which formation these beds belong. It can be shown that the Edlington Formation is absent locally (eg the Holme Pierrepont Borehole, 6306 3932). With the limited data available, particularly the uncertainty regarding the status of the non-carbonate strata tentatively assigned to the Cadeby Formation (above) it is impossible to provide a definite maximum thickness for the formation. It probably thickens to the east, and is unlikely to exceed 4m in thickness, but could feasibly total about 12m if beds otherwise attributed to the Cadeby Formation are included or in sequences where the Edlington Formation grades upwards into beds of the Sherwood Sandstone Group.

4.4 SHERWOOD SANDSTONE GROUP

The Sherwood Sandstone Group (formerly 'Bunter Sandstone' and 'Keuper Sandstone') is not exposed in the district, but a small outcrop is conjectured beneath the drift deposits of the Trent floodplain (Figure 2), on the basis of the thickness and attitude of overlying strata as proved in a number of boreholes.

The Group is divided into the Nottingham Castle Sandstone Formation (formerly the 'Bunter Pebble Beds') and the Lenton Sandstone Formation (formerly the 'Lower Mottled Sandstone'). Correlation of the presently used lithostratigraphy with that of previous workers is summarised in Table 4.

The rocks of the Group indicate a gradual, but increasingly important change to fluvial conditions following the late Permian shallow marine and continental deposition. The Lenton Sandstones conformably overlie the Edlington Formation and the Nottingham Castle Sandstones are overlain disconformably by rocks of the Mercia Mudstone Group. In the East Retford district to the north, Smith and others (1973, p.105) have placed the lower limit of the Triassic System at the base of the 'Pebble Beds' (Nottingham Castle Sandstone); this apparently arbitrary placement may be equally applicable in the Nottingham area. The Nottingham Castle Sandstone is believed to be of Scythian age in the Nottingham area (Warrington and others, 1980); the age of the Lenton Sandstone is not certain. The apparently gradational passage from the Edlington Formation to the Lenton Sandstone in the region is discussed by Frost and Smart (1979).

Suggestions that the Nottingham Castle Formation was deposited by a major northward flowing river (Wills, 1956; Taylor, 1974) have been refuted by Bryant and Burley (1986). In the Nottingham area, Bryant and Burley (1986) report dominantly north-easterly and easterly directed palaeocurrents, and suggest derivation of the sandstones from uplands to the west via a series of alluvial fans. However, they propose no original source for abundant well-rounded quartzite pebbles within the Group; nor do they explain the overall lack of pebbles of Carboniferous and Permian age, if the sediments were ultimately derived from the west. A compromise is provided by the palaeo-geographical reconstruction (Audley-Charles, 1970) which indicates major detritus movement into the Midlands area from the south via the

Worcester graben, with a (possibly periodic) bifurcation of flow towards the north-west (into the Irish Sea graben) and towards the east (into the North Sea basin). Thus, pebbles sourced in northern France would reasonably be found in alluvial fan sequences bearing evidence of west-east palaeocurrents and the absence of a significant amount of westerly sourced pebbles is more readily acceptable.

4.4.1 LENTON SANDSTONE FORMATION

In the Nottingham region, the Lenton Sandstone consists of vivid red-brown and orange-brown, sporadically mottled yellow, fine- to medium-grained, friable sandstone. It is commonly argillaceous and locally pebbly and is interbedded with subordinate red-brown and grey-green silty mudstone. Its age is uncertain; the lower parts at least are Permian, higher beds are probably Permian, but deposits of Triassic age could be present towards the top of the formation.

The formation is not exposed in the district but it has been penetrated by numerous boreholes. Lithological descriptions are poor and it is rarely possible to recognise the upper or lower boundaries with certainty. The more reliable records indicate a minimum of 9.5m and a maximum of about 18m for the Lenton Sandstone but lesser or greater thicknesses could be unrecognised locally.

4.4.2 NOTTINGHAM CASTLE SANDSTONE FORMATION

The Nottingham Castle Sandstone consists almost entirely of sandstone with extremely subordinate conglomerate, siltstone, and mudstone. The sandstone is predominantly buff to red-brown, medium- to coarse-grained, poorly sorted, moderately friable and almost invariably cross-bedded. Pebbles, particularly quartzite and quartz pebbles, occur scattered throughout, commonly aligned along foreset laminae or concentrated on scour surfaces to form conglomeratic bases to some beds.

The formation is not exposed in the district and nor is it confirmed to subcrop beneath drift deposits, but a small outcrop is conjectured beneath the Trent floodplain on the evidence of the sequence and structure proved in adjacent boreholes. The formation is proved at depth by many boreholes and, as with the Lenton Sandstones, there is local uncertainty over the precise lower and, to a lesser degree, upper limits of the unit. Where these limits are clearly defined an average thickness of about 75m of Nottingham Castle Sandstone is present. Where the boundary between the Lenton Sandstone and Nottingham Castle Sandstone is less clear, combined thicknesses of 86m to 106m have been recorded and it seems most likely that much of this variation is within the Lenton Sandstone.

4.5 MERCIA MUDSTONE GROUP

The term Mercia Mudstone Group was introduced by Warrington and others (1980) as an approximate replacement for 'Keuper Series', a term which had acquired mixed chrono- and lithostratigraphical connotations and had hence become unsatisfactory. In Nottinghamshire, the boundaries of the Mercia Mudstone Group correspond exactly with those of strata formerly considered part of the 'Keuper Series'. The history of stratigraphical subdivision of the Mercia Mudstone in the Nottingham area is illustrated in Table 4. Elliott (1961) proposed a scheme with a number of formations which could be identified mainly on the evidence of structures visible in borehole cores. The scheme was a significant advance in the treatment off Triassic lithostratigraphy and was adopted with or without minor modifications by other workers. The recent

MIDLANDS HULL (1869)		NOTTINGHAM LAMPLUGH AND OTHERS (1908/10)	NOTTINGHAM SWINNERTON (1918) SMITH (1912)	NOTTINGHAM ELLIOTT (1961)		NORTHEASTERN MIDLANDS KENT (1968)		NOTTINGHAM WARRINGTON AND OTHERS (1980)		NOTTINGHAM PROJECT (1989)	
KEUPER	Rhaetic or Penarth Beds	"White Lias"/ Upper Rhaetic		KEUPER		UPPER RHAETIC	Cotham Beds	PENARTH GROUP	Lilstock Formation Cotham Member	PENARTH GROUP	Lilstock Formation Cotham Member
		Avicula contorta shales				LOWER RHAETIC	Westbury Beds		Westbury Formation		Westbury Formation
	NEW RED MARL	Tea Green Marl			Parva Formation			MERCIA MUDSTONE GROUP	Blue Anchor Formation	MERCIA MUDSTONE GROUP	Blue Anchor Formation
		KEUPER MARL							Glen Parva Formation		Cropwell Bishop Formation
					Trent Formation				Trent Formation		
					Hollygate Skerries				Hollygate Skerries		Hollygate Sandstones
					Edwalton Formation				Edwalton Formation		Edwalton Formation
					Cotgrave Skerry				Cotgrave Skerry		Cotgrave Sandstone
					Harlequin Formation				Harlequin Formation		Gunthorpe Formation
					Carlton Formation				Carlton Formation		
					Radcliffe Formation				Radcliffe Formation		Radcliffe Formation
	Waterstones	Keuper Waterstones	Keuper Waterstones		Waterstones				Colwick Formation		Sneinton Formation
	Building Stones										
	Basement Beds		Keuper Basement Beds		Woodthorpe Formation				Woodthorpe Formation		
BUNTER	Upper Red and Mottled Sandstone	Bunter Pebble Beds	BUNTER	BUNTER				SHERWOOD SANDSTONE GROUP	Nottingham Castle Formation	SHERWOOD SANDSTONE GROUP	Nottingham Castle Sandstone Formation
	Conglomerate or Pebble Beds										
	Lower Red and Mottled Sandstone	Lower Mottled Sandstone							Lenton Sandstone Formation		Lenton Sandstone Formation

Table 4. Summary of the lithostratigraphy of the Sherwood Sandstone, Mercia Mudstone and Penarth groups of the Nottingham area

resurvey of the Nottingham area by officers of the BGS has shown that only two of Elliott's proposed sub- divisions, the Radcliffe and Edwalton formations, are mappable at the surface throughout the Nottingham area. The others are not mappable individually or only traceable locally. Accordingly, a revised stratigraphical treatment of the sequence (Table 4) has been proposed (Charsley and others, in press) and is adopted in this report.

The nature of the base of the south Nottinghamshire 'Keuper' sequence (now Mercia Mudstone Group) has been discussed in detail by Lamplugh and others (1908), Swinnerton (1918) and Elliott (1961). It is marked by the upward change from coarse sandstone into interbedded sandstone and mudstone lithologies. The average thickness of the group is 225m in the Nottingham area (Elliott, 1961). A good reference section, illustrating the base of the group, is exposed at Sneinton and has been described by Lamplugh and others (1908) and Charsley (1989a). The group is believed to range from Anisian to Rhaetian in age in the Nottingham area (Warrington and others, 1980).

The Mercia Mudstone Group consists predominantly of red with subordinate green, commonly silty mudstone and siltstone, with calcareous or dolomitic cements in places. Sandstone occurs mainly in the lower part of the group (Sneinton Formation), although thin well-cemented sandstone or siltstone beds (locally termed 'skerries') occur throughout the sequence. The term 'skerry' has been used in geological literature for grey and green-grey sandstone and siltstone, lithologically distinct from the red-brown mudstone comprising the bulk of the group. During the present survey, indurated beds of red-brown mudstone and siltstone, commonly associated with grey-green siltstone and sandstone, have been recognised and mapped by the features they produce. These beds are, for the purpose of the present work, termed 'skerries'. They are not sufficiently distinctive to make them individually identifiable.

Vein and nodular gypsum is common throughout much of the group, but is most abundant towards the top (Cropwell Bishop Formation).

The full sequence of Mercia Mudstone Group formations, with the exception of the Blue Anchor Formation at the top, is at outcrop in the district. Approximately 190m of strata occur at crop; thicknesses of individual formations are laterally variable.

4.5.1 SNEINTON FORMATION

The Sneinton Formation (Charsley and others, in press) is the approximate equivalent of the 'Keuper Waterstones' of Lamplugh and others (1908), which they recognised as a mappable division between the 'Bunter Pebble Beds' and the 'Keuper Marl'. However, other workers recognised two or more subdivisions in this part of the sequence (Table 4), restricting the term 'Waterstones' to the upper part and terming the lower part 'Keuper Basement Bed'. These two units were later renamed the 'Colwick Formation' (Warrington and others, 1980) and 'Woodthorpe Formation' (Elliott, 1961) respectively. BGS mapping in the Nottingham area has been unable to separate these two formations. Consequently, they have been combined as a single unit, the Sneinton Formation; the base, and an almost complete section of the formation are exposed in Sneinton, in east- central Nottingham (Charsley, 1989a). The average thickness of the formation in the Nottingham area is 45m (Elliott, 1961), but in the Radcliffe on Trent district the maximum recorded thickness is 34m.

The formation consists of interbedded fine-grained sandstone, siltstone and mudstone, with subordinate pebbly sandstone; the beds are mainly red-brown and brown-grey, but less commonly grey-green. Micaceous laminae, ripple marks and

cross-lamination are common throughout. Locally the base is marked by a development of pebbly sandstone characterised by small quartz pebbles.

In adjacent areas to the north it gives rise to an incised, undulating surface topography, in which the more prominent sandstones can be usefully feature mapped in part, but here the more extensive outcrops (Figure 2) are drift covered and the formation is visible only in partly artificial sections along old river bluffs north of the Trent. The strata weather to a very silty loam, which is locally very sandy. The formation has formerly been quarried on a small scale for building stone (see Section 7.4).

Overall exposure is poor. The best sections occur in a disused quarry [6006 3974] and active railway cutting in the north-west of the district. The top of the former is inaccessible and the loose nature of the face makes detailed examination both difficult and hazardous; the following general section was recorded:-

	Thickness(m)
Radcliffe Formation (mainly inaccessible)	
Mudstone and siltstone, red, green and pink, finely laminated; thickness estimated	c.2.0
Sneinton Formation	
Sandstone, red-brown, fine- to medium-grained, interbedded with mudstone, red-brown, sandy. Thin beds and laminae of green siltstone at irregular intervals throughout; sandstone beds thicker towards base of section. Top not accessible; thickness estimated	c.7.0

The face of the old quarry passes into a railway cutting to the east and the smaller thickness of strata exposed includes the junction between the Radcliffe and Sneinton formations. Proximity to the busy railway line and the danger of falling debris make detailed examination inadvisable. Somewahat farther to the north-east, beyond a downfaulted section of Gunthorpe Formation strata, the upper beds of the Sneinton Formation are again exposed and may be examined in small cliffs/cuttings [6055 3996] which are approachable from the north and fenced off from the active railway line. The following short section was measured:-

	Thickness(m)
Radcliffe Formation (top inaccessible)	
Mudstone and silty mudstone (? as below); estimated	c.1.50
Mudstone and silty mudstone, red-brown and pink with some grey-green, well laminated, with thin beds of grey-green siltstone; less well laminated and more red-brown towards base	1.20
Sandstone, pale brown, fine-grained, vaguely laminated near top, unlaminated in lower half	0.18
Mudstone, silty, and siltstone, interlaminated with fine-grained sandstone, mainly deep red-brown with pinkish red, micaceous sheen on bedding planes. Very finely laminated siltstone, dark brown and green, at base	2.10

Sneinton Formation

Sandstone, green, fine-grained, with crude lamination and micro-vuggy weathering, passing down by intercalation with dark brown silty mudstone	c.1.00
Mudstone, silty and sandstone, fine- to medium-grained, interbedded, red-brown with discontinuous green bands. Sandstone beds to 0.1m become more common downwards, with massive bed 1.4 to 1.8m down	3.60
Sandstone, red-brown, fine- to medium-grained, individual beds 0.1 to 0.2m thick; base not seen	1.20+

No further exposures are recorded within the district, but it is considered probable that a massive bed of grey-green, fine- to medium-grained sandstone visible at or just below water level at the foot of the river cliff at Radcliffe on Trent [c.6461 3987] is the highest sandstone of the Sneinton Formation (cf Radcliffe Formation, below).

The Sneinton Formation has been proved in its entirety by numerous boreholes across the district. In detail considerable internal variation is displayed by the various sequences recorded, but overall the lithological elements remain constant and distinctive. Small scale sedimentary structures noted at outcrop and in borehole cores are discussed in detail by Elliott (1961).

Fossils recorded from the Sneinton Formation in the Nottingham area include rare *Lingula*, fish, trace fossils and plant debris as well as palynomorph assemblages possibly indicative of Anisian age (Warrington and others, 1980). No fossils are recorded from the Sneinton Formation in the Radcliffe on Trent district.

4.5.2 RADCLIFFE FORMATION

The term Radcliffe Formation was introduced by Elliott (1961). A good section in the Trent river cliff at Radcliffe on Trent is defined as the type; it is described in detail below.

The formation consists of red-brown, pink and grey-green, laminated mudstone, siltstone and subordinate fine-grained sandstone, with rare thicker beds of fine-grained sandstone. Common sedimentary structures include pseudomorphs after halite, desiccation cracks, water/gas escape structures and wave ripples. The average thickness of the formation in the Nottingham area is 12m according to Elliott (1961); it is known to thicken to the east (Charsley and others, in prep.) and thicknesses of 11.5 to 13.6m are recorded in this district.

The formation crops out across the northern part of the district (Figure 2), most of the outcrop being covered by alluvial deposits of the River Trent. Exposures are found only in the river cliffs at Radcliffe and the old quarry and railway cutting east of Colwick Wood (cf Sneinton Formation), and these exposures are today less accessible and more overgrown than formerly.

The type section for the formation in the river cliffs at Radcliffe on Trent is a composite of two closely adjacent and probably overlapping sections [c.6461 3987]. A highly detailed measurement of the sections was carried out by R.E. Elliott and D.Raisbeck in 1956. This is recorded in BGS files (SK63NW/335) and reproduced here using mainly the original nomenclature, but with thicknesses metricated and including the current interpretation of the boundary positions:-

Thickness(m)

Southern section

Gunthorpe Formation

Marl, reddish brown with few green patches, silty, with many gypsum veins to 75mm thick; top not seen — c.3.05+

Marl, reddish brown, silty, sandy in parts, interbedded with fine-grained marly sandstone, light green with reddish brown patches:

sandstone	c.0.15m		
marl	c.0.46m		
sandstone	c.0.13m		
marl	c.0.13m		
sandstone	c.0.33m		
marl	c.0.28m		
sandstone	c.0.08m	passage base	c.1.55

Marl, reddish brown with small green patches, slightly sandy; base not seen — c.0.61+

Possible gap between sections, estimated — c.0.90

Northern section — Thickness(m)

Gunthorpe Formation (continued)

Marl, reddish brown, with many irregular gypsum veins; inaccessible, thickness estimated — c.0.76

Radcliffe Formation

Marl, green and reddish brown, banded — c.0.15

Marl, reddish brown with irregular gypsum veins — c.0.61

Marl, green and reddish brown, banded — c.0.61

Marl, reddish brown with irregular gypsum veins — c.0.79

Siltstone, pale brown becoming pale green laterally, coarse, well laminated, with marl laminae and lenses, few thin gypsum veins — c.0.61

Marl, reddish brown, silty, well laminated, with many layers of coarse siltstone (to 25mm) and few gypsum veinlets — c.0.63

Siltstone, pale brown, coarse, well laminated, with chocolate brown marl laminae towards top and base, rippling, salt pseudomorphs, few gypsum lenses near passage base — c.0.50

Marl, deep reddish brown, few gypsum nodules and veinlets; interlayered junction — c.0.25

Sandstone, light green, fine-grained, loosely cemented, unlaminated; mottled passage base — c.0.18

Sandstone, marly, passing down to light reddish brown marl, passing down to dark reddish brown marl, unlaminated — c.0.25

Sandstone, pale green, fine-grained, rippled, interbedded with reddish brown silty marl:

sandstone	c.24mm
marl	c.61mm
sandstone	c.49mm
marl	c.114mm
sandstone	c.76mm
marl	c.49mm
sandstone	c.49mm

interfingering at base — c.0.42

Marl, chocolate brown, minor bright green mottling, purplish tint, silty near base, gypsum lenses to 25mm, passage base c.0.15

Siltstone, pale brown, fine, and reddish brown silty marl, interlayered and interlaminated, some micaceous planes; interlaminated base c.0.41

Marl, chocolate brown and siltstone, pale brown, fine, interlaminated, well laminated; a layer near the top is buckled at intervals of about 0.45m; sharp base c.0.30

Siltstone, coarse, and pale brown and chocolate brown marl, interlayered and interlaminated; sharp base c.0.18

Marl, chocolate brown and pale brown passing down to purplish brown and light green, well laminated, with many silty laminae, thin gypsum lenses; interlaminated base c.0.20

Marl, light green and pale brown with some chocolate brown, purplish in parts, silty, with sporadic siltstone layers, finely laminated and layered, rippling, salt pseudomorphs in lower half; sharp irregular base c.0.48

Siltstone, coarse, lighter brown sandy layers, darker brown marly layers, laminated in parts, sugary gypsum layers near top, few thin chocolate brown marl laminae, little mica; passage base c.0.46

Siltstone and well laminated marl, interlayered and interlaminated, all grades from chocolate brown marl to pale brown very fine sand, few pale green laminae, gypsum nodules in lower half, sporadic gypsum lenses to 25mm thick, lower 0.90m poorly exposed c.2.59

Marl, reddish brown, pale green patches, sandy lenses, vague laminae in parts; passage base c.0.48

Marl, dark reddish brown, green in parts, silty, vague laminae c.0.28

Siltstone, pale greenish grey, coarse, well cemented, few thin marl layers, reddish brown, few marl laminae and flecks c.0.48

Marl, reddish brown, well laminated, silty laminae and layers, micaceous sheens c.0.46

Siltstone, greenish grey, with layers of reddish brown silty marl c.0.61

[probable base of Radcliffe Formation: see below]

The original record ends the section at river level, but inspection during the present survey revealed the upper surface of a massive sandstone bed normally below water. A small unrecorded thickness of strata might intervene between the lowest Radcliffe Formation beds as described above and the upper surface of the massive, grey-green, fine- to medium-grained sandstone, which is considered to be the highest unit of the Sneinton Formation.

To avoid possible conflict between two different records of this important type section remeasuring and redescription were not undertaken. The term 'marl' as used above would be replaced by either mudstone or silty mudstone in modern usage, but otherwise it seems unlikely that the description by the original author on the Radcliffe Formation could be bettered. Rapid examination revealed that the quality of the section had deteriorated due to weathering, soil creep and vegetation, but the main lithologies of the Radcliffe Formation may still be examined here and in less complete sections to the north where the old river cliff veers away from the present river course. The top of the formation is not well exposed but may generally be interpreted to lie at or just above the top of the vertical to sub-vertical

cliffs of interlayered and interlaminated strata, above which the hillside is far gentler, with scattered exposures of blocky reddish brown mudstone.

On the north side of the Trent the Radcliffe Formation is exposed in the upper part of the old quarry east of Colwick Wood and in cuttings to the east and north east of this locality. With the exception of the two exposures described in the Sneinton Formation section (above) access is difficult and hazardous. Additionally the Radcliffe Formation is proved by many boreholes and the distinctive laminated lithology has provided a recognisable marker horizon to aid interpretation of the sub-drift stratigraphy and structure.

4.5.3 GUNTHORPE FORMATION

Elliott (1961) recognised two subdivisions, the Carlton and Harlequin formations, between the Radcliffe Formation and the Cotgrave 'Skerry' (Table 4). The boundary between his two units was drawn - on sedimentological grounds - immediately above the uppermost occurrence of distinctive 'flow-type' breccias. This level lies approximately 3m above a thin resistant feature-forming horizon which was believed by Smith (1913) to form the extensive plateau of Mapperley Plains in north-east Nottingham. Elliott (1961) named this resistant bed the 'Plains Skerry'. Recent mapping by officers of the BGS, as part of the Nottingham Project, has shown that a package of several resistant dolomitic siltstones and sandstones occur around the horizon of the 'Plains Skerry', and that the Mapperley Plains plateau cannot be attributed singly to any one of them. Furthermore, the 'Plains Skerry' cannot be differentiated from other similar resistant beds in exposed sections. In the absence of a distinctive mappable marker horizon, it has not proved possible to distinguish between the upper part of Elliott's Carlton Formation and the Harlequin Formation. A single mappable formation, the Gunthorpe Formation, has therefore been established (Charsley and others, in press) to encompass the former Carlton and Harlequin formations. The name is derived from Gunthorpe Weir, where a section of the middle part of the formation is exposed (Rathbone, 1989b).

The formation consists of interbedded red-brown and subordinate grey-green mudstone, siltstone, and very fine-grained sandstone. The beds can be assigned to a blocky facies - comprising mudstone and siltstone, and a thinly bedded and laminated facies - comprising mudstone, siltstone, and sandstone. These facies types, and their probable depositional environments, have been detailed by Arthurton (1980) and further details are not given here.

The formation includes thick units of blocky, silty mudstone which have been widely exploited for brick clay in parts of the Nottingham area. Indurated, sporadically feature-forming, dolomitic siltstones and fine-grained sandstones ('skerries') occur at many levels; they are particularly numerous c.15-25m above the base of the formation in some areas but none can be individually identified as the 'Plains Skerry'. Halite pseudomorphs, rarely up to 30mm across, but typically much smaller, and desiccation cracks are common throughout the laminated facies. The base of the formation may be gradational over a few decimetres. An average thickness of 67m in the Nottingham area (Elliott, 1961) is in close agreement with the thickness proved in this district, but the formation is commonly up to c.80m thick in the Nottingham Project area (Charsley and others, in press).

Soils associated with the 'skerries' almost invariably contain brash of grey-green siltstone and/or very fine-grained sandstone. The siltstones and sandstones are commonly cross-laminated and, where capped by mudstone, show well preserved low amplitude ripple marks, many with a wavelength range between 20-100mm and amplitude range from about 2-8mm. Fairly high amplitude climbing

ripple lamination, ripple collapse structures, and load structures are also preserved in many sandstone fragments (Rathbone, 1989a,b).

The majority of the Gunthorpe Formation outcrop (Figure 2) is covered by the alluvial deposits of the River Trent and older drift deposits. Where more or less drift-free it forms gullied undulating slopes. Tops of hills capped by the Gunthorpe Formation are commonly extremely gently rounded, almost flat and have the appearance of dip-slopes. However, detailed augering in the rural areas, and observations of temporary diggings in the urban areas have proved that in general these hills are capped by soft red-brown silty mudstone above the feature-forming 'skerries`. The mudstone cap is, in part, up to c.1m thick, but it is commonly thinner and in places scattered pieces of the green siltstone or fine-grained sandstone have been ploughed to the surface. The landscape has simply not yet fully matured. The strata weather to produce a fairly heavy, but fertile, silty clay soil.

The Gunthorpe Formation crops out extensively throughout the central part of the district, but exposure is poor.

In the north-west corner of the district Gunthorpe Formation strata are exposed in a railway cutting where they are faulted down between Radcliffe/Sneinton formation beds to the north and south. The sequence dips very gently towards the cutting and only a small thickness of generally similar beds is visible. The position of these beds within the formation is unknown, the top and basal contacts being nowhere exposed. A typical section of beds at [6025 3976] comprises the following:-

	Thickness(m)
Gunthorpe Formation (top inaccessible)	
Mudstone, red-brown, blocky	0.30+
Siltstone, grey-green, very thinly bedded	0.15
Mudstone, red-brown, silty, blocky	0.45
Siltstone and silty mudstone, grey-green but including some red-brown, irregularly very thinly interbedded and interlaminated, with mud cracks, salt pseudomorphs and cross lamination	1.00
Siltstone, grey-green, convolute bedding	0.12
Mudstone, red-brown, silty, blocky, with thin bands of grey-green siltstone in top 0.24m and band of indurated siltstone (0.04) near base	1.80+

Gunthorpe Formation strata form the upper part of the river cliff at Radcliffe on Trent, but with the exception of the beds overlying the Radcliffe Formation type section (described above), no worthwhile exposures are available. South of the river cliff the Gunthorpe Formation forms a pseudo dip-slope above a marked 'skerry` feature but no exposures are present. Augering has proved the following general sequence [c.6482 3982]:-

	Thickness(m)
Soil and head	
Soil, dark brown, clayey with sand grains	0.20
Clay, brown, locally yellow, sandy, structureless	0.10
Clay, orange-brown, locally reddish brown, sandy	0.20
Clay with sand, reddish brown, aggregates of pale green fine sand, mainly weathered mudstone as below	0.30

Gunthorpe Formation

Mudstone, reddish brown, vaguely laminated, some paler layers and aggregates and grains of pale green fine to medium sand	0.20
Interlaminated pale green siltstone or fine-grained sandstone and pale reddish brown mudstone. More massive and predominently siltstone to base (?'skerry`)	0.20
Mudstone. reddish brown, structureless	0.20+

Somewhat farther south the topography cuts back below the level of the 'skerry` feature and a number of shallow trenches on a small building plot [6468 3945] provided the following poor composite section:-

	Thickness(m)
Head	
Clay, brown, sandy, with stones	0.50
Gunthorpe Formation	
Mudstone, red-brown, slightly sandy, with thin beds of green siltstone and laminae of fine-grained sandstone	0.50+

South and south-west of Radcliffe many drainage ditches in a flat and mainly drift covered area have been excavated down to the level of the Gunthorpe Formation, but generally only a weathered upper surface of red-brown or, in places, green mudstone is visible. An inaccessible steep stream bank south of Stragglethorpe sewage works [6423 3789] reveals an estimated 0.5m of reddish brown, purplish red and green, poorly laminated mudstone overlain by drift deposits and made-ground.

To the south-east the land rises fairly steeply above the drift covered flat and small sections of the higher beds of the Gunthorpe Formation were provided by temporary excavations into the hillside below North Farm. The lower of these [6430 3756] revealed:-

	Thickness(m)
Soil and thin clayey **head**, red-brown, pebbly	0.40
Gunthorpe Formation	
Mudstone, red, blocky (maximum thickness)	1.00
Siltstone, green, massive top, laminated base	0.10
Mudstone, reddish brown, alternating with green siltstone and green mudstone (Harlequin facies)	0.20+

Somewhat higher up the bank to the south-east [6439 3757] the second excavation showed:-

	Thickness(m)
Gunthorpe Formation	
Mudstone, red, blocky, weathered	0.20
Mudstone, green, with subordinate red, blocky layers; thins to north (maximum thickness)	0.20
Mudstone, red, slightly silty, blocky	0.40
Siltstone/silty mudstone, green	0.05
Mudstone, red, blocky, with bands and patches of green mudstone	1.50+

The beds described in the latter section are probably the lower part of a c.6m thick bed of relatively homogeneous blocky mudstone which forms the uppermost part of the Gunthorpe Formation and which has been worked throughout the area as a brick clay and agricultural 'marl`.

Elsewhere in the district the weathered upper surface of the Gunthorpe formation is present in a number of stream beds and drain floors but the exposures reveal only blocky red-brown or, rarely, green mudstone, with or without thin siltstone interbeds. Similarly past gravel workings in the Trent valley have cut down into the upper surface of the formation, exposing only weathered blocky mudstone with sporadic thin beds of soft or indurated green siltstone. Most such exposures are now lost to backfilling, flooding or landscaping, but workings active at the time of survey around [6074 3782] showed about 1.0m of blocky red-brown mudstone with irregular green bands and patches, typical of the middle part of the Gunthorpe Formation.

As mentioned above the uppermost part of the Gunthorpe Formation in the district and elsewhere in the Nottingham area is a 6m-thick unit of homogeneous blocky mudstone. Almost everywhere in the more upstanding and drift-free areas this mudstone occupies the steepest part of a scarp slope which leads up to a break of slope at the base of the Cotgrave Sandstone Member, the slope change marking the top of the Gunthorpe Formation. Locally the steep slope is pock- marked by the semi-healed scars of former small scale 'marl` workings.

4.5.4 EDWALTON FORMATION

The Edwalton Formation was defined by Elliott (1961), with its type section at Edwalton Hill brick pit, west of the present district, in which a good section of the lower part of the formation was exposed. Much of the evidence for the limits of the formation derived from a study of cored boreholes, particularly the small scale structures that they revealed. Though the basis of definition was mainly sedimentological Elliott (1961) found it expedient to draw the base of the unit at the base of the 'Cotgrave Skerry`, a mappable horizon which is marked by a break of slope feature in suitable topographic situations. Likewise the change of sedimentological criteria marking the top of the formation was almost coincident with the top of another mappable unit, the 'Hollygate Skerries` and for convenience this horizon was adopted as the upper formational boundary. Subsequently Warrington and others (1980) referred to the 'Cotgrave Skerry` and 'Hollygate Skerries` as members, but did not define them. Field mapping as part of the Nottingham Project revealed that the Edwalton Formation could be recognised and mapped throughout the project area by reference to the key marker beds provided by the 'Cotgrave Skerry` and 'Hollygate Skerries` and the formation has been adopted as defined by Elliott (1961), but with the marker 'skerries` now referred to as the Cotgrave Sandstone Member and the Hollygate Sandstone Member (Charsley and others, in press). There is no continuous nor even representative surface section of the formation as a whole, but a cored reference section obtained from the Cropwell Bridge Borehole (SK63NE/28) is deposited at BGS, Keyworth.

The formation, including its bounding members, averages about 46m in thickness, the bulk of which consists of blocky or, more rarely, poorly laminated red- brown or grey-green silty mudstone or siltstone. A variable number of dolomitic siltstone and fine- to medium-grained sandstone 'skerries` are present within the central part of the sequence. The Cotgrave Sandstone Member is a persistent bed of red-brown or yellow, fine- to medium-grained sandstone which forms a prominent feature and locally includes a mudstone or siltstone parting of variable thickness. At the top of the formation the Hollygate Sandstone Member is a composite unit of alternate grey-green to yellow, fine- to coarse-grained sandstones and red-brown to pale green mudstones. The feature formed by the Hollygate Sandstone is in places very similar to that of the Cotgrave Sandstone and some confusion has arisen in the past but has more recently been resolved on the basis of increased borehole information.

The topography that has developed on the Edwalton Formation outcrop in the Radcliffe district is considerably more varied than that of the formations lower in the Mercia Mudstone Group. This is a due to a combination of several factors, particularly the absence of drift deposits over most of the outcrop, an alternation in relative resistance to erosion through the formation and numerous faults, even the smallest of which can significantly displace 'skerry` features in the very gently dipping sequence. Earlier interpretations of the structure in the Radcliffe - Cotgrave area assumed too steep a dip for the various Triassic formations and small faults were often overlooked when correl- ating sequences between boreholes. Acceptance of a regional dip of 1 degree or less, together with the recognition that the intricate feature pattern often reflects truncation rather than failure of the 'skerry` beds has allowed a complex structure to be mapped in the higher, relatively drift-free ground provided by the Edwalton Formation and younger beds in the district. In addition to the obvious features found at the base of the Cotgrave Sandstone Member and below the lowest sandstone of the Hollygate Sandstone Member several intermediate 'skerries` provide mappable and probably correlatable horizons in this and the adjacent district to the east (Lowe, 1989). Locally the Cotgrave Sandstone, higher sandstone 'skerries` and Hollygate Sandstone form extensive dip-slopes which generally carry distinctive sandy soils and upon which sandstone slabs are often ploughed up. The outcrop of the Hollygate Sandstone Member is particularly distinctive in the amount of fine to coarse sand in the soil and although it is rarely possible to map individual sandstone bands for any distance the well-drained soil and the nature of crops grown upon it generally allow easy recognition of the change to overlying mudstones of the Cropwell Bishop Formation.

4.5.4.1 Cotgrave Sandstone Member

Borehole records in the BGS archives show that the earliest name applied to this unit was the 'Cotgrave Place Skerry`, Cotgrave Place being a farm [c.6315 3712], about 2km north-west of Cotgrave village, where the base of the sandstone produces a marked feature. In his description of the Mercia Mudstone formations, Elliott (1961) made no reference to this earlier terminology, only to the 'Cotgrave Skerry`. Though this abbreviated term is undoubtedly less cumbersome it is also an unfortunate choice, insofar as the 'Cotgrave Skerry` is not at outcrop in or near Cotgrave. More confusing still, much of Cotgrave and its environs lies on the outcrop of a higher, equally prominent, 'skerry` unit, the Hollygate Sandstone Member, as described below. The 'Cotgrave 'Skerry` was considered as a member of the Edwalton Formation by Warrington and others (1980) and is now renamed the Cotgrave Sandstone Member.

No exposure of the Cotgrave Sandstone has been located in the district but it is known from many borehole records and these have enabled its outcrop (Figure 2) to be plotted in the west, beneath drift, in an area where the boreholes also reveal a complex fault structure. In the eastern part of the district the outcrop is mainly drift-free and the base of the member can generally be traced by the presence of a break of slope at the top of the blocky Gunthorpe Formation mudstones. Generally the lowest part of the member is a sandstone bed only about 0.5m thick above which up to two metres of mudstone may be present below the main sandstone bed which is up to 2.5m thick and includes a siltstone parting at some localities. In suitable topographic settings the two sandstones and intervening mudstone are recognisable at surface; elsewhere, as for instance in steep scarp faces or in drift covered areas, the Cotgrave Sandstone is mapped as an undifferentiated unit, even though borehole data confirm its tri-partite nature. In other parts of the Nottingham area and at a few localities in the district the lower sandstone is either absent, or the

intermediate mudstone is absent, such that only one sandstone unit up to about 3m thick is recognised. Overall thickness variation between 1.5m and 4.8m is recorded in the district, but this follows no discernible regional trend; similarly the internal variation, whereby the upper sandstone thins or thickens and the mudstone below behaves reciprocally, conforms to no obvious pattern. It is assumed, therefore, that the Cotgrave Sandstone represents the deposits of an episode of sheet flooding of regional extent which probably swept across a flat or gently undulating land surface and possibly had several sediment sources. The overall and the internal variations reflect primary factors of local importance, such as the channels followed by the main flood surges and peripheral areas where flooding was less severe, proximity to the sediment sources, or actual variation in the nature of source sediment.

In the extreme west of the district the Cotgrave Sandstone Member was proved in the highly weathered upper levels of two boreholes on the edge of West Bridgford, Leahurst Gardens No.2 and No.3 (SK63NW/14 and 15). In both cases the records reveal more than one sandstone bed, but recovery was poor and it is uncertain whether or not a higher sandy 'skerry' is present in borehole No.3. Precise overall and individual thicknesses are uncertain. The lowest sandstone is pale green to off-white in colour, medium-grained, partly well-cemented and partly muddy. The thickness of about 1.5m compares well with the thickness proved for the Cotgrave Sandstone in the area to the west (Charsley, 1989a) and the mudstone parting is thus assumed to be missing in this area, the next higher sandstone, proved in the No.3 boring being, more than 3m above and probably correlating with an un-named 'skerry' which is mapped in the eastern part of the district. Narrow drift covered outcrops of Cotgrave Sandstone shown on the geological map in the area between Gamston and West Bridgford are calculated, on the basis of borehole provings, to satisfy the geometrical requirements of the structure and stratigraphy. A degree of confirmation is provided by features mapped into the area from the west and by concentrations of sandstone debris proved in shallow trial pits north of Hall Farm, Gamston [c.603 374].

Southwards and eastwards presence of the Cotgrave Member is indicated by a number of gamma-ray logs in the open hole section of deep boreholes and in the record of the Edwalton Borehole, drilled in 1875. The latter records one bed of hard grey sandstone 2m thick; the gamma-ray logs suggest sandstone development at or close to its expected depth. Still farther south the member is more convincingly proven by boreholes (SK63NW/316, 318, 321) in the Chestnut Farm Series and others (SK63NW/81,82,85,87) south of Tollerton Airport. In these holes the Cotgrave Sandstone is at such a depth as to confirm that the major sandstone development upon which the airport lies is the higher Hollygate Sandstone and not the Cotgrave Sandstone as previously assumed (eg Elliott, 1961). Almost every record reveals a basal sandstone averaging 1m in thickness overlain by up to 1.5m of mudstone and an upper sandstone bed about 2.5m thick. At least six records prove the base of the Hollygate Sandstone Member about 40m above.

Crossing to the north-east side of a complex fault system which runs from Cotgrave to Gamston (Gamston Fault, cf Structure, below), the Cotgrave Member is at outcrop around Cotgrave Place. A narrow and partly conjectural outcrop is present beneath drift deposits adjacent to the Grantham Canal [c.627 368], but the base of the member can be traced around the Cotgrave Place hill on the basis of a break of slope and minor old 'marl' workings in the Gunthorpe Formation below. The crop is traceable, though displaced by faults, to the eastern edge of the district. At Cotgrave Place two sandstone units and intervening mudstone are recognisable, and, somewhat higher, a third sandstone, which is considered to be a separate 'skerry', is mapped. North-eastwards it is possible only to map one sandstone unit, though the

higher 'skerry' is still present, suggesting the possibility of some lateral facies variation within the lower part of the Edwalton Formation in this area. Near the eastern edge of the district the Cotgrave Sandstone Member caps several low hills, locally with only the thin lower sandstone and the overlying mudstone preserved on gentle pseudo dip-slopes.

The continued presence of the tripartite Cotgrave Sandstone sequence in this quarter of the district is confirmed away from Cotgrave Place by many shallow boreholes which will not be mentioned individually but including holes in the Peas Hill, Cotgrave Bridge, Woodgate Lane, Cotgrave Church, Stragglethorpe Lane, Clipston Lane and Candleby Lane series. In these various boreholes the lower sandstone unit varies from 0.5 to 1m in thickness with up to 1.75m of mudstone below the main sandstone, which is 2m to 2.5m thick. Higher sandstone or siltstone 'skerries' are recorded in some boreholes and several holes are situated sufficiently far back from the Cotgrave Sandstone outcrop to prove the Hollygate Sandstone Member and the intervening Edwalton Formation strata.

4.5.4.2 Hollygate Sandstone Member

Borehole records in the BGS archives show that an earlier name applied to this unit was the 'Hollygate Lane Skerries'. Hollygate Lane lies on sheet SK63NE, and leads north-eastwards from Cotgrave village towards Hollygate Farm. In his description of the Mercia Mudstone formations, Elliott (1961) made no reference to this earlier terminology, only to the 'Hollygate Skerries', though he did mention the occurrance of the sandstones at Hollygate Lane and in boreholes of the Hollygate Lane Series. The abbreviated term is less cumbersome and is equally suitable, insofar as Hollygate Farm and Hollygate Lane lie upon the outcrop of the beds described. The 'Hollygate Skerries' were considered as a member of the Edwalton Formation by Warrington and others (1980) and are now renamed the Hollygate Sandstone Member.

The Hollygate Sandstone Member comprises a number of thin sandstones with interbedded mudstone and siltstone. Up to six individual sandstones have been recorded in boreholes, but the nature of the sequence, especially where highly weathered close to the surface, has led to generally poor recovery of cores and more or fewer sandstones might be present locally. In general, sandstone comprises about 60 to 75 percent of the member's 6 to 9.5m thickness. The sand- stones are pale grey-green to brown, fine- to coarse-grained; locally they are poorly sorted and/or poorly cemented. Intervening mudstones are red-brown or, more rarely, grey-green and almost invariably silty with scattered or locally concentrated sand grains. Descriptions from boreholes show that the intervening beds attain siltstone grade at some locations. In borehole logs the sequence is commonly difficult to interpret due to mixing of the beds during drilling, but the overall sandy lithology stands out from less sandy formations above and below.

Locally the lowest sandstone, which marks the base of the member, caps a marked escarpment feature. The scarp face, up to 5m high, is formed of blocky red mud- stone of the Edwalton Formation, which has been worked from numerous small 'marl' pits along the outcrop. Down dip of the scarp crest is a dip slope, or series of dip-slopes, of the overlying sandstone beds. It is rarely possible to map individual beds of sandstone for more than a short distance, partly because of their lateral impersistence, partly due to extensive weathering and breakdown of the rocks near surface. However, the outcrop (Figure 2)is well marked by a covering of pale brown sandy soil in most areas. Augering on the dip slopes of the member may prove mudstone beneath the sandy soil cover, but sandstone is normally encountered only a small distance below. The sandstone is commonly penetrable by the auger and appears as pale brown or pale green medium to coarse sand.

Exposures of the member are few; those which are recorded show only a small part of the full thickness. South-east of Nottingham Airport an exposure in a deep drainage ditch [6236 3577] shows 0.5m of red-brown blocky mudstone of the Cropwell Bishop Formation overlying the upper beds of the Hollygate Sandstone. These comprise 0.1m of interbedded red and green, fine-grained sandstone and siltstone over 0.1m+ of grey, fine-grained sandstone. Dips in this area are extremely gentle and generally towards the east; local variation is probably due to the effects of minor faulting. To the west of the airport sandstone debris is common on the dip slopes and pale green, generally fine-grained sandstone is poorly exposed in a number of overgrown ditches. Still farther south-west, across a significant fault, the Hollygate Member has a slightly steeper dip towards the south-east and forms a somewhat narrower outcrop on low ground north and west of Homestead Farm [6115 3515]. The only exposure recorded is in a ditch at [6063 3504], where a small thickness of highly weathered medium-grained sandstone is overlain by thick sandy Head. Elsewhere debris of green or pale brown, fine- to medium-grained sandstone is common on minor dip slopes; sandy soils are present across the entire outcrop in this area. On the north-west side of Cotgrave in the south-east of the district the Hollygate Sandstone is similarly identified by sandy soil across its outcrop. Debris of brown, medium-grained sandstone has been dug from several drainage ditches, but exposure is very poor. Where rock is visible there is an alternation of red-brown sandy mudstone and green or brown medium-grained sandstone, a combination of lithologies which typifies the Hollygate Member. The limits of the member beneath the built-up part of the area are based partly upon borehole information. Beneath the spoil heaps of Cotgrave Colliery the outcrop is drawn on the basis of observations recorded during earlier surveys.

4.5.4.3 Edwalton Formation, undifferentiated

Generally about 36 to 40m of predominantly red-brown mudstone, silty mudstone and siltstone between the Cotgrave Sandstone and Hollygate Sandstone members comprise the remainder of the Edwalton Formation. Thin to moderately thick beds of green mudstone and siltstone occur throughout the division and were considered by Elliott (1961) to be concentrated within three 'belts`. Also a feature of the Edwalton Formation are vein-type breccias (Elliott, 1961), in which the original rock is cut by a crudely rectangular vein system to such a degree that locally the primary structures are obliterated. This feature, far more readily identified in borehole cores than in weathered surface sections, has still to be fully explained, but recognition that the sequence is more heavily faulted than previously supposed has led to the suspicion that the more intensely brecciated zones are related to tectonic factors. Within the sequence are a number of relatively thin, mainly grey-green sandstone or very coarse siltstone units which are locally well cemented and form marked 'skerry` features. No single 'skerry` within the undifferentiated unit is recognisable with certainty across the district, but developments of sandy horizons at two levels are worthy of note.

To the east of the Gamston-Cotgrave fault belt a significant sandstone 'skerry` lies 2 to 5m above the Cotgrave Sandstone. Near Cotgrave Place the unit is recognised by topographic features and by spreads of sandy soil and sandstone brash across south-eastward sloping dip slopes. Augering on the dip slopes confirms the presence of greenish brown, fine- to medium-grained sandstone with scattered coarse grains and coarse layers. Towards its top the unit has interlaminae of red-brown mudstone. Possibly as much as 2m of sandstone is present in this 'skerry`; a thin residual cap of mudstone is preserved at a high point on the dip slope. Eastwards much of the outcrop of the 'skerry` is hidden by the Cotgrave Colliery spoil heaps and is shown in its calculated position on the geological map. South-east of North Farm, Stragglethorpe, its

outcrop widens to form extensive dip slopes, liberally covered in sandstone brash and sandy soil. The topogrpaphy here suggests a possible broad, gentle anticlinal flexure with NW-SE axis, or a number of very small faults might be responsible for a swing of the dip direction. A number of small exposures are found close to Stragglethorpe Lane. In a drainage ditch [6431 3719 to 6448 3716] are discontinuous sections of generally fine-, locally medium-grained flaggy sandstone. Eastwards, at the side of the Lane [c.6485 3714] similar sandstone is locally visible, though largely obscured by creep from the field above. At both localities the sandstone is relatively thinly bedded and the beds are disrupted - this is probably due to disturbance during ditch and road cutting rather than any geological effect. Elsewhere in the district 'skerry' development at about this horizon is confirmed by borehole records, but poor recovery in the upper, weathered, levels of many boreholes has led to rather uninformative logs and lateral correlation is uncertain.

At a somewhat higher level in the Edwalton Formation, generally about 8 to 12m below the base of the Hollygate Member, boreholes indicate another sandstone 'skerry' unit. One, or locally two, thin beds of fine-grained sandstone are recorded across most of the district. No outcrop has been mapped since in the east the potential position is beneath colliery spoil heaps and to the west drift of various types masks most of the topographic features. There are three localities where this higher 'skerry' might be assumed to occur:

a. South of the Grantham Canal at Gamston [c.606 364] where a ridge of red-brown mudstone, cut by the Lings Bar road, is capped by sandy debris. Augering revealed no definite sandstone, but highly weathered sandstone might be preserved on top of the feature.

b. Peas Hill (or Peasehill) Farm [c.632 361] occupies a low hillock with its lower slopes covered by till. The top is essentially drift free and a pit revealed almost 2m of red and green mudstone close to the highest point. A 'skerry' is almost certainly present below this level, forming a vague feature around the north-western side of the hillock. Boreholes of the Peas Hill Series do not confirm the 'skerry' since no cores were recovered at this high level.

c. West of the Stragglethorpe to Cotgrave road [6411 3612] a small feature within the steep slope leading up to the base of the Hollygate Member is covered by sandy soil and limited sandstone brash. Augering revealed no definite 'skerry', but highly weathered sandstone probably comes to the surface here. On the eastern side of the same road earlier surveys noted features at about this same level, but the area is now totally covered by made ground.

Though these details of the two most prominent 'skerries' within the Edwalton Formation of the Radcliffe on Trent area are vague and partly interpretive, they are included to provide continuity with the account of similar beds in the adjacent Cropwell Butler (SK63NE) district (Lowe, 1989).

4.5.5. CROPWELL BISHOP FORMATION

Above the Edwalton Formation, Elliott (1961) defined two higher formations within the Mercia Mudstone Group, the Trent Formation, overlain by the Parva Formation. The latter formation included essentially green beds previously termed the 'Tea Green Marl' and underlying red-brown beds, grouped together on the basis of sedimentary structures and their contained fish remains. The base of the Parva Formation was described as sharp at some localities, but interdigitative elsewhere. Warrington and others (1980) retained the Trent Formation, but divided the Parva into Blue Anchor Formation (equivalent to the

former 'Tea Green Marl') above and the Glen Parva Formation. This division provided a readily mappable upper unit to the Mercia Mudstone - the Blue Anchor Formation - but the boundary between the Glen Parva and Trent formations, which was the same as that between the former Parva and Trent, remained locally vague. During the BGS mapping of the Nottingham area it became apparent that the Parva/Trent boundary was generally unrecognisable for mapping purposes and a new division, the Cropwell Bishop Formation (Charsley and others, in press), was defined to include all those beds previously termed Trent and Parva formations. There is no exposed type section for the Cropwell Bishop Formation, but a reference section of the basal 29m from the Cropwell Bridge Borehole (SK 63 NE/28) is held at BGS Keyworth and a composite section through the entire formation (c.52m) is provided by cores from two Keyworth boreholes (SK 63 SW/36 and /38).

In the Radcliffe on Trent district only the lower part of the formation, an estimated 24m of strata, is represented, all these beds previously being assigned to the Trent Formation. These lower beds comprise predominantly red-brown or brown blocky mudstone and silty mudstone. Impersistent beds of grey-green siltstone and silty mudstone also occur. About 10 to 12m above the base of the formation is a sandy 'skerry' development which includes two, or more rarely one or three, thin sandstone beds. These are the Windmill Hill Skerries (Windmill Skerries of Elliott, 1961), a term used informally and without strict definition during the resurvey. Gypsum is very common within the Cropwell Bishop Formation, the mineral occurring as veins, nodules and beds which are locally of economic value. Close to the surface much of the gypsum has been removed by solution, locally contributing to a substantial lowering of the landscape; only in a few deep ditches or in borehole cores from below the weathered zone is the full extent of the gypsum revealed.

In the south-west of the district the Cropwell Bishop Formation is present in the area around Homestead and Chestnut farms on the outskirts of Tollerton. No exposure is recorded, but the basal part of the Formation forms steep slopes of heavy red clay above lower ground occupied by the Hollygate Member. Thin beds of green, medium-grained sandstone, proved by augering, lying 10 to 12m above the base of the Formation are the local equivalents of the Windmill Hill Skerries. The Chestnut Farm No.6 Borehole (SK63NW/321) [6143 3518], commencing close to the highest stratigraphical level reached in this outcrop, proved one thin sandstone belonging to the Windmill Hill Skerries in its very weathered upper part. The base of the Cropwell Bishop Formation was reached approximately 13m below this sandstone and the Hollygate Sandstone Member, which here includes five beds of sandstone, was 8m in thickness. About 39m of mudstone and silty mudstone with one thin sandstone bed comprised the undifferentiated middle part of the Edwalton Formation, overlying a 2m-thick sandstone assumed to be the Cotgrave Sandstone Member.

Across a fault zone to the north-east a similar part of the sequence is at outcrop in generally low ground between Nottingham (Tollerton) Airport and the Plumtree-Cotgrave road. Much of the area is covered by fairly thick drift deposits, mainly of lacustrine origin, which probably occupy extensive zones of solutional lowering. Locally, however, small hillocks of essentially drift-free ground rise above the drift flats and a few small exposures are recorded. Elsewhere deep drains have been excavated through the relatively soft drift deposits, revealing small sections of weathered solid material at depth.

A drainage ditch east of the airport [6244 3619] exposes beds which might include part of the Windmill Hill Skerries, though their presence cannot be confirmed by mapping due to the drift cover:

	Thickness(m)
Lacustrine deposits	
Clay, brown, silty	0.60
?Head	
Clay, sandy, with rare rock fragments	0.30
Cropwell Bishop Formation	
Mudstone, green, silty and sandstone, fine-grained, interbedded; much broken. Gentle dip increases to 30 degrees	0.70+

The change of dip revealed in the above exposure is almost certainly due to drag folding adjacent to a fault, itself unexposed, a short distance to the south.

Farther south-west the same drainage ditch penetrates the drift to expose the basal part of the Cropwell Bishop Formation:

	Thickness(m)
Lacustrine deposits	
Silt, red-brown, locally clayey	1.50
Silt and clay, red-brown, sandy	0.30
?Head	
Chaotic mixture of sandstone and siltstone slabs in a matrix of red-brown clay, green clay and sandy clay/silt, crudely stratified in part, but with layers deformed and squeezed	c.0.50
Cropwell Bishop Formation	
Mudstone, red-brown, blocky	0.50
Edwalton Formation (Hollygate Sandstone Member)	
Sandstone, red and green,fine-grained, interbedded with siltstone	0.10
Sandstone, grey, fine-grained	0.10+

Somewhat farther south another drainage ditch [6266 3542] exposes strata fairly low in the Cropwell Bishop Formation, in ground where the beds lie almost horizontally:

	Thickness(m)
Lacustrine deposits	
Silt, grey-brown, loamy, with scattered gypsum fragments and blocks	1.0
?Head or remanie till	
Clay, silty with abundant pebbles, merging upwards and downwards into the adjacent beds	c.0.2
Cropwell Bishop Formation	
Mudstone, green with reddish patches, silty, degraded, structureless	c.0.9
Gypsum, massive, fibrous	0.1
[auger hole continues:]	
Mudstone, green with thin red-brown bands, becoming redder with depth; some gypsum	0.5
Mudstone, red-brown, structureless	0.2+

Other minor exposures are recorded in deep ditches in this area, but they reveal nothing more than highly weathered red or locally green mudstone and silty mudstone, typical of the lower part of the Cropwell Bishop Formation.

Beds which include part of the Windmill Hill Skerries are very poorly exposed in a shallow ditch on a drift-free knoll to the south [6262 3517]:

	Thickness(m)
Cropwell Bishop Formation	
Mudstone, red, massive/blocky, (thickness not measured)	
Sandstone, yellow and grey with red laminae, medium-grained, well-sorted, irregularly banded	0.05
Sandstone, similar to that above, but softer and more regulary banded; passes down	0.05 to 0.1
Mudstone, green, sandy, interbedded with dark red mudstone, (thickness not measured)	

To the east of the above exposure the surface of the knoll is close to being a dip slope of the sandstone bed, being covered thinly and patchily by red mudstone, but with sandstone debris profusely brought to the surface by ploughing. The dip here is very gentle towards the south-east and the same thin sandstone is probably responsible for a 'skerry' feature on the northern side of the next rising ground, across a shallow drift-filled depression.

The Windmill Hill Skerries, locally up to three in number, are mapped on the basis of features and auger holes between the above localities and the western outskirts of Cotgrave, where the sequence is moved relatively south-eastwards by faulting. Outcrops of Cropwell Bishop Formation strata around Cotgrave are mainly based upon borehole data, though locally, where ploughed fields remain, the change from sandy soils of the Hollygate Member can be identified. North of the village a limited section remains visible in the old Windmill Hill Brickpit [6437 3574], now largely infilled and overgrown:

	Thickness(m)
Soil and weathered rock slope (not measured)	
Cropwell Bishop Formation	
Mudstone, brick red with green inclusions, blocky	1.2
Sandstone, pale green, fine- to medium-grained, with small solutional cavities (Windmill Hill Skerries)	0.4
Mudstone, brick red with rare green patches, blocky. Minor gypsum veining becomes intense locally to produce a pseudobreccia	2.0+

An earlier and more detailed section measured at Windmill Hill Brickpit by R E Elliott, when the exposure was more extensive, is included in the BGS records system (SK63NW/29).

No further exposures of the Cropwell Bishop Formation are recorded within the district.

5 QUATERNARY (DRIFT GEOLOGY)

5.1 HEAD

Head, as mapped, consists mainly of colluvial deposits in hollows and near the base of the steeper slopes, but it also includes solifluction deposits. It is widespread throughout the district, but has generally been mapped only where a thickness in excess of 1m occurs. The deposits are locally derived and their lithologies closely reflect those of their upslope source rocks and are, therefore, variable over the differing solid outcrops. Locally solifluction debris is probably derived from pre-existing drift deposits, particularly till, and in these areas there must be a degree of uncertainty over the true status of any stony sandy clay or silt, the most typical Head lithology. The true solifluction deposits probably date from the Devensian, when the Nottingham area was south of the main ice front and periglacial conditions prevailed. Similar conditions possibly persisted into the early Flandrian. Other deposits mapped as Head, particularly colluvial material, have been forming throughout the Flandrian and are still being deposited at the present.

Mapped head is rarely more than 3m thick, and commonly <1.5m thick; it is almost invariably confined to the foot of steep slopes or within relatively narrow valleys, drainage gullies and structural depressions. Good sections in Head deposits are rare and, considering the highly variable nature of the material, both locally and laterally, it is not considered worthwhile to describe scattered exposures here. Head in various forms is included in a number of measured sections reproduced in the solid geological descriptions in this report.

5.2 ALLUVIUM

The flood plain of the River Trent crosses the northern part of the district and includes the products of a number of depositional and erosional phases. Most recent of these is the present phase, responsible for the remodelling and redistribution of older river deposits within the Trent valley and the occasional spread of fine-grained material, during very high flood events, across the full width of the flood plain. Exposures of the upper part of these deposits are numerous along the banks of the Trent, but the depth of water and the rate of flow of the river commonly make detailed examination of the sections difficult. Disused gravel quarries north and south of the river were, in 1988, largely flooded or backfilled and landscaped, affording few useful sections. However, active gravel pits west of Holme Pierrepont provided several almost complete sections.

The thickness of the Trent alluvium is commonly between 5 and 7m, and it is almost invariably between 5 and 10m. Boreholes have proved small areas where the alluvium is between 4-5m thick and, less commonly, >10m thick; thicknesses for much of the area were contoured using borehole data, some of which is now lost, by Spenceley (1971). On both sides of the flood plain the modern alluvial deposits thin to a feather edge against older solid and drift except where they abut upon recent river cliffs or where the alluvium ramifies into relatively narrow tracts in active or abandoned tributary drainage routes. Within several of these side arms the true alluvial material owes more of its origin to floods of the main river extending up the tributary than to deposition by the, generally misfit, stream within the drainage route. Away from the main valley the alluvium, in most cases, passes into deposits of lacustrine or mixed fluvial and lacustrine origin, the boundary being taken where the former lakes were ponded against the Bassingfield ridge (sections 5.4 and 5.5).

In broad terms the alluvium of the Trent valley is of three types:

a) Sand and gravel. The lower part of the Trent alluvium is composed mainly of pebbly sand and gravel. These deposits have been recorded up to c.7m in thickness, but they average about 3.5m in thickness. Quite marked variation takes place over small distances, reflecting irregularities in both the basal and top surface of the gravels. The deposits have been recorded in numerous boreholes in the district but they are poorly exposed except in the working quarries where it is generally not possible to sensibly differentiate alluvial material from older river deposits of similar lithology. The borehole records indicate that the gravels are very dense at some levels, especially towards the base, and this too is probably indicative of a passage into still older deposits.

Those sands and gravels which are considered alluvial were probably derived by recent reworking by the Trent of the older Holme Pierrepont, Beeston and Bassingfield sand and gravel deposits. Lenticular clays preserved locally within and overlying the sand and gravel sequence probably indicate deposition within abandoned channels, with thin silt beds representing the deposits of periodic floods.

b) Peat and silty peat. Deposits of dark brown and black silty peat and peat, fibrous in part and containing decayed wood fragments, locally rest upon the gravels. It has been recorded up to c.1.6m in thickness, but it is typically much thinner or absent. Lamplugh and others (1908, p.81) described the peat as occupying hollows in the gravels in the Netherfield and Colwick area; they suggested that the peat resulted from slow filling up of abandoned channels in the gravels below.

c) Clay, silt and sand. The upper part of the Trent alluvium consists of grey-brown, sporadically clayey, silt and fine sand with lenses and stringers of pebbly sand and gravel, and organic clays in places. These deposits cover most of the flood-plain of the Trent, giving rise to brown loam or sandy loam soils with local gravelly patches. Thickness varies considerably from <1 to c.4m, but it commonly ranges between c.1-2.5m. This variation is due mainly to irregularity of the basal boundary. However, a marked topography of up to c.1m of abandoned channels and levees is present in places. In most areas, the surface of the floodplain is almost flat, though this may be due mainly to artificial levelling during arable farming and landscaping in the urban areas. Additionally, a number of 'islands' of older sand and gravel are preserved above the flood plain.

Exposures of alluvial silt and sand occur in numerous places along both banks of the Trent, where up to 2.0m of brown silt and fine sand with slightly inclined very thin beds of medium- to coarse-grained sand are visible. The deposits are typically thinly bedded and laminated in part, and some sandy beds are cross-laminated. Lenses of pebbly sand and gravel occur at all levels. Plant remains are sporadically present throughout. Similar deposits have been recorded in numerous boreholes on the flood plain.

Away from the Trent flood plain, spreads of alluvium are of limited extent and comprise the recent deposits of a number of small brooks which flow essentially north-westwards towards the Trent from higher ground beyond the district to the south and east. These deposits, mainly of silt grade are only separately identified in the relatively narrow stretches of valley where the brooks flow between, into or out of broad, flat bottomed depressions, formerly occupied by permanent or seasonal lakes and now filled by lacustrine deposits (section 5.5). Boundaries between these deposits which, are lithologically

similar, are largely conjectural or based upon landform interpretation. East of Chestnut Farm [c619 352] a minor alluvial fan probably marks the point where a now vanished stream overflowed along a fault-guided hollow from one lake depression to another.

Details of several exposures which include alluvial deposits are reproduced at the end of section 5.3.

5.3 HOLME PIERREPONT SAND AND GRAVEL

The Holme Pierrepont Sand and Gravel is equivalent to the Floodplain Terrace of Posnansky (1960), and the Floodplain Sand and Gravel of Brandon and Sumbler (1988). Outside the district, it has yielded fauna and implements confirming a Devensian to Flandrian age at several localities (cf. Posnansky, 1960).

In the urban area of Colwick, in the north-west of the district, no evidence now exists as to the presence of the Sand and Gravel, and its limits have been taken from the Primary County Series Geological maps. The rural outcrops of the deposit have been partially destroyed by gravel extraction. Elsewhere small terrace features which mark the limits of these older sands and gravels against the modern alluvium have been locally smoothed by recent agricultural activity. In the west of the district, between Gamston and Adbolton, there is uncertainty whether irregular 'islands' of sand and gravel surrounded by alluvium are remnants of the Holme Pierrepont deposits or the planed off equivalent of the still older Bassingfield Sand and Gravel. Insofar as undoubted Bassingfield deposits occur to the south at a somewhat higher level, and pending more definite information, these 'islands' have been referred to the Holme Pierrepont Sand and Gravel.

The Sand and Gravel deposits occur in places c.1 to 2m above the alluvium, commonly with a marked break in slope. Elsewhere the change from the sand and gravel deposits to alluvium ranges from a diffuse, slight break in slope to a virtually imperceptible change. Where observed, the soils of terrace deposits are a grey-brown very sandy loam with abundant pebbles and cobbles. In this district Holme Pierrepont Sand and Gravel is probably preserved beneath the alluvium, though much has been reworked and redeposited by the modern river Trent and is included with the alluvium. Lithologically there is little difference between the alluvial sand and gravel and the older Holme Pierrepont deposits from which they derive; locally the latter deposits exhibit a denser or more compact aspect than the recently redeposited beds.

Exposures are few, those in the working or recently abandoned quarries being generally very similar in the lithologies, thicknesses and relationships that they reveal. In the past, exposures in pits north of the Trent revealed the trunks of numerous trees as well as remnants of ancient fish weirs. South of the river, at Holme Pierrepont, three dug-out canoes of Iron Age or Roman origin were located below the alluvial gravels. The former finds have proved useful in plotting former courses of the river dating back at least 6000 years (Salisbury and others, 1984); the canoes and associated shell-rich clay deposits (Cummins and Rundle, 1969), together with a study of sedimentary structures exposed when the pits were active, have provided similar pointers to the former nature of the meandering river channel. The deposits of the Trent flood plain in this district have been studied in detail, mainly from the point of view of their resource potential, by Spenceley (1971), much of his interpretation being based upon shallow borehole records which are no longer available.

An exposure visible in the active quarry [6082 3822] during the survey showed the relationships between the alluvium (including the deposits of an infilled channel) and the Holme Pierrepont deposits:

	Thickness(m)
Alluvium	
Silt and clay, red-brown, with common pebbles	0.30
Clay, grey, homogeneous with scattered pebbles, common bivalves and layers rich in small (to 1cm) gastropods [in-filled ox-bow lake or channel]	1.00
Holme Pierrepont Sand and Gravel	
Gravel and sandy gravel, medium with fine pebbles, some coarse, thickness variable, sandy at base	2.00

On Gunthorpe Formation

Somewhat farther south in the same quarry [6074 3782] a more complex sequence within the Holme Pierrepont Sand and Gravel was exposed:

	Thickness(m)
Alluvium	
Silt, sandy, brown, with pebbles	0.40
Holme Pierrepont Sand and Gravel	
Gravel, sandy, orange matrix, fine and medium pebbles, very crude planar and cross lamination and pod-like inclusions of medium quartz sand. Base cuts into beds below	0.50 - 0.90
Sand, medium-grained, quartzose, well-sorted, cross-bedding dips eastwards	0 - 0.20
Gravel, sandy, fine pebbles	0 - 0.10
Sand, medium-grained, well-sorted	0.10 - 0.20
Gravel, sandy, with discontinuous layers of sand; overall downward coarsening, base obscured by debris	c.3.00

On Gunthorpe Formation

West of Holme Pierrepont Church a section in a deep drainage ditch [6231 3925] is thought to show Holme Pierrepont Sand and Gravel overlying the older Bassingfield deposits:

	Thickness(m)
Holme Pierrepont Sand and Gravel	
Silt, orange-brown, pebbly at top, with sporadic pebbles below	0.70
Gravel, sandy, fine and medium pebbles, thins and dies to west	0 - 0.05
Silt, orange-brown, sporadic fine pebbles	0.10
Gravel, sandy, mainly fine and medium pebbles, some coarse; pebbles sub-rounded and rounded, some angular, including quartzite, quartz, flint and sandstone. Upper surface rises towards the east	1.00
?Bassingfield Sand and Gravel	
Gravel, sand, very clayey, locally a sandy, pebbly clay, dark brown, soft to firm	0.30+

5.4 BASSINGFIELD SAND AND GRAVEL

The age and origin of the Bassingfield Sand and Gravel are somewhat uncertain. Deeley (1886) included the deposits within his 'Interglacial River Gravel' division, postulating a later return to glacial conditions across the district. During the primary geological survey the deposits were described as 'Older River Gravel' or 'Late Glacial Flood Gravel', the field geologists at

that time being unable to support Deeley's view of more than one glacial period in the region. Later workers have tended to follow the same broad view and the general consensus (eg Posnansky, 1960; Brandon and Sumbler, 1988) has been that the deposits post-date the last glaciation in the area. There has also been general agreement that the Bassingfield Sand and Gravel equates with the Beeston Sand and Gravel (previously referred to as the Beeston 'Terrace'), which on the basis of contained faunas in other areas is accepted as being of Ipswichian age.

Mapping during the Nottingham Project has produced no positive evidence for either the age or origin of the Bassingfield Sand and Gravel, but there are several negative indications that the deposits are not completely equivalent to the Beeston Sand and Gravel. In fact if any part of the Beeston deposits are equivalent to the Bassingfield sequence, doubt must be cast upon those beds being Ipswichian. Lack of exposure in either deposit weighs against direct comparison; nor is it possible on the basis of the few pre-existing descriptions of former exposures to form any definite conclusions.

Topographically the Bassingfield Sand and Gravel is not a typical river terrace landform, this being explained by Lamplugh and others (1908) as an effect of differential erosion. Its form is essentially ridge-like in the main outcrop, which stretches along the southern margin of the Trent flood plain from West Bridgford (sheet SK53NE) to Radcliffe on Trent. In places the ridge crest lies some 5m above the modern alluvium to the north, which places it some 3 to 4m above the expected upper surface of the Holme Pierrepont Sand and Gravel terrace in this area. On the south side of the ridge crest the ground also drops away and locally, where Head deposits do not obscure the detail, a relief of up to 5m above lacustrine or alluvial deposits is preserved. Away from the main outcrop, in this area and in the adjacent West Bridgford district (Charsley 1989a), a number of small 'islands' of Bassingfield Sand and Gravel have been mapped on the basis of topography. The high points of these knolls, assumed to be remnants of a continuous sand and gravel spread, are generally at least 2m above the Holme Pierrepont terrace level and locally a slightly greater relief is preserved. A well-marked step is visible in many places along the northern edge of the main outcrop and sporadically around the margins of the smaller outcrops where recent fluvial or agricultural activity has not smoothed the topography. It is assumed to be an erosional feature cut by the Trent as it meandered across the older sand and gravel spread, lowering the general level of the meander belt. Any fine material within the pre-existing deposits (see below) was probably carried outside the district and the medium and coarse fractions were redistributed as the Holme Pierrepont Sand and Gravel.

Lithologically the upper part of the Bassingfield Sand and Gravel is not unlike the younger Holme Pierrepont and alluvial gravel deposits. Scattered poor exposures and the abundant pebbles visible in the soil indicate a generally sandy gravel which is slightly clayey or contains discontinuous beds of sand locally. The gravel is predominently of medium, generally well-rounded pebbles, with lesser proportions of fine and coarse pebbles and rare cobbles. Clast lithologies are mixed; quartzite is generally predominant, though locally (?Carboniferous) sandstone and siltstone are equally abundant. Lesser amounts of quartz, dark igneous material, limestone and flint, which is usually sub- angular, are usually present. Organic material has been recorded at one locality (see below).

The base of the Bassingfield Sand and Gravel is nowhere convincingly exposed, though several natural sections and temporary excavations have shown beds which are probably at, or close to, the lower limit. A number of hand auger holes have provided additional information. At almost every locality where

the lower part of the formation has been seen the sand and gravel becomes clayey or very clayey, to such a degree that sandy, pebbly clay is a more accurate description. In the west of the district there is a downward passage into dominantly clayey deposits, which have been mapped as undifferentiated glacial deposits around Gamston. A temporary section sunk through the base of the Bassingfield deposits subsequent to the survey was reported to have passed directly from sand and gravel into weathered Mercia Mudstone, suggesting that the supposed glacial material is discontinuous, or that it is locally less clayey, or that the clay-rich beds are in fact not truly glacigenic but are solifluction deposits (Head) which have incorporated sand and gravel from the topographically higher Bassingfield ridge. Eastwards from Gamston it becomes impossible to recognise a separate clay-rich unit for mapping purposes, but all exposed sections indicate a downward increase in clay content.

Deeley (1886) figured a section within his 'Interglacial River-gravel' at Gamston, which showed the gravel to be highly contorted. This was taken to be indicative of later over-riding during a glacial re-advance. A more modern explanation is that the contortion represents classic periglacial deformation structures. Quoting an earlier paper by Shipman (1879) Deeley describes similar convolutions, caused by lateral force, within a sand and gravel sequence at Beeston. No similar structures have been noted within the relatively better exposed upper levels of the Bassingfield deposits during the resurvey. The lower beds were nowhere well enough exposed for such structures to be visible. Lacking a detailed locality for the section at Gamston, it has not been possible to ascertain whether the affected beds were in the upper or lower part of the unit and hence the possible relationships between these beds and those in Beeston remain uncertain.

The main evidence for the assigning an Ipswichian age to the Beeston 'Terrace' hinges upon the occurrence of faunas indicative of a temperate climate in deposits, such as those at Allenton, upstream of Beeston, which are correlated with the Beeston deposits on morphological grounds. Artefacts have been located within the Beeston Sand and Gravel and these also are interpreted as indicating an Ipswichian age. However, according to Brandon and Sumbler (1988), "... the Beeston Terrace deposits are assumed to be coeval..." with the Ipswichian deposits upstream. Thus some doubt remains regarding the age of the Beeston deposits; greater uncertainty must exist concerning the age of the Bassingfield Sand and Gravel, no faunal remains or artefacts having been reported from these beds.

On the basis of the scanty evidence mentioned above and the sections described below, it is suggested that the base of the Bassingfield Sand and Gravel is interdigitative with underlying mixed clayey and sand and gravel deposits, including sandy till (see later) and possibly laminated clay or silt. Thus the basal part of the formation, at least, appears to belong to an ice-marginal or glacial melt-out sequence and the lower deposits are probably glacial flood gravels. If this assumption is correct it is unlikely that the Bassingfield Sand and Gravel is of Ipswichian age, as suggested by its previously accepted correlation with the Beeston 'Terrace'; whether the whole of the sand and gravel preserved within the Beeston 'Terrace' can also still be assigned to the Ipswichian, must also be reconsidered.

A number of generally rather poor exposures within the Bassingfield Sand and Gravel are described below, commencing with the closest to Radcliffe on Trent in the east of the district, where the deposits become unmappable as they thin against the Mercia Mudstone and are locally obscured by later Head and fluvial deposits. A number of temporary exposures in the Gamston area were examined after the mapping was complete, but these do not markedly alter either the map or the broad interpretation outlined above.

Much of the south-western suburbs of Radcliffe on Trent lie on Bassingfield Sand and Gravel, but sandy pebbly soil and sandy gravel from occasional shallow excavations are the only surface indications within the built-up area. A ditch [6388 3888] gives a poor indication of the clayey nature of the lower part of the formation:

	Thickness(m)
Soil and sub-soil	
Loam, fine, well-drained, with abundant pebbles of quartzite, quartz and sandstone	0.2
Bassingfield Sand and Gravel	
Sand, clayey, fine to medium, quartz, moderately well sorted; brown matrix; passing down	c.0.3
Gravel, very clayey, sandy, locally sandy pebbly clay, brown; pebbles mainly quartzite and quartz	0.4+

Fields to the south and south-west show a gently rounded ridge crest and abundant pebbles within a sandy soil and there are several small exposures of clayey pebbly sand in the south side of the old Nottingham Road. Two small stream valleys cut through the sand and gravel ridge hereabouts, but only poor exposures of clayey gravel, gravel and sandy gravel are visible below fluvial deposits. A small, flooded pit [6320 3828], dug to provide aggregate during renovation work revealed the following:

	Thickness(m)
Bassingfield Sand and Gravel	
Gravel, sandy, very poorly sorted, including fine sand to cobble-size material, with coarse sand and medium gravel most common fractions. Gravel mainly rounded quartzite, quartz and igneous rock types but including tabular sandstone and siltstone and angular flint. The sandy matrix is locally poorly cemented, giving the appearance of a heterolithic conglomerate	c.2.0
?Clay underlying the gravel below water level	

A short distance to the south-west, three parallel trenches [c.6309 3813] and an auger hole revealed the following composite section:

	Thickness(m)
Bassingfield Sand and Gravel	
Gravel, sandy, locally clayey, mainly fine and medium pebbles with some coarse	upto 2.0
?Sandy till	
Clay, sandy, pebbly, with sporadic cobbles of sandstone and quartzite	2.0
Clay, sandy with rare pebbles, wet	0.4
Gunthorpe Formation	
Mudstone, silty, red-brown	0.2+

South-westwards the Bassingfield ridge continues, but it is more complex, morphologically, than in the area previously considered - there are several vague crests and knolls with intervening hollows or pits. It is uncertain whether this irregularity is of natural origin or whether relatively minor localised aggregate extraction has taken place in the past. A previously significant gravel pit, Bassingfield Quarry [626 377] was totally infilled at the time of resurvey, with only scattered pebbles and sand visible among adjacent waste material. Posnansky (1960), however, reported about 4 to 5m of "medium-sorted sand and gravel" with some clay in pockets.

West of the backfilled quarry the ridge is cut by the valley of Polser Brook. There is no exposure of Bassingfield Sand and Gravel below the alluvium and lacustrine deposits associated with this valley, but pebbly clay and pebbles are locally visible.

To the west the ridge is somewhat broader and locally includes several crests which are not all parallel to the long axis of the ridge. Subsidiary crests and associated hollows appear to be of natural origin and probably indicate the approximate lines of former drainage routes, operative before the establishment of the various valleys which now cut through the ridge. Sandy pebbly soil with pebbles locally very abundant, is ubiquitous across this tract, but only limited exposures of clayey pebbly sand to 1m in thickness were noted in ditches north of Bassingfield village.

A series of shallow auger holes between Bassingfield Lane and the Grantham Canal, south of Cherry Tree Cottage proved the base of the Bassingfield Sand and Gravel; the underlying beds include sandy pebbly clay and laminated clay, as described in section 5.6. Old gravel workings between Bassingfield and Gamston, east of the new Lings Bar road are now largely obscured, but these are possibly the ones referred to by Deeley (1886) and Posnansky (1960). At the time of resurvey a little over 2m of sandy gravel, locally clayey, with lenses of sand, was exposed south of the Council Yard [6043 3735], but this section has since been obscured. A short distance to the east a small scar showing slightly clayey sand and gravel is the last vestige of the former pit shown on Posnansky's (1960) figure 6. A temporary section adjacent to the Council Yard [6056 3754] showed alluvium overlying sand and gravel, possibly all of which belongs to the Bassingfield sequence:

	Thickness(m)
Made ground	
Tarmac and hardcore	0.40
Alluvium	
Silt, grey to yellowish grey, becoming paler and clayey with depth, scattered pebbles, passage base	0.25
?Holme Pierrepont or Bassingfield Sand and Gravel	
Sand, pebbly, clayey, yellow to orange, locally more clayey	0.35
?Bassingfield Sand and Gravel	
Clay, sandy, pebbly, orange brown	0.20
Sand with pebbles, locally silty or clayey, intrudes into bed above as flame structures	0.40+

Across the shallow hollow followed by the Lings Bar road the old village of Gamston and much recent new housing lie on the flanks of the highest remnant of the Bassingfield ridge. On the western margin of the district the ridge is cut by the valley of a small brook; similar deposits continue beyond the valley in the West Bridgford district (Charsley, 1989a). Very poor and obscure exposures on the east side of the brook indicate that the basal part of the Bassingfield Sand and Gravel includes at least 1.8m of ill-sorted clayey, sandy gravel, with rare cobbles, which becomes more clay-rich downwards. One section shows these deposits resting upon soft red clay, with pebbles near the junction, this being considered to be weathered Mercia Mudstone. Another section, however, just a few metres from the last, shows a variable thickness of grey pebbly clay overlying the red clay and passing obscurely upwards into the gravelly beds. Since the resurvey numerous shallow trenches have been dug across the area as part of a modern housing development project. Many have

exposed gravel and sandy gravel close to the surface, others have shown that deposits of Bassingfield type are preserved beneath lower ground, considered to be Holme Pierrepont Sand and Gravel at the surface, to the north of the ridge. The most complete section [6032 3732] showed:

	Thickness(m)
Chaotic overburden and excavated debris (not measured)	
Holme Pierrepont Sand and Gravel	
Sand, clayey, brown with orange mottling, with scattered fine and medium pebbles	0.50
Sand, orange, fine- and medium-grained	0.30
?Bassingfield Sand and Gravel	
Gravel, sandy, clayey, with orange-brown matrix	0.40
Clay, grey and orange, some sand and fine, rounded pebbles	0.20
Sand, red, medium-grained	0.10
Clay, sandy, pebbly or clayey, sandy gravel, heterogeneous, including yellow-brown and orange clay matrix and angular to rounded clasts	0.60+

Somewhat farther south [6035 3707], close to the top of the ridge, the following section, of particular interest for the presence of organic material, was measured:

	Thickness(m)
Soil, sandy, with 5-10% gravel.	
Gravel rounded to well-rounded, quartzite with some sandstone, plus small angular to sub-angular flints	0.15
Bassingfield Sand and Gravel	
Sand, pebbly, medium- to coarse-grained, mainly quartz. Gravel mainly fine, about 80% quartzite with about 5% each of sandstone, quartz and flint (as above)	0.20
Gravel, fine to coarse pebbles, mainly rounded to well-rounded; quartzite 65-70%, sandstone (including coarse-grained) 20-25% with minor quartz, dark igneous and flint. Maximum pebble size seen 10x7x5cm. Vague imbrication dips towards south. Iron-rich lenses locally. Slab of red/green fine-grained sandstone 35cm long and 5cm thick with angular margins noted in same bed c.3m W. of measured section. Sharp but irregular base	0.60
Sand, yellow-brown, medium-grained, some coarse grains, clean, sub-angular to sub-rounded, mainly quartz with up to 10% lithic grains. Up to 5% of very fine to fine gravel locally	0.20
Sand, moderate reddish brown, similar to bed above, but with minor fine sand; sporadic rounded pebbles with clayey sand coating	0.45
Sand, clayey, yellowish, reddish brown, very ill-sorted, with a large proportion of medium to coarse sand, granules and fine pebbles	0.10
Peaty silt and sand, not clayey; laminated maximum	0.08
Sand, reddish brown, medium-grained, well-sorted, low fines, making water base not seen	0.15+

Samples collected from the thin peaty horizon have been reserved for faunal and pollen analyses, with a possibilty of absolute dating if the material proves suitable, but no results are currently to hand.

A shorter section in a new road cutting to the north [3722 3713] exposed beds lower within the Bassingfield sequence:

	Thickness(m)
Soil, pebbly, sandy, grey-brown	0.50
Bassingfield Sand and Gravel	
Gravel, clayey, sandy, mainly medium pebbles, quartzite most common, with quartz, Carboniferous sandstone/siltstone, rare igneous and flint	0.40
Clay, sandy, pebbly (or very clayey sandy gravel), deep red, pebbles mainly fine and medium, no obvious structure	0.20
Sand, pebbly, medium- and coarse-grained with granules and scattered pebbles, mainly quartzite with lesser quartz, sandstone and flint; orange-brown fines	c.0.20
Gravel, clayey, sandy, mainly medium pebbles with minor amounts of fine and coarse, locally clayey, pebbly sand; poorly sorted	c.0.40+

5.5 LACUSTRINE DEPOSITS

Large areas of essentially flat ground south of the Bassingfield Sand and Gravel ridge are covered by silty and clayey deposits, locally up to about 3m thick, which were laid down within permanent and ephemeral lakes. The modern day flats are crossed by misfit streams and networked by man-made drains, the surface drainage escaping northwards through the several gaps in the Bassingfield ridge referred to in section 5.4. Thus there is locally an interfingering of alluvial and lacustrine sediments within the areas shown on the geological map as being lacustrine; only close to the ridge in the down-stream direction and where streams from higher ground to the south enter the flats has it proved feasible to place boundaries between these sets of deposits. Within the lacustrine sequence are beds which are rich in bivalve and gastropod remains. Previously termed 'Shell Marl' (eg Lamplugh and Gibson, 1910), these deposits are often brought to the surface by ploughing, but none have been separately delimited during resurvey. Beds of peat or peaty sediment are also present locally within the lacustrine sequence, these marking periods of reversion to swamp conditions as the lakes either silted up or were partially drained. Bones and artefacts have been recovered from the lower parts of the lacustrine sequence, which together with the shells already mentioned, all of existing species, suggest an age no older than late Devensian to early Flandrian. The oldest beds are assumed to date from the climatic amelioration after the Devensian cold stage, about 10000 years ago, and deposition has been more or less continuous since then. In relatively recent times the lakes and swamps were drained and the small streams began to cut down into and remove the lacustrine material.

Many of the areas occupied by lacustrine flats are depressions which formed as the land surface was lowered in response to gypsum solution, particularly within the Cropwell Bishop Formation. In areas where streams enter the lacustrine depressions, flowing from higher till-covered or Mercia Mudstone areas to the south, thin, unmappable fluvial deposits probably overly the lacustrine beds. Elsewhere recent colluvial material has moved downslope from solid or till outcrops, over-riding and masking the edges of the lacustrine flats.

Numerous small sections occur in drains and brooks across the district. Most show limited thicknesses of grey, green, red-brown or yellowish clay and silt, with or without organic remains overlying weathered Mercia Mudstone, and are

within the areas where the lakes and swamps were shallow, at the limits of flooding. Elsewhere, towards the centres of the various depressions the lakes were deeper and more long-lived, providing thicker and more complex sequences, with older drift deposits preserved at the base at some localities.

A section in a stream north of Cotgrave sewage works [c.6387 3569] shows up to 1.5m of silt and clay with peaty layers which can be seen to overlie sandy till to the north, where the lacustrine deposits thin above a local rise in the older material. About 1.5km to the north-west [c.6268 3685] up to 2m of brown and reddish brown loamy silt and clay overlies stoney clay (see section 5.6). The most complete and best exposed sections are in the deep drainage ditch which carries Polser Brook past the eastern side of Tollerton Airport. An abbreviated composite section is noted on the geological map [6217 3547], the full sequence being:

	Thickness(m)
Soil, brown, silty; thickness variable, say	0.20
Lacustrine deposits	
Silt, red-brown, massive; very rare shell fragments throughout, with shell concentration in lower c.15cm	1.00
Silt, clayey, grey, reddish locally; abundant mollusc debris; passage base	c.0.20
Silt, sandy/clay, grey; abundant mollusc debris, rare bones and rare rock fragments. Variable silt/sand/clay suggests possible interlamination, not visibly apparent due to the desiccated nature of the section	0.25
Clay, silty, grey; some sand grains and rare rock fragments; shell debris rare/scattered and as thin (=1 shell thick) layers. Base shell-rich	0.20
?Reworked sandy till/lacustrine deposits	
Clay, very sandy, pebbly, matrix grey-brown sandy clay, locally ?reduced blue-grey silty clay. No visible bedding. Pebbles mainly medium and coarse with fine; sub-rounded to rounded quartzite (predominant), igneous, sandstone and quartz, with sporadic sub-angular flint.	0.25
?Sandy till	
Clay, sandy, pebbly, matrix red-brown sandy clay. Pebbles mainly fine, rounded to angular, with a discontinuous layer of medium and coarse pebbles at the base. Locally the basal coarser-pebble layer is replaced laterally by medium- to coarse-grained red sand. Base of unit at water level; nature of lower contact uncertain	0.25
Below water level (lithology uncertain)	
Silt(?), green-grey, massive, possibly weathered Mercia Mudstone	0.05+

The nature of the two units of sandy, pebbly clay beneath the definite lacustrine deposits is uncertain and is considered further in section 5.6.

Westwards across a more elevated area, mainly of drift-free Mercia Mudstone, is another lacustrine basin, on the eastern fringe of West Bridgford. There are numerous exposures along the partly artificial route of a brook which flows across Edwalton Golf Course and northwards to cut through the

Bassingfield ridge at Gamston. Up to 2m of grey clay and silt with organic layers and beds rich in molluscan shells is visible. Locally a thin layer of stony clay is preserved beneath these beds and weathered Mercia Mudstone below; elsewhere the lacustrine silt and clay rests directly upon weathered bedrock. In the northern part of this flat, the brook has cut down in response to a lowering of base level, probably caused by human intervention to the north, and a slightly lower flat, at least partly covered by alluvial deposits, has been cut. The presence of lacustrine deposits at depth was confirmed by a series of trial pits, one of which, [6047 3586], close to the mapped limit of the alluvium, showed:

	Thickness(m)
Soil and alluvium	
Clay/silt, brown	0.30
Lacustrine deposits	
Clay, pale grey and yellow, with shells	0.20
Peat, black	0.10
Silt, sandy with some clay, yellow-brown	0.40
Silt, clayey, blue-grey and yellow-orange, fossil roots and mollusc shells. Rare pebbles and gypsum fragments near base	1.30
Edwalton Formation	
Mudstone, silty, red-brown, weathered at top, with gypsum veinlets increasing downwards	0.90+

Farther north [6037 3611] another trial pit showed:

	Thickness(m)
Soil and alluvium	
Silt, brown	0.20
Lacustrine deposits	
Clay, silty with some sand, pale brown, calcareous with shells	0.30
Peat, black, fibrous	0.30
Clay, pale, soft, as above	0.30
Clay, green, mottled yellow and blue-grey, with fossil roots	0.90
Silt, clayey, blue-grey, homogeneous	0.40
Edwalton Formation	
Mudstone, slightly silty, red-brown, blocky, with gypsum veinlets, weathered	0.60+

Lacustrine deposits and sequences including mixed fluvial and lacustrine material are present in adjacent districts to the west, south and east.

5.6 SANDY TILL AND UNDIFFERENTIATED COMPLEX DRIFT DEPOSITS

In the Wolds area to the south and east of the Radcliffe on Trent district deposits of lodgement till are preserved at altitudes generally greater than 70m OD (Crofts, 1989a and 1989b). These deposits, which contain chalk, indicating derivation from the east, are of uncertain age though earlier workers have suggested they are Wolstonian (eg Posnansky, 1960; Mitchell and others, 1973). Glacial deposits derived from the north, which must have crossed the area now occupied by the Trent valley, are recorded at similar altitudes, for instance at Wilford Hill (Charsley, 1989a). Deeley (1886) applied a nomenclature which is difficult to reconcile with modern terminology, but by implication he too regarded the eastern till as

Wolstonian, recognising one younger and two older (Pennine) boulder clays in the area. These might possibly be construed as Devensian and Anglian (or older) in age. Brandon and Sumbler (1988), having studied sand and gravel deposits in areas to the north- east, deduced either an Anglian or Wolstonian age for the deposition of the chalky till.

Across parts of the Radcliffe on Trent district and adjacent areas deposits of probable glacigenic origin are present at lower elevations, generally lower than 40m OD. These beds are poorly exposed but appear to include tills, generally of sandy or very sandy pebbly clay lithology, together with mixed and highly variable deposits of sand, silt and clay, an assemblage fairly typical of glacial melt-out sequence. Insofar as these deposits occupy areas of low ground which are believed only to have been formed, by downcutting, after the deposition of the eastern till and equally old, or older, Pennine-derived till to the north and west, it appears that they must belong to a later cold stage. It is generally accepted that the Nottingham area lies outside the limit of Devensian glaciation so these deposits must be at least as old as Wolstonian. The corollary of this is that there was either extreme erosive downcutting between the deposition of the chalky lodgement till and deposition of melt-out material from the same ice-sheet, or that the chalky till is older than Wolstonian. Further, if the chalky till and Pennine tills are Anglian and the low level tills and their associated melt-out deposits are Wolstonian, it is probable that at least part of the Bassingfield Sand and Gravel sequence (section 5.4) is also Wolstonian.

Exposure of these mixed glacigenic deposits is very poor. They are mapped through and around Cotgrave village, mainly on the evidence of pebbly clay soil, scattered temporary exposures and auger holes. Pebbles are locally in great abundance, for instance in a shallow valley east of Cotgrave sewage works [c.640 355]. Drains to the north and west of the latter location show poor exposures of generally grey, pebbly clay, but no more than 1m is visible in any section. Stiff grey clay soils mantle slightly higher ground around Peas Hill (Peasehill) Farm, this area too including abundant pebbles and scattered cobbles.

Lower ground between this area and the Bassingfield ridge to the north and the drift-free area around Tollerton Airport to the west is covered by lacustrine sediments, but as indicated in section 5.5, pebbly clay is locally exposed at depth. Along the eastern edge of Tollerton Airport, a narrow strip of clayey soil with abundant pebbles is preserved above the level reached by the lake deposits. The Airport and its surrounding area are essentially drift-free but augering reveals thin, unmappable, smears of sandy pebbly clay. Westwards is another lacustrine depression where most exposures indicate that no glacial drift is preserved beneath the more recent material. A ditch section [6027 3536], however, exposes silty, shelly lacustrine beds overlying stony clay, this in turn lying on green silty mudstone of the Edwalton Formation.

The Bassingfield ridge, to the north, has been dealt with in considerable detail in section 5.4, including a number of sections which indicate the presence of probable glacigenic deposits below the sand and gravel sequence. Two additional sections are possibly significant to the understanding of the relationships between the Bassingfield Sand and Gravel and the underlying deposits. A temporary excavation [6402 3925] on the outskirts of Radcliffe on Trent showed up to 2m of variably clayey sandy gravel beneath the Trent alluvium. Although a narrow remnant of the Holme Pierrepont Sand and Gravel is mapped less than 100m away from the site, the lithology is more akin to that of the Bassingfield Sand and Gravel which is at surface a further 60m away. Augering below the floor of the excavation revealed grey-brown clay, far harder than one have been expected in a fluvial sequence, with sporadic

small pebbles and rock fragments. Definite solid deposits were not proved within the limits of augering. The clay below the gravels was somewhat disturbed by the auger but showed crude lamination in parts; elsewhere it was more till-like in appearance. This sequence is now interpreted as passing through the feather edges of the alluvium and Holme Pierrepont plus Bassingfield sand and gravel, to enter glacial melt-out deposits.

Farther west, on the southern flank of the main sand and gravel ridge between Gamston and Bassingfield, a series of four auger holes proved the following broad succession:

	Thickness(m)
Hole 1 (the highest)	
Bassingfield Sand and Gravel	
Sandy gravel overlying clayey, pebbly sand	not measured
Hole 2	
Sandy clay soil	0.2
Sandy till and undifferentiated drift deposits	
Clay, dark brown with yellow streaks, sporadic pebbles; passing down	c.0.3
Clay, sandy, pebbly, yellow, ill-sorted, passing down	c.0.3
Sand, clayey, pebbly, rough, yellow, ill-sorted, wet	c.0.6
Sand, as above but with bands of red-brown fine-grained sand	0.2+
Hole 3	
Sandy till and undifferentiated drift deposits	
Clay, laminated overlying till	not measured
Hole 4	
?Sandy till and undifferentiated drift deposits	
Clay, brown [possibly Head]	not measured

on Edwalton Formation mudstone

The above series of holes confirmed the presence of a narrow strip of clay-rich deposits between the base of the Bassingfield Sand and Gravel and the underlying solid sequence, the outcrop of which extends westwards to the limit of the district. Though not measured in detail a marked variation of lithology is apparent and a passage upwards into the sand and gravel deposits is indicated.

5.7 CALCAREOUS TUFA

Calcareous tufa does not appear on the geological map, but blocks of pale brown 'cindery' material occur where brought to surface by ploughing around a strong spring [6271 3529] north-east of Tollerton. The tufa is probably a chemical deposit, formed as saturated spring water de-gasses, losing carbon dioxide to the atmosphere and precipitating calcium carbonate. The spring is close to a fault line and it is assumed that the calcite rich solutions are transported either from the topographically higher and generally calcareous Hollygate Sandstone Member to the north, or from Jurassic limestones, also topographically higher, somewhat farther to the south. Analysis of the spring water might provide a clearer indication of the origin.

6 STRUCTURE

6.1 FOLDING

During the Variscan Orogeny, the Carboniferous rocks of the region were uplifted and basin inversion took place. Subsequent uplift during Mesozoic times, culminating in the Alpine Orogeny, gently folded the Carboniferous and younger strata.

The overall fold structure of the district is simple. The Carboniferous beds dip at angles of c.1.5 to 5 degrees towards the north-east, with an overall decrease in the amount of dip towards the north-east. The overlying Permo-Triassic beds dip at very low angles, rarely greater than 1.5 degrees in a broadly south-easterly direction. Locally, as for instance in the area south of Tollerton Airport, the dip is less than 0.5 degrees. These low dip values are partly responsible for producing an apparently complex outcrop pattern in areas of marked relief. Sparse underground data indicate that there is a swing of strike in the Carboniferous rocks in the southern part of the district; a gentle anticline with WNW/ESE axis is possibly present, sub-parallel to the margin of the Widmerpool Gulf (see below).

6.2 FAULTING

The district is cut by many faults, a small number of which are fairly major structures with throws of up to 60m. A larger number are if intermediate size, with throws greater than 8m, but the majority have less than 8m throw, many being as low as 1 or 2m. Apparently large displacements of outcrops across the minor faults are a reflection of the low regional dip. Many of the minor faults are mapped on the basis of the truncation of topographic features and the actual fault lines are necessarily interpretive in the areas where similar rock types are juxtaposed between the feature-forming horizons. Confirmation of the general structure is provided by shallow boreholes and by surface augering. Less reflection of the surface fault pattern is provided by the structure interpreted and confirmed by mining in the Coal Measures. A number of more significant structures known in the Carboniferous rocks can be recognised at the surface. These faults probably affected the older rocks during Variscan times and were reactivated during Mesozoic and/or Tertiary earth movements. The sense of reactivation was not necessarily the same as the original movement, nor did all reactivated structures propagate upwards as a single fault plane. More often, a simple structure within the Coal Measures ramifies into a zone of lesser faults in its upward extension through the Permian and Triassic sequences. In some cases it can be shown that the cumulative throw across a fault zone is about equal to the throw of a single fault proven at depth. Not all faults inferred or proven in the Coal Measures are recognised at surface and, partly for the reason outlined above, not all those mapped at the surface can be identified on mine plans.

The major fault trend in the district (Figure 2) varies between close to west/east and close to north-west/south-east. A minority of small faults have trends between north/south and NNE/SSW. In detail most of the main structures in the Carboniferous and younger rocks are on trends closer to west/east and the lesser faults, including those only apparent in the Permo-Triassic sequence are oblique to this trend. This effect might be partly due to strike-slip movement along the major structures producing secondary wrenches within the younger rocks between.

On a regional scale the district lies on the hinge zone of a half graben structure, the Widmerpool Gulf, with its main ramification in areas to the south-west. The main fault structures, including the Harlequin Fault and the

Clifton-Gamston Fault (see below) are sub-parallel to the hinge line and it is likely that the heavy faulting across the Radcliffe on Trent district, between the Harlequin Fault to the north and the Flawforth Fault zone in districts to the south and west (Crofts, 1989a; Charsley, 1989a,b), is in some way linked to activity along this hinge, which in turn probably reflects pre-existing basement structures.

The Harlequin Fault, a major fault of regional significance, has an arcuate, broadly east/west trend and throws down c.30m to the north. Leaving the northern margin of the district the fault continues eastwards with a throw of up to 50m (Rathbone, 1989a,b). North-westwards the fault merges with a number of lesser structures before finally joining the Cinderhill Fault system (Dean, 1989).

Several faults are plotted beneath the Trent alluvium on the basis of limited borehole data and the actual lines of these structures and their eventual linking with structures mapped in areas to the south must be regarded as partly conjectural. In the north-east several faults of relatively small southerly downthrow merge beyond the district margin to the east to form the Foss Bridge Fault (Lowe, 1989). Several other faults of intermediate and small throw follow sub-parallel trends to the south of this line, their presence indicated by displacements of the Cotgrave Sandstone and locally confirmed by borehole records.

The Clifton-Gamston Fault, known simply as the Gamston Fault in this area, enters the district north of Gamston and follows a west/east course beneath the Bassingfield ridge. Its position at rockhead is based upon a limited amount of underground data, being under thick drift for this section of its length. To the west (Charsley, 1989a) the fault is recorded to have an 80m throw in the workings of Clifton Colliery, but at the surface in this district the maximum calculated throw is 60m, in the west. Eastwards the amount of throw is less, calculated as c.35m near Bassingfield. South-east of the latter village the supposed single sub-drift fault line splits into several somewhat smaller fractures which run eastwards and south-eastwards through the Cotgrave area. The westernmost branch has a throw of about 10m and in an area of very low dips and gentle topography, has the effect of juxtaposing the Hollygate Sandstones with the Windmill Hill Skerries in the Cotgrave area and shifting the outcrop of the Hollygate Sandstones north-westwards from Cotgrave towards Bassingfield. The detailed history of the various components of the Gamston Fault system in this area is yet to be fully elucidated, it being apparent that there is significant disagreement between the patterns of surface and underground faulting, both in terms of sense of movement and amounts of displacement. Reactivation of early structures in the opposite sense is probably responsible for some of the complexity.

South-west of the Gamston Fault the outcrop of the Hollygate Sandstones provides evidence of a number of faults, mainly with small throws, which trend approximately north-west/south-east. Variation of the amount of throw along the length of these structures is apparent locally and this is partly due to the additive and subtractive effects of merging fault lines and partially due the fault movement being taken up by adjacent, en echelon, fractures. Mine plans for the area indicate that significant faults lose throw and terminate over short distances, with the throw on adjacent, sub-parallel fractures behaving reciprocally. A particularly complex fault structure on the western margin of the district, between West Bridgford and Gamston, is confirmed by close lithological control in a number of shallow boreholes.

The exact position and amount of throw of all faults in the district is partly conjectural, particularly beneath superficial deposits. Fairly close control

is offered where the major features formed by the Cotgrave and Hollygate Sandstone members are displaced; elsewhere the identity of displaced features is less certain and the lines of faults through featureless ground between are interpretive. Only in the north-western corner of the district, in the Colwick railway cuttings, are faults visible; the spacing of fractures at this locality is in keeping with that in the more heavily faulted parts of the district.

7 ECONOMIC GEOLOGY

7.1 COAL

Three of the Nottinghamshire named coal seams have previously been worked in the district; they are the Deep Hard, Deep Soft and First Piper. Limited workings in the latter seam entered the district in the west, originating in the now abandoned Clifton Colliery. Somewhat more extensive workings in the Deep Hard seam, beneath the south-west corner of the district, were also from Clifton. Limited amounts of the Deep Soft seam were extracted from parts of two panels which entered the eastern side of the district from Cotgrave Colliery. By far the greatest extraction has been within the Deep Hard panels driven from Cotgrave; only one panel was active beneath the district at the time of the resurvey.

The sequence of coal seams is described in section 3; many unmined seams remain below parts of the area, and of those mined, only the Deep Hard has been almost completely worked out. In the future it may become economic to work some of the remaining coals, depending upon the obvious factors of depth, thickness, quality and geological structure, but currently the industry is in decline locally and its future is uncertain.

7.2 BRICK CLAY

In the Nottingham area as a whole, large scale extraction of brick clay has been restricted mainly to the Gunthorpe Formation, principally in the lowest 15-20m of the formation and at a level just below the base of the Cotgrave Sandstone. This is due as much to the geomorphological requirements for extraction as to the suitability of lithology. At both of these levels, the presence of overlying shallow dipping resistant beds can result in a good scarp slope, allowing easy access for extraction and creating minimal overburden.

No large brick-pits are known to have been worked in the Radcliffe on Trent district, but suitable lithologies and a suitable topographic settings are present locally below the outcrop of the Cotgrave Sandstone in the east of the area. A small abandoned quarry on the western side of Windmill Hill, Cotgrave [6437 3782], has been described as a brick-pit, but must have been a very small operation, working highly gypsiferous red mudstones in the lower part of the Cropwell Bishop Formation.

Much of the Gunthorpe Formation, particularly the lowest c.15-20m and the highest c.15m of strata, and parts of the Edwalton Formation, particularly the beds below the Hollygate Sandstone Member, form substantial potential brick clay reserves in the district.

7.3 SAND AND GRAVEL

The alluvial sand and gravel deposits of the Trent valley are one of the major geological resources in the Nottingham area. They have been exploited on a large scale in several parts of the region.

In the area between Radcliffe on Trent and Colwick gravel has been dug from large pits on both sides of the Trent. Many of these workings are now backfilled or derelict, either landscaped or returned to nature, some being incorporated within the Holme Pierrepont National Water Sports Centre.

All the above disused workings were concentrated entirely upon the pebbly and cobbly sands and gravels within the lower part of the Trent alluvium and the

Holme Pierrepont Sand and Gravel. The overlying silts and sands in the alluvial areas were stripped off as overburden.

Present extraction is progressing eastwards across the tract north of the A52 (Radcliffe) road and south of the line of Adbolton Lane/Holme Lane. Most of the potential reserves underlie agricultural land, the limit of the sand and gravel spread corresponding closely to the edge of the urban area of Radcliffe. A small area of potential sand and gravel lies on the north bank of the Trent opposite Radcliffe, but the northward extension of this possible resource may well be sterilised by the ramifications of Stoke Bardolph sewage treatment works in the adjacent, Carlton, district (Rathbone, 1989a).

The sand and gravel deposits of this stretch of the Trent valley, with particular reference to exploitation planning, were studied in depth by Spenceley (1971). Although the geological details and interpretations were not in total agreement with those deduced during the resurvey, being based in part upon the primary survey, the treatment of the sand and gravel as a potential resource would be difficult to improve.

Those limited exposures within active sand and gravel workings visible during the resurvey, and the logs of available boreholes, are not particularly instructive as to whether Bassingfield Sand and Gravel is preserved below the younger flood plain deposits. However, by implication, since upstanding 'islands' of these older gravels are mapped at surface within the flood plain, it is assumed that the same material is present locally at depth. If so, it can only be assumed that the Bassingfield deposits are extracted with the younger material and do not prove to be excessively 'clayey'. Some borehole records indicate a markedly higher density (marked by higher SPT values) at lower levels within the gravel sequence below the floodplain, possibly due to the presence of the older deposits.

Past workings within the Bassingfield Sand and Gravel have been limited. Two minor quarries are known to have been worked, the larger east of Bassingfield, the other east of Gamston. Both are mentioned in section 5.4. The surface extent of these deposits in the district covers about 3 square kilometres and their thickness is locally up to 5m. However, major parts of the outcrop have no resource potential due to sterilisation by buildings and much of the total area, away from the ridge crest, probably includes much thinner deposits. In addition, the available information indicates that at least part of the sequence is very 'clayey', and even that part previously worked at the Bassingfield pit was described as including pockets of clay (Posnansky, 1960). Thus, although the Bassingfield Sand and Gravel might represent a significant resource in terms of predicted volumes within the outcrop and beneath adjacent deposits, in terms of its overall quality it seems unlikely that it will be considered as a commercially viable commodity in the immediate future. In the meantime, minor extraction by local landowners and developers, from the less clayey upper levels, will probably continue.

7.4 SANDSTONE

One small disused sandstone quarry [6006 3974] occurs in the Sneinton Formation at Colwick. It is now largely backfilled and it appears that extraction was not very great. The small scale extraction of sandstone for building purposes has taken place elsewhere in the Nottingham area within this formation; in fact, part of the formation was formerly named the "Building Stones" (Hull, 1869).

7.5 MARL

Scattered small pits on the outcrop of the Gunthorpe and Edwalton formations were probably formerly worked for agricultural marl. Most of the pits are located in the steep faces below the Cotgrave and Hollygate Sandstone members. Marl is no longer of value to modern farmers and no extraction occurs today. Most of the pits are being rehabilitated into the landscape as a result of deep ploughing and soil creep.

7.6 HYDROCARBONS

No drilling for hydrocarbons has yet taken place in the district, but the area lies close to the productive parts of the East Midlands Oilfield, where important oil and gas accumulations have been proved (Kent, 1954, 1985). Minor hydrocarbon shows are recorded in deep coal exploration boreholes.

8 HYDROGEOLOGY

The high porosity and permeability of the Sherwood Sandstone Group have led to its development and exploitation as a major aquifer in many areas; in Nottinghamshire alone, some 450Ml per day are abstracted for public supply (Firman and Lovell, 1988). Pumping of the aquifer takes place from boreholes at depths of up to 500m and as far as 20km from crop (Bath and others, 1987). Historically, groundwater levels in the Nottingham region have continually fallen due to the scale of abstraction; however, since 1976 groundwater levels in the region have risen, with a concomitant overall fall in abstraction for industrial purposes (Firman and Lovell, 1988).

The water supply of Nottinghamshire has been described in a memoir by Lamplugh and Smith (1914). Water boreholes drilled in the district invariably tapped the Sherwood Sandstone aquifer. Records occur of scattered water boreholes being drilled for industrial supply in Nottingham region up until at least 1968.

In the Mercia Mudstone Group, the flow of water is mainly by fissure flow with some movement along the more porous 'skerries'. The yields are variable and unpredictable, but the quality is generally good. Disused wells occur scattered across the outcrop of the Mercia Mudstone Group.

On the Trent floodplain, the gravels contain a plentiful supply of water, but because the aquifer is shallow, it is affected by surface conditions and the quality is variable and commonly unsafe.

9 MAN-MADE DEPOSITS

The presence of man-made deposits has potentially serious implications for the present and future development of the region. They are discussed briefly below, but it is beyond the scope of this work to provide further details.

9.1 COLLIERY WASTE TIP

Large colliery waste tips [645 365] from Cotgrave Colliery occur north of Cotgrave village. The area is shown on the 1:10 000 Geological Map as "Made Ground". The Cotgrave tips have been partially landscaped and, in places, returned to agriculture. Within the large area of made ground are narrow tracts, along the railway lines and the Grantham Canal, where the man-made deposits are thin or absent; other parts of the area are covered by stockpiles of coal. The tips, which form a conspicuous feature of the district, particularly where not rehabilitated, generally consist of inert material, but probably include a considerable proportion of coal. They rest partly upon the Hollygate Sandstone Member, which contains water-bearing sandstones. The possibility of intermittent natural springs beneath the tips appears slight in the context of the local structure, but old versions of the Ordnance Survey maps of the area, produced prior to the tipping of spoil indicate "rises" on the edge of the affected area. After heavy rainfall flow from intermittent springs beneath tipped material can trigger downslope movement. The lessons taught by the Aberfan disaster should never be forgotten by future developers and planners.

9.2 BACKFILLED EXCAVATIONS

Backfilled excavations of various depth and size for sandstone, sand and gravel, clay for brick-making, marl pits and ponds are scattered across the district. Commonly, there is no surface indications of their former extent or, in some cases, of their actual presence. In many instances, details have been taken from archival material; in general, no information regarding the nature or state of compaction of the fill material is available.

There are many backfilled former sand and gravel pits in the Trent valley with no records of the type of infill material. Pits on the north side of the Trent [c.637 399] were, in 1988, scheduled to be infilled by slurried waste from Gedling Colliery to the north. Also north of the Trent, pits around [632 398] were licenced for the disposal of concrete waste; infilling was almost complete in 1988. South of this area a number of pits between the Trent and Radcliffe have been totally filled and the surface returned to farming; the nature of the fill is unknown. Westwards towards Holme Pierrepont several pits have been landscaped, with local infilling, to provide fishing ponds. Still farther west are the ramifications of the Holme Pierrepont National Water Sports Centre, where abandoned gravel workings have been landscaped, with some backfilling and some additional excavation, to provide a wide range of recreational facilities. The nature of fills used is unknown, and the same is true of a similar landscaped area north of the river which comprises the Colwick Water Park and Marina. Old pits east of the Colwick Water Park [c.616 396] are backfilled and derelict, also with no details available of the nature of the fill. Adjacent to active gravel workings south of Adbolton Lane are large areas of derelict pits which will ultimately be landscaped, but which appear to include backfilled sections. This fill is presumed to be redistributed material from adjacent excavations, but this is unconfirmed. The whole of the Colwick-Holme Pierrepont-Radcliffe on Trent section of the Trent flood plain should be treated with caution by planners and developers insofar as it is impossible to provide meaningful boundary lines between areas of natural, made and landscaped ground across much of the area. The situation is

dynamic, but in addition, the alteration of the landscape has been so rapid that detailed records of quarry limits and areas of tipping seem not to have been kept.

South of the A52 (Radcliffe) road is a small private tip at Bassingfield Quarry [626 377]. In 1988 the quarry appeared to be close to capacity, the visible material being predominantly building waste and domestic rubbish. No details of the nature of the whole of the backfill are, however, available.

9.3 GENERAL REFUSE TIPS, EXCLUDING BACKFILL

Domestic and industrial refuse tips contain a wide admixture of materials for which there are no reliable data. Archival records have proved inadequate in providing the total distribution of waste tips, and it is inevitable that not all have been located. Only minor rubbish tips have been identified in the district, though it is suspected that quantities of refuse will have been included within the backfilled areas mentioned above. A small area on the outskirts of Radcliffe [6438 3945] is partially covered by mixed domestic and building waste; elsewhere smaller tips exist, associated with farms and the larger, older, houses in the rural areas.

9.4 MADE GROUND, UNDIFFERENTIATED

This category consists of material deposited on top of the original land surface, though in some cases the top- and sub-soil may have been removed first. It includes major road and railway embankments, and other significant constructional areas. Within any developed area, such deposits are inevitably more widespread than can be economically mapped, only the more substantial areas of made ground have been shown on the geological map.

9.5 LANDSCAPED GROUND

Landscaped ground is not delineated on geological sheet SK63NW, but areas of significant landscaping are noted on the map. The notes are used for areas where the original land surface has been extensively re-modelled by earth-moving and tipping, but where it is impractical or impossible to delineate individual deposits of made ground or backfill. Made ground is usually extensive in such areas and substantial thicknesses may be present locally. It normally consists of topsoil, sub-soil and rubble but often includes material brought in from elsewhere, including waste and mining spoil. Landscaping is ubiquitous in urban areas and should be expected where urban development is shown on the topographic base map. In the Trent valley much of the ground between the mapped spreads of made ground and backfilled pits is landscaped and it is probable that areas of backfilled and made ground are present but undetected beneath the landscaped surface. Likewise, it is probable that a proportion of the area mapped as made ground on the evidence of topographic variation will be, in reality, merely landscaped.

10 GEOLOGICAL HAZARDS

This section is intended as a summary of the principal geological hazards identified in the area at the last date of survey. **It is not exhaustive and should not, under any circumstances, be used to replace any part of a geotechnical site investigation.**

10.1 LANDSLIP

The incidence of landslipping in an area is mainly influenced by the strength of the slope-forming material, the angle of slope, the underlying geological structure and the hydrogeological regime controlling the water content of the slope.

The unweathered Mercia Mudstone is a stiff to hard heavily overconsolidated mudstone composed mainly of silt-sized aggregations of clay minerals. It is usually sufficiently strong to sustain steep slopes without failure. Locally, thin sandstone bands transmit water through the Mercia Mudstone and minor landslipping might be expected to occur. However, no slips of this nature have been noted during the resurvey and nor were any major spring lines, which might eventually affect slope stability and promote landslipping, recorded.

However, weathered Mercia Mudstone is weaker and the aggregations may have broken up into their mineral components. The weathered zone of slopes is therefore susceptible to movement if there is a sufficient input of water from natural or artificial sources. Under the present climate, natural water input is not generally sufficient to promote movement. However, under the wetter, freeze/thaw, periglacial conditions at the end of the Devensian ice age, movement may have occurred as shallow landslips or solifluction. The degraded products of the processes described above may be preserved unrecognised on slopes today; they may include relict shear surfaces which could be reactivated by loading or undercutting slopes or by introducing water into the slope from drains or soakaways.

Two small areas of active or potential slip were noted in the district, the instability in both cases being caused by natural or artificial cutting and the nature of the geological structure. Several sections of the railway cutting at Colwick [6017 3973 to 6057 4000] show widening of joint or minor fault planes sub-parallel to the cut. This widening is being accelerated by vegetation growth and root activity as well as by climatic factors. A shallow dip into the cutting also contributes to the potentially unstable situation.

At the southern end of the river cliff at Radcliffe on Trent [c.6457 3979] are minor landslips and numerous large fallen blocks. Although the dip here is gently away from the river, providing an inherently stable situation, there has been a degree of undercutting, leading to the collapse of unsupported material. Locally the situation is made worse by minor flows of water which appear to spring from open joints after being channelled downwards from the surface or from thin sandstone beds within the sequence. Periodic freeze and thaw of the water within the minor joints and fractures above the undercut cliff-foot must contribute to the overall instability.

10.2 HEAD

Head deposits are poorly consolidated and may be susceptible to further downslope movement following periods of heavy rain, snow or frost, especially if undercut or loaded by an overlying structure. They may also contain relict shear surfaces which could be reactivated under certain conditions. Great care must therefore be taken to identify head deposits in site investigation boreholes and pits.

Head deposits at the foot of long and steep Mercia Mudstone slopes merit particular caution, as they may be thick and difficult to distinguish from bedrock. The presence of 'exotic' clasts derived from solid formations or drift deposits (eg."Bunter" pebbles) are a reliable guide to identification.

10.3 ALLUVIUM, RIVER TERRACE AND LACUSTRINE DEPOSITS

As a generalisation, layers and lenses of organic-rich silt and clay are not solution within alluvium, and peat has been recorded in several boreholes drilled within the Trent alluvium and has been exposed by trial pits within the fluvial and lacustrine deposits of the district. Organic rich deposits are normally highly compressible compared to their adjacent deposits, and could give rise to excessive and differential settlement of when loaded by overlying structures.

10.4 GYPSUM SOLUTION

Due to its solubility in freely flowing groundwater, extensive dissolution of gypsum has taken place within the Mercia Mudstone in a zone (the so-called solution zone) several metres thick below the base of the subsoil or drift deposits (Elliott 1961). Much of the solution seems to have been accomplished by groundwater flow along bedding planes, joints and fissures (Firman and Dickson, 1968). Although most of the solution of gypsum is believed to have taken place during glacial or periglacial conditions, the process may be continuing, albeit much more slowly, today (Firman and Dickson 1968). In borehole cores from below the solution zone, gypsum veins and nodules may constitute over 30% of the total thickness in parts of the sequence. However, almost no gypsum is exposed at crop in the Nottingham area, except in areas where the rateof erosion exceeds the rate of solution, for example on river cliffs or in man-made excavations (Firman and Dickson 1968).

The depth of the solution zone is controlled mainly by groundwater circulation conditions. Normally, the zone is only a few metres thick. However, in the vicinity of faults and heavily jointed areas, the depth of the solution zone may be as much as 30m (Elliott, 1961). In areas where the solution zone is deeper, lowering of the land surface will be greater due to the removal of a greater volume of gypsum from the sub-surface. Solution depressions created by this process have been mapped in several parts of the Nottingham area, principally on the crop of the Cropwell Bishop Formation (Charsley and others, in press). Irregular, often closed, depressions, not explainable by normal patterns of surface erosion, are ubiquitous on the crop of this formation (Howard, 1989).

In the Ripon area, North Yorkshire, solution of Permian gypsum has generated major subsidence problems (Cooper 1986, 1988). No similar examples have been recognised in the Nottingham area, where gypsum solution has, to date, not proved to be a geotechnical hazard. However, this may be due to the paucity of urban development on the outcrop of the Cropwell Bishop Formation, the main gypsiferous horizon within the Mercia Mudstone.

There are three possible circumstances in which gypsum solution could produce geotechnical problems in this area:

(a) Collapse of underground solution voids.

This factor is the principal cause of subsidence in the Ripon area (Cooper, 1986), where groundwater solution along joints in thick beds of gypsum forms large cavities; these subsequently collapse, causing foundering of overlying

strata. This is far less likely to occur in the Nottingham area for two main reasons. Firstly, groundwater flow within the gypsum beds and adjacent strata in the Cropwell Bishop Formation seems to be considerably less than in the Permian rocks of the Ripon area, limiting the rate of solution taking place at present. Secondly, although gypsum makes up a fairly large proportion of the Cropwell Bishop Formation by thickness, most of it is disseminated as thin veins or small nodules, limiting the potential size of cavities. Only in the thicker Tutbury and Newark gypsum beds could significant voids form; a cavity occupying the full thickness of the Tutbury Gypsum could, in theory, have a maximum height of 2.5m. However, in view of the probable very slow rate of gypsum solution, it is very unlikely that such a large cavity could develop under natural groundwater conditions. Moreover, there is no field evidence of subsidence hollows produced by collapse of any such cavities on the crop of the Cropwell Bishop Formation: those subsidence depressions that are present almost certainly reflect fluctuations in the depth of the gypsum solution zone and were probably formed by gradual lowering of the land surface.

(b) Slow solution of gypsum.

Slow solution of gypsum below a man-made structure could lead to uneven foundation settlement and result in structural damage.

(c) Unconsolidated "pocket" sediments.

Unconsolidated sediment deposited within natural solutional depressions ("pocket" deposits), may be highly compressible and could cause excessive and possibly uneven settlement and structural damage.

Within the district only the outcrop of the Cropwell Bishop Formation poses a significant risk of subsidence due to gypsum solution, a somewhat smaller risk being present on the outcrop of the Gunthorpe Formation. Areas of lacustrine deposits overlying solid rocks of both formations are believed to occupy depressions which are, at least in part, of solutional origin. However, the threat of significant or catastrophic subsidence into solutional cavities appears to be extremely small.

10.5 UNDERGROUND MINE WORKINGS

BGS archives indicate the presence of substantial underground coal workings beneath the Radcliffe on Trent district. Subsidence has undoubtedly occurred in the past, and the reader is strongly advised to contact British Coal for information regarding underground mining activities in this, or any other part of the Nottingham area.

The escape along faults of dangerous gases from abandoned mine workings should be considered a remote possibility, even with mining at considerable depth.

10.6 MAN-MADE DEPOSITS

Man-made deposits represent a potential hazard in three main ways:

(a) The often uncompacted or poorly compacted nature of man-made deposits can give rise to unstable foundation conditions. The composition can be highly variable from site to site and within short distances on a single site. In places deposits may be very weak or cavernous and cause excessive and uneven settlement. Organic material within made ground may rot, causing cavitation and settlement below surface structures. When spoil is dumped on a slope, the buried soil/organic layer may be weak and therefore might form a potential failure surface. Poorly managed groundwater flow can produce catastrophic failure of poorly compacted embankments and spoil heaps.

(b) Toxic residues, either as a primary component of the man-made deposit or generated secondarily by chemical or biological reactions, can migrate both within a deposit itself, and into adjacent permeable strata. This situation presents a potentially serious hazard with regard to landfill sites situated upon strata which are in hydraulic continuity with the Sherwood Sandstone aquifer or where possible hydraulic pathways along fault planes could lead to this formation.

(c) Toxic or explosive gases, particularly methane, can be generated within waste tips, landfill sites and in disused mine workings. Such gases can migrate - sometimes through adjacent permeable strata - and accumulate within buildings or excavations either nearby or some distance away (Aitkenhead and Williams, 1987). There are many backfilled sand and gravel pits in the Holme Pierrepont and Colwick areas for which no record of the infill materials has been located.

These possibilities should be addressed by appropriate geotechnical site investigations in areas where man-made deposits are likely to be present. The man-made deposits shown on sheet SK63NW represent those that were identifiable at the time of survey. They were delineated principally by the examination of documentary sources and the recognition - in the field - of those areas where artificial modification of the natural topography has taken place. Only the more obvious man-made deposits can be mapped by this method and the boundaries shown are likely to be locally imprecise.

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