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Geology of the Swadlincote and Church Gresley districts

1:10 000 sheets **SK31 NW** and **SK21NE**
Part of 1:50 000 sheets 141 (Loughborough),
155 (Coalville), 154 (Lichfield) and 140 (Burton)

J N CARNEY

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Swadlincote, Church Gresley, North-West Leicestershire, South Derbyshire

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1. INTRODUCTION

This report describes the geology of 1:10 000 sheets SK31NW (Swadlincote) and SK21NE (Church Gresley). The combined area (hereafter referred to as the 'district') falls mainly within the 1:50 000 Geological Sheet 141 (Loughborough), and partly within Geological Sheets 155 (Coalville), 154 (Lichfield) and 140 (Burton). The district was first geologically surveyed at 1:10 560-scale by E Hull between 1850 and 1860, and published as part of the Old Series One-inch geological sheets 62E and 63W. The primary survey of the district was carried out by C Fox-Strangways in 1892-1896 and published on the Derbyshire (DY) six-inch County Series Sheets DY59, 60, 61, 62, 63 and Leicestershire (L) Sheets L15 and 22 (detailed sheet compilations are given on the accompanying 1:10 000 maps). The One-inch to one-mile New Series Geological Sheet 141 (Loughborough) was published in 1904; an accompanying memoir was also produced (Fox-Strangways, 1905). Following amendments to the Coal Measures by G H Mitchell, shown on separate copies of the six-inch County Series Sheets, a revised one-inch sheet was published in 1950.

Sheet SK31NW was resurveyed south of gridline $^{3}181$ at 1:10 560-scale by B C Worssam in 1967-70. The same worker carried out a more extensive re-survey of Sheet SK21NE, to the south of gridline $^{3}165$ and west of gridline $^{3}270$. The mapping was completed at 1:10 000-scale by J N Carney in 1995, under the direction of T J Charsley (Regional Geologist). This later mapping constitutes part of the Loughborough Geological Mapping Project.

The easternmost sheet, *SK31NW*, lies partly within the North West Leicestershire District and partly within the South Derbyshire District administrative areas. The principal urban centres comprise the conurbation of Woodville and Swadlincote, and the smaller settlements of Moira and Blackfordby farther south. A gently undulating topography is developed on the Coal Measures whereas the more resistant Triassic strata, in the north-east, give rise to a low but commonly steep-sided dissected plateau attaining 184 m above OD. Rivers drain northwards to the Trent Valley, or southwards to reach the Trent via the River Mease. Mixed agriculture is practised in the north-eastern part of the sheet, with arable cultivation more important on the higher ground underlain by Triassic strata. Industry is centred on the exposed coalfield to the south-west of the Boothorpe Fault, where the Productive Coal Measures mainly crop out. Underground coal and clay mining has now ceased, and has been replaced by consumer industries, light engineering works, and factories based on the local fireclay resources. The opencast working of coal and fireclay has affected some 70 per cent of the land area, but all of the older sites have recently been returned to recreational use and/or rough pasture. At present there are three remaining voids, at the Donnington Extension [305 177], Albion [314 176] and Moira [316 162] sites: in 1995 opencasting mining for coal was started at the new Shellbrook site [329 163].

Sheet SK21NE lies within the South Derbyshire District administrative area. It includes the expanding urban conurbation of western Swadlincote and Church Gresley, and the smaller settlements of Overseal, Linton and Caldwell. The topography is gently undulating, rising to 125 m on Coal Measures strata at Church Gresley [299 190], and to a similar height on the Trias-covered ground near Park Farm to the south [269 152]. The north-eastern boundary of the Triassic outcrop is expressed as a discontinuous north-westerly ridge extending from Overseal to Castle Gresley and beyond this, to the northern margin of the map sheet. To the west of this ridge, the Triassic strata give rise to undulating ground, with a low-lying area in the north-west which encroaches upon the margin of the River Trent floodplain. The largest river system breaches the Triassic ridge at Castle Gresley, from where it flows north-west to join the River Trent south of Burton; the other streams drain westwards to the Trent. Underground coal extraction has now ceased, but originally occurred throughout the exposed coalfield and beneath the Linton, Coton Park and Caldwell areas of the concealed coalfield. Opencast workings for coal and fireclay formerly occupied most of the region between Overseal and Church Gresley, but these sites have since been returned to farming and/or recreational use. The single remaining quarry is Nadins Opencast Site, located west of Swadlincote [278 196], where coal is extracted down to the Main seam. Nadins site in part occupies a derelict industrial complex of factories that had grown along an old railway line; it borders a major area of regeneration on the outskirts of Swadlincote, involving the growth of light engineering, consumer industries, civic amenities and housing estates. Mixed agriculture with a large proportion of arable crop production is carried out in the rural areas to the west, underlain by Triassic strata or Drift; the former colliery sites at Linton and Coton Park are now in the process of restoration.

Corresponding reports covering contiguous 1:10 000 sheets are:

SK31NE (Ashby de la Zouch)	Carney, J N (1996)
SK32SW (Hartshorne)	Barclay, W J (1996)
SK22SE (Newhall-Bretby)	Barclay, W J, same report

An index to the adjacent 1:10 000 geological map sheets is given in Figure 1.

This report should be read in conjunction with the 1:10 000 scale geological sheets SK31NW and SK21NE. They show the outcrop limits of solid geological formations and superficial deposits. These are for the most part unexposed, being hidden beneath soil or man-made deposits. Their outcrop limits, represented by geological boundary lines, are mostly inferred from landforms and soil type, or are extrapolated from adjoining areas. The distribution of coal seams is chiefly determined by extrapolations of subsurface information, including mine plans, previous interpretations of coal exploration records (e.g. Spink, 1965) and opencast completion plans, and therefore cannot take into account the effects of local structural or sedimentological complexities. The map is therefore the interpretation of the surveyor, based on information to hand at the time of the survey, and all geological boundaries carry an element of uncertainty. Boundaries of solid formations which (in the opinion of the surveyor) can be located to an accuracy of 10 m or less on the ground, are shown as unbroken lines on the map; all other less-certain boundary lines are shown broken.

Copies of the 1:10 000 maps can be purchased from BGS, Keyworth. It should be noted that copyright restrictions apply to the use of these maps, or parts thereof, and to the direct copying of the illustrative and text material of this report. This report constitutes an internal

SK22SW	SK22SE	SK32SW	SK32SE
SK21NW	SK21NE	SK31NW	SK31NE
SK21SW	SK21SE	SK31SW	SK31SE

Figure 1 Location of the district with respect to adjacent 1:10 000 mapped sheets

publication of the BGS and any information extracted from it should be acknowledged by a bibliographic reference (see inside front cover).

Throughout this report, National Grid references are given in square brackets and all lie within 100 km grid square SK unless otherwise stated. The borehole numbers given are those of the BGS archives where they are prefixed by the number of the 1:10 000 map sheet.

2. GENERAL ACCOUNT

A stratigraphical summary of the district is given in Table 1. The oldest rocks, proved only in the Rotherwood Borehole, consist of dark grey mudstones and siltstones of Upper Cambrian age, which are correlated with the *Stockingford Shale Group*. These strata represent quiet-water suspension and distal turbidite deposits accumulated in outer shelf marine environments. They were laid down in the later stages of a marine transgression across the Precambrian landmass that had commenced in lowermost Cambrian times (e.g. Taylor and Rushton, 1971).

The deformation of the Stockingford Group, involving tilting, partial recrystallization and the imposition of a cleavage, is attributed to either or both of the Caledonian (Ordovician) and Acadian (Siluro-Devonian) structural events.

By Lower Carboniferous (earliest Dinantian) times the Central England crust was undergoing extension, to form a block-faulted terrane. The district occupied an uplifted landmass to the south-west of the Widmerpool Half Graben (Ebdon et al., 1990), remaining emergent during the Tournaisian and early Visean, but eventually subsiding upon the re-commencement of rifting later in the Visean (late Asbian to Brigantian), when it was submerged beneath seas transgressing from the north. The initial deposits of the *Carboniferous Limestone* are conglomerates and mudstones, the reddening in the latter perhaps indicative of lateritic weathering in the source region (Worssam and Old, 1988, p.3). Dolomitic limestones were next laid down in shallow waters, as part of a widespread but thin sequence that gradually wedges out southwards, towards the Wales-Brabant palaeo-high.

A hiatus in sedimentation followed, which lasted until the middle part of the Namurian (Kinderscoutian), when coarse-grained sandstones and intercalated mudstones of the *Millstone Grit Group* were laid down. The earliest Millstone Grit strata do not occur in this district, but they infilled the Widmerpool Half-Graben, which was no longer actively subsiding. By the middle part of the Namurian, however, the graben had been overtopped and the delta systems prograded southwards, lapping on to the Carboniferous Limestone across the district (Fraser and Gawthorpe, 1990; Leeder 1982). The succession is predominantly fluvio-deltaic in character, but also received periodic marine incursions.

Continued fluvio-deltaic and fluvio-lacustrine sedimentation in an area of subdued topography formed the *Coal Measures* sequence, whose conformable contact with the Millstone Grit is everywhere occupied by mudstones of the Subcrenatum Marine Band. The lowermost strata are similar to the Millstone Grit in containing relatively few coal seams; they are capped by a thick succession of sandstones correlated with the *Wingfield Flags.* The overlying Productive Measures, commencing at the Kilburn seam, are characterised by cyclic sequences of lacustrine mudstone, distributary channel siltstones and sandstones and coal seams. The horizons of the Vanderbeckei and Cambriense marine bands have been identified, showing that strata of the Lower, Middle and Upper Coal Measures are present. Modern interpretations indicate that several depositional environments co-existed, leading to complex lateral and vertical facies changes (Fulton and Williams, 1988; Guion et al., 1995, Table 1). This model is corroborated by sedimentological studies in Nadins Opencast Site undertaken in support of the present survey and presented in a separate report (Jones, 1995). Midway through the Middle Coal Measures the style of sedimentation changed, with the deposition of the *Pottery Clays formation.* These strata constitute a condensed depositional sequence: they exhibit the usual cycles of lacustrine mudstones, overbank siltstones and mudstones and distributary channel sandstones, but deposition was punctuated by protracted periods of pedogenesis under poorly-drained conditions, indicated by deeply-penetrating seatearth fabrics, and frequent episodes of peat mire accumulation (coal seams). A marginal marine situation for the district is further suggested by the several marine bands within the sequence.

As the culminating phases of Variscan deformation approached, the coal basin was uplifted, exposing the strata to local reddening and pedogenic weathering. Alluvial fan complexes spread across the district, depositing mudstones and sandstones constituting the *Etruria Formation* of the *Barren Measures* sequence (e.g. Corfield et al., 1996). The succeeding *Halesowen Formation* reflects a temporary return to poorly-drained conditions, and elsewhere in central England is unconformable on the Etruria Formation (Corfield et al., 1996). The topmost Westphalian unit, the *Meriden (Keele) Formation,* is a redbed association containing detritus eroded from the rising Variscan nappes to the south; it is interpreted as a regional molasse-type deposit by Besly at al. (1993).

The final Variscan movements formed a block-faulted terrane across the district. The principal structures, with north-westerly orientations, are probably reactivated basement boundaries whose formation dates back to 'Charnian' (Precambrian) or 'Caledonian' (Ordovician to Silurian) orogenic events. The Boothorpe Fault, with south-westerly normal downthrow, was responsible for the preservation of the Productive Coal Measures sequence within a gentle, south-east plunging syncline. A parallel structure extends north-westwards from Overseal but is wider and considerably more complex than the Boothorpe Fault, possessing systems of elongated basins and domes disposed in a pattern suggestive of sinistral transcurrent movement between underlying blocks. This structural axis is possibly associated with a transference of displacement between the Coton Park Fault in the north, and the Netherseal Fault. The latter structure trends south-westwards and may pass southwards in to the Western Boundary Fault of the Warwickshire Coalfield. Structures subordinate to the north-westerly faults have northerly and east-north-easterly trends. The former indicates a Precambrian ('Malvernian') structural inheritance, while the north-easterly cross-faults are of a trend that is dominant in Charnwood Forest, and could have been transmitted from Precambrian or Caledonian-age basement discontinuities.

The earliest Triassic strata, deposited on an irregular and eroded Carboniferous land surface, are the clay- or sand-matrix, subangular conglomerates of the *Moira Formation*, referred to the base of the *Sherwood Sandstone Group*. The unit is distinctive in containing locally-derived clasts of extremely low sphericity, some showing wind-faceting. Their lithologies indicate derivation by the erosion of Carboniferous and Precambrian (Charnian) fault-blocks that had been uplifted by the Variscan earth movements. The deposits may represent either colluvial debris flows, or accumulations of material rapidly deposited from sheetfloods. The clasts evidently had a long history of weathering and wind-abrasion before incorporation into the Moira Formation, and are suggested to have originally lain on a pediment surface. The processes of scouring and gully erosion that eventually concentrated the clasts may have been triggered by steepened gradients during development of the north-eastern marginal slopes of the Needwood and Hinckley basins of Triassic deposition. Isopach maps suggest that the Moira Formation occupies west or south-west orientated channels, consistent with such an origin (see also Worssam and Old, 1988, Figure 14). The succeeding coarse-grained sandstones and conglomerates of the *Polesworth Formation* rest with irregular base on the Carboniferous rocks. Their feather-edge lies in Sheet SK31NW, from where they thicken westwards, in to the north-eastern flank of the Needwood Basin which is represented in Sheet SK21NE. The predominant Polesworth clast lithologies indicate a distant source region, probably in northern France or southern England (e.g. Audley-Charles, 1970), and their high degree of roundness is indicative of a long transport history; a subordinate population of clasts are subangular, however, and may have been derived locally from the underlying Carboniferous strata. The sedimentary architecture and coarse grain size of the Polesworth Formation indicate proximal fluvial channel environments, with little preservation of distal channel or overbank facies: foreset inclinations suggest deposition from north to north-westwards-flowing river systems.

Faulting and/or flexuring imposed irregularities on the top surface of the Polesworth Formation, before deposition of the predominantly fine-grained argillaceous sandstones and laminated, slightly micaceous mudstones of the *Bromsgrove Sandstone Formation.* These beds represent upwards-fining alluvial cycles (e.g. Worssam and Old, 1988, Figure 17), the thickness of the intercalated mudstones and siltstones indicating the formation of extensive floodplains or ephemeral lakes. The gradients of the rivers were probably lower than those typical of the Polesworth Formation, and this may have been a consequence of sedimentation outstripping the rate of subsidence within the rapidly-filling Needwood Basin.

A further progressive diminution of the arenaceous clastic supply resulted in an upwards gradation into the strata of the *Mercia Mudstone Group*. The laminated silty and sandy mudstones of the *Sneinton Formation* and the *Radcliffe Formation* reflect deposition within ephemeral bodies of shallow water, into which arenaceous material was supplied by floodwater from distant river systems. The blocky and massive mudstones of the overlying *Gunthorpe* and *Edwalton formations* probably resulted mainly from the accumulation of wind-blown sediment (Arthurton, 1980, p.54).

A second tectonic episode, of unspecified Mesozoic or Cenozoic age, reactivated many of the principal Carboniferous faults which were transmitted, with reduced throw, through the

Triassic strata. One important post-Triassic structure has defined the present north-eastern boundary of the Polesworth Formation on Sheet SK21NE; a west-throwing normal fault would be compatible with observations that the Triassic strata hereabouts are commonly tilted to the south-west at angles of up to 22 degrees.

Any strata deposited between the early Triassic and Quaternary period were removed by erosion in Mesozoic to Cenozoic times.

The earliest Quaternary deposits comprise till derived from ice sheets which inundated the area. The age of this glacial advance was previously placed within the 'Wolstonian' (Saalian of Europe) Stage of the Upper Pleistocene (e.g. Rice, 1968), but the weight of new evidence from the English Midlands now suggests that it was older, belonging to the Middle Pleistocene (Elsterian) Stage which deposited the glacial drift of East Anglia and Warwickshire (Sumbler, 1983). During the Anglian glaciation of Central England ice-flow was initially from the north-west with Pennine Ice advancing from the north. This was succeeded by ice that moved across from Scandanavia and eastern Scotland (e.g. Rose, 1994). The north-western advance is represented in this district by red-matrix tills enclosing 'Bunter' quartz pebbles and sandstone fragments of mainly Triassic derivation. The Glaciolacustrine Deposits of Sheet SK21NE are stoneless clays representing the remnants of former glacial lakes that developed either beneath the ice sheets or along their margins. Geographically, these deposits have been placed within the 'Lullington Valley' province of glaciogenic sedimentation, rather than being part of the type 'Wolston' succession of Leicestershire and Warwickshire (Worssam and Old, 1988, Figure 22). Streams which flowed beneath or along the front of the ice sheets left behind Glaciofluvial Deposits of sand and gravel, now found either as lenses within the till or as more extensive superficial spreads.

The present topography of the district was moulded by the phases of stream incision that accompanied and followed ice retreat. The sands and gravels of the River Terrace Deposits, in Sheet SK21NE, accumulated after the final withdrawal of the ice sheets. As the rivers cut down into glacial deposits and underlying bedrock, each phase of aggradation and rejuvenation left behind the deposits of former floodplains, which are now seen as terraces perched on the valley sides. The youngest units in the area consist of patchily-developed deposits of alluvium and head. The latter consists of weathered bedrock or glacial material transported downslope by solifluction processes.

3. CAMBRIAN

3.1. Stockingford Shale Group *(Sheet SK31NW)*

Cambrian strata were proved beneath Carboniferous Limestone in the BGS Rotherwood Borehole (SK31NW/260)[1], between 173.9 m and the bottom of the hole at 199.0 m depth. They consist of dark grey, thinly bedded mudstones and siltstones with nodules of siderite

[1]For borehole details see Section 10

and dolomite. Acritarch assemblages indicate a Merioneth (Upper Cambrian) age for the sequence (Worssam and Old, 1988, p.20). The overall lithology and biostratigraphy of these beds invite correlation with the middle to upper part of the Stockingford Shale Group, whose main outcrop is in the Nuneaton inlier (Taylor and Rushton, 1971).

AGE	UNIT	THICKNESS (m)
QUATERNARY	DRIFT:	
	Head	up to 3
	Alluvium	up to 3
	River Terrace Deposits	~2
	Glaciofluvial Deposits	?up to 9
	Glaciolacustrine Deposits	?up to 11
	Till	up to 6
TRIASSIC		
	MERCIA MUDSTONE GROUP	
	Edwalton Formation	23+
	Cotgrave Sandstone Member	~2.5
	Gunthorpe Formation	~73
	Radcliffe Formation	13
	Sneinton Formation	12
	SHERWOOD SANDSTONE GROUP	
	Bromsgrove Sandstone Formation	30-100
	Polesworth Formation	0-170
	Moira Formation	0-42
UPPER CARBONIFEROUS		
	BARREN MEASURES	
	Meriden Formation	38+
	Halesowen Formation	69
	Etruria Formation	36-45+
	COAL MEASURES	
	Upper Coal Measures	20+
	Middle Coal Measures	285-310
	Lower Coal Measures	290-400
	MILLSTONE GRIT GROUP	66-73+
LOWER CARBONIFEROUS		
	CARBONIFEROUS LIMESTONE	112
UPPER CAMBRIAN	STOCKINGFORD SHALE GROUP	25+

Table 1 Sequence of geological units in the district (some of these subdivisions may be revised at a later date, and may thus not appear on the published maps)

The Cambrian strata dip at 60-70° and are affected by a strong cleavage oriented at right angles to the bedding; their deformation is discussed in Section 8.1

4. LOWER CARBONIFEROUS (Dinantian)

4.1. Carboniferous Limestone (Visean) (*Sheet SK31NW only)*

Carboniferous Limestone forms a 112.4 m thick sequence in the Rotherwood Borehole, described by Worssam and Old (1988, p.21). The basal beds, unconformably overlying the Cambrian strata, commence with 4.3 m of sandstone, siltstone and conglomerate, the latter with Cambrian mudstone and Dinantian limestone clasts. They are succeeded by 5.1 m of red, ochreous mudstone which in turn is overlain by 14.6 m of grey mudstones with marine shelly faunas. The latter are abruptly overlain by an 80 m-thick sequence consisting mainly of limestone and dolomite, with subordinate mudstone, siltstone and sandstone beds. Certain carbonate sequences exhibit calcareous nodules within a matrix of dark grey, laminated and highly fossiliferous mudstone. The topmost Carboniferous Limestone strata comprise 7.5 m of grey fossiliferous siltstones and mudstones. These are succeeded with apparent conformity by the Millstone Grit, but the latter's mid- to upper Namurian age suggests that a sedimentary break must have occurred across this interval.

A Brigantian age was deduced from corals found in the carbonates of the Rotherwood Borehole (Worssam and Old, 1988, p.22).

5. UPPER CARBONIFEROUS (Silesian)

5.1. Millstone Grit Group (Namurian)

The Millstone Grit crops out only on Sheet SK31NW, but is inferred to conformably underlie the Lower Coal Measures throughout both map sheets. It rests with non-sequence upon Brigantian-age beds of the Carboniferous Limestone in the Rotherwood Borehole, and only the latest three stages of the Namurian are represented (Figure 2), these being the Kinderscoutian (R_1), Marsdenian (R_2) and Yeadonian (G_1). The marine bands which define these stages are all present except the Bilinguis Marine Band, which is generally absent from the eastern Midlands sequences (Ramsbottom *in* Taylor and Rushton, 1971 p.59).

Worssam and Old (1988, p.23) note that palaeontological correlations between local Millstone Grit sequences are problematical, first because data from the older boreholes is sparse and in particular the Subcrenatum Marine Band, marking the base of the Coal Measures, cannot generally be identified with certainty. Second, many goniatite-pectinoid-phase marine bands are replaced southwards by *Lingula* bands whose correlation is uncertain.

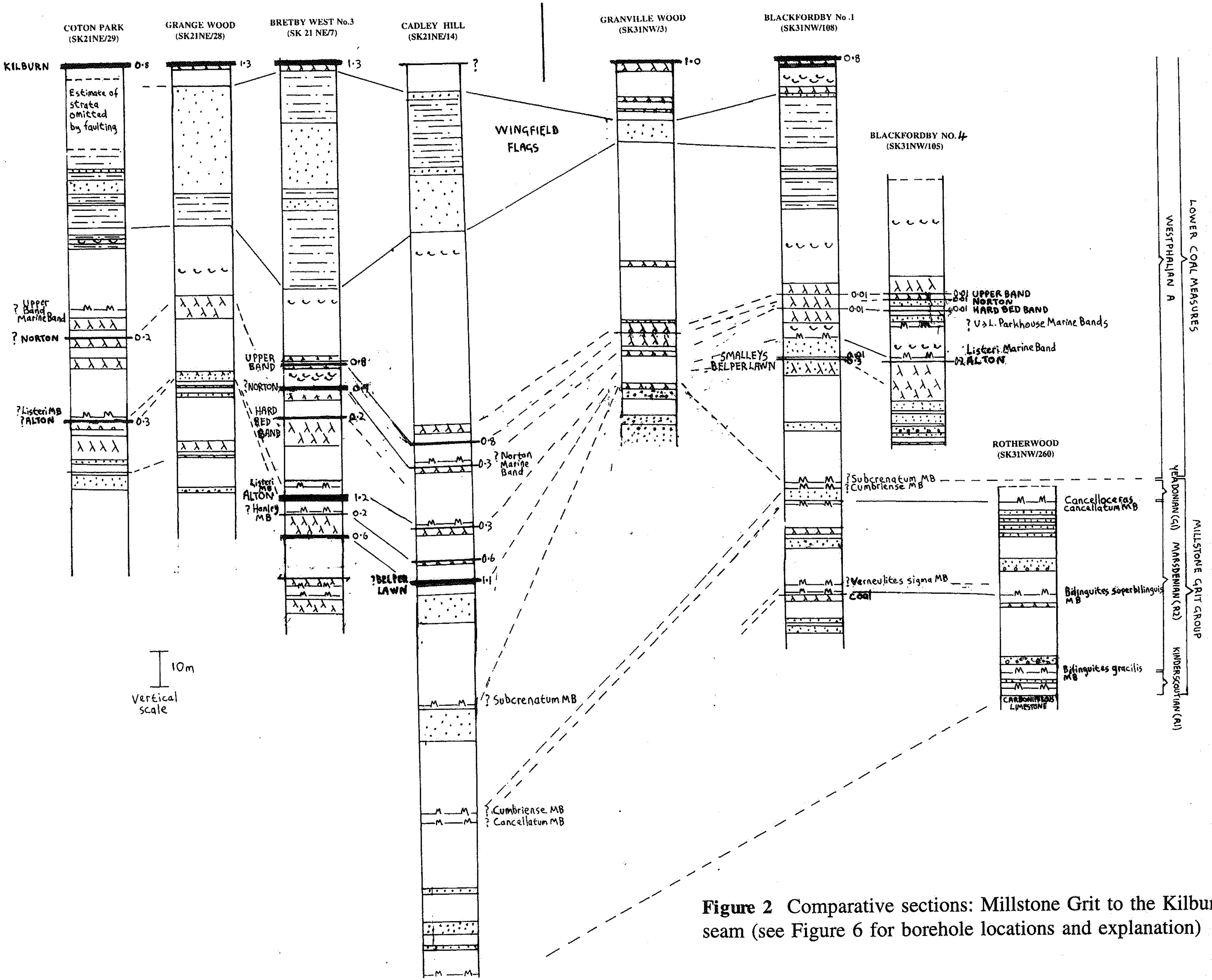


Figure 2 Comparative sections: Millstone Grit to the Kilburn seam (see Figure 6 for borehole locations and explanation)

Details; Sheet SK31NW

A total thickness of 66m can be estimated for the Millstone Grit if the *Lingula*-bearing mudstones at 137.2 m in the Blackfordby No.1 Borehole (SK31NW/108) represent the Subcrenatum Marine Band.

The outcrop of Millstone Grit near Valley Farm [3445 1545] is faulted against the Coal Measures on either side, and overlain by Triassic strata to the south-west. Mapping shows that beds of coarse-grained and pebbly sandstone are intercalated with mudstone which weathers to stiff grey clay. The Rotherwood Borehole, sited on this outcrop, proved 61.5 m of Millstone Grit (Figure 2). The borehole details (Worssam and Old, 1988, p.24) include faunal identifications of fish debris, bivalves and goniatites indicative of the **Gracilis** and **Superbilinguis** Marine Bands both being present. A further marine band, 4.5 m from the top of the hole, was tentatively identified as the **Cancellatum Marine Band**. It was suggested that by comparison with the Blackfordby No.1 Borehole (see below), the Rotherwood Borehole must have commenced about 20 m below the top of the Millstone Grit. This may be erroneous, however, because in the Blackfordby No.1 Borehole the Cancellatum Marine Band occurs only about 5 m below *Lingula*-bearing beds marking the Subcrenatum Marine Band.

The lowest proven Millstone Grit beds in the Blackfordby No.1 Borehole comprise 3 m of grey, micaceous, laminated mudstones and siltstones. These are overlain by 2.2 m of grey, upwards-fining sandstone and then by two further sandstone beds, each being 0.8 m thick. The stratigraphical level of these sandstones is equivalent to that of the Ashover Grit in the Derby district (e.g. Frost and Smart, 1979). They are succeeded by 7.2 m of green-grey siltstone and mudstone, then by 0.15 m of coaly shale surmounted by a thin coal seam. The overlying **Superbilinguis Marine Band** has yielded a fauna of *Reticuloceras reticulatum* mut y, *Lingula* and unspecified marine lamellibranchs accompanied by fish fragments. It is succeeded within one metre by the **Verneulites sigma Marine Band**, with *Gastrioceras ?sigma*, *Lingula* and fish fragments (identifications by J E Wright). The next interval comprises 10 m of predominantly dark grey, laminated, micaceous and pyritous mudstones succeeded by 3 m of grey, coarse-grained to pebbly sandstone. This is overlain by 10 m of green micaceous siltstone and brown micaceous mudstone, the latter with a seatearth at the base. Capping these beds, the **Cancellatum Marine Band** is a black mudstone which contains goniatite fragments tentatively identified as *Gastrioceras cancellatum*, accompanied by *Lingula* and fish fragments. The succeeding interval is primarily occupied by a 3.6 m bed of grey, laminated sandstone, parts of which are coarse-grained and pebbly. Resting on the sandstone are dark grey mudstones containing the **Cumbriense Marine Band,** with a fauna of *Gastrioceras cumbriense*, *Lingula*, *?Dunbarella*, fish fragments and foraminifera. The 1.5 m interval between this and the Subcrenatum Marine Band is occupied by dark grey mudstone, It is noted that the sandstone between the Cumbriense and Cancellatum marine bands is not represented in the Dole's Farm Borehole, on the adjacent map sheet to the east (Carney, 1996), nor is it present in the Derby district (Frost and Smart, 1979). Similarly, the Rough Rock, located elsewhere between the Subcrenatum and Cumbriense horizons, is absent from here.

In the Granville Wood or Granville Colliery Borehole (SK31NW/3), a possible proving of Millstone Grit was made at 133 m depth (Mitchell and Stubblefield, 1948). This was not substantiated by faunal evidence, but by the occurrence of coarse-grained and pebbly sandstones between 143 and 145 m depth. Figure 2 shows that for these strata to be Millstone Grit would require the attenuation of the Lower Coal Measures sequence below the Kilburn seam. The sandstones may instead equate with the coarse-grained sandstones occurring about 20 m below the Alton seam in the Blackfordby No.4 Borehole.

Details; Sheet SK21NE

No boreholes on this sheet have penetrated to the base of the Millstone Grit Group. In the Bretby West No.3 Borehole (SK21NE/7), the Lower Coal Measures are faulted against a seatearth which forms the highest bed of the Millstone Grit. It is underlain by black to dark grey mudstones with *Lingula*, *Dunbarella*, fish fragments and goniatites indicative of the **Cancellatum Marine Band**. About 3 m below this are further dark grey mudstones with *Lingula.* They are underlain by 4 m of seatearth extending to the base of the hole.

In the Cadley Hill Borehole (SK21NE/14) the horizon of the Subcrenatum Marine Band was tentatively identified as the dark grey mudstones with *Lingula* at 475 m depth. It overlies 7.6 m of sandstone which may be equivalent to the Rough Rock. Notes on the borehole log suggest that the horizons with goniatites and *Lingula* about 18 m below this sandstone may be the Cumbriense and Cancellatum marine bands. This correlation was not substantiated by faunal identifications, but if correct would indicate a greater thickness for the Subcrenatum to Cumbriense sequence compared with that in Sheet SK31NW farther east (Figure 2). This borehole also proves that the Millstone Grit is at least 73 m thick hereabouts.

5.2. Coal Measures (Langsettian to Bolsovian)

The Coal Measures of this district form a continuous sequence which Fox Strangways (1907) originally placed within a single 'Leicestershire and South Derbyshire Coalfield'. There are, however, two principal areas of coal extraction, which have come to be known as the Leicestershire Coalfield, in the east, and the South Derbyshire Coalfield to the west. Spink (1965) placed the boundary between these two coalfields at the Boothorpe Fault, in Sheet SK31NW, believing that the lithological characteristics of the measures were different on either side. On the other hand, Worssam and Old (1988) followed the practice of Mitchell and Stubblefield (1948) in placing the coalfield boundary along the axis of the Ashby Anticline, which lies to the east of the two mapped sheets. The latter practice is followed in this report, so all of these strata are assigned to the South Derbyshire Coalfield. The reasons for doing this are twofold; first, it cannot be shown for certain that all stratigraphical variations between the two coalfields occur across the Boothorpe Fault. Secondly, coal-seam nomenclature differs between the two coalfields (Spink, 1965, Figure Table 1), and it is more convenient to place the boundary along a structural axis from which the bulk of the succession has been removed by erosion, and which therefore corresponds to an area of greatly reduced mining activity.

On Sheet SK21NE, the South Derbyshire Coalfield comprises an exposed part, in the east, and a 'western extension' concealed beneath Triassic strata to the west of the Netherseal Fault (e.g. Jones, 1975; Greig and Mitchell, 1955). Elsewhere the Triassic cover is patchy and does not warrant further division of the coalfield into concealed or exposed parts.

Natural exposures of the Coal Measures are rare, but information from old shaft and borehole records, and from transient exposures in some of the large opencast sites, shows that the succession comprises cyclic repetitions of mudstones, siltstones and seatearths, with subordinate beds of sandstone and ironstone, and numerous seams of coal. The Subcrenatum, Vanderbeckei and Aegiranum marine bands (Ramsbottom et al., 1978) have been identified. They allow the sequence to be subdivided since they mark, respectively, the bases of three stages (Langsettian, Duckmantian and Bolsovian, respectively the former Westphalian A, B and C Series). Langsettian corresponds with the Lower Coal Measures, but the Middle Coal Measures covers both the Duckmantian and the lower part of the Bolsovian. Within the latter stage, the base of the Upper Coal Measures is taken at the Cambriense Marine Band. In the western, concealed coalfield the highest beds of the Upper Coal Measures are overlain by redbeds of the Barren Measures, belonging to the Bolsovian and Stephanian stages.

In the Middle Coal Measures above the Upper Kilburn seam an important facies change occurs, to a sequence with several marine bands, numerous coal seams and thick intervening seatearths, many of the latter being resources of high quality fireclay. This sequence, informally known as the Pottery Clays Formation, extends from just below the Maltby Marine Band upwards to include the whole of the Upper Coal Measures. The Aegiranum (Mansfield) Marine Band was recognised in these strata by Mitchell and Stubblefield (1948), in Robinson and Dowler's Clay Pit at Overseal, and they gave it the local name of the Overseal Marine Band. They also found two lower *Lingula* bands, which Calver (1968) correlated with the Maltby (Two Foot) and Haughton marine bands. Worssam and Old (1988, p.34) reported that the Clown Marine Band occurs in the Acresford No.6 Borehole of the Coalville district, while the present report reviews literature which indicates a further *Lingula* horizon, equivalent in position to the Sutton Marine Band. Above the Aegiranum Marine Band, recent discoveries have been made of marine horizons up to and including the Cambriense Marine Band, as well as of tonsteins (Worssam et al, 1971; Worssam, 1977). Therefore the South Derbyshire Coalfield has the full complement of late Duckmantian marine horizons found in neighbouring coalfields. The biostratigraphical correlations demonstrate that the Pottery Clays Formation is a condensed sequence, only about as quarter as thick as sequences at the same stratigraphical level in North Derbyshire and Nottinghamshire (e.g. Frost and Smart, 1979).

Comparative sections in the Coal Measures across the two map sheets are shown in Figures 2-5. The records on which they are based commonly lack details of seatearths and fossil horizons, but their absence from the sections does not necessarily mean that they do not occur in the sequence. The numerous coals of the Pottery Clays are difficult to correlate individually, except where the marine bands or tonsteins occur, and the convention of numbering them, devised by Jago (*in* Worssam et al, 1971; Worssam, 1977) is adopted here as in the Coalville district farther south (Worssam and Old, 1988). This system was adapted from that formerly used by the NCB Opencast Executive, and is based on the sequence originally exposed in Ensor's No.1 Quarry, Woodville [3060 1765], on Sheet SK31NW, where the coals were numbered downwards from 1 to 8. By adding the number 20 to each of these, to allow for the naming of higher seams outside the quarry, and the prefix P (for Pottery), these became the P21 to P28 seams. The seatearth below P40 is the lowest worked for fireclay, and so to complete the nomenclature of the sequence the numbers P41 to P43 have been given to the three thin seams above the Upper Kilburn. Further discussion of the revised numbering of these seams is given in Worssam and Old (1988).

Summary descriptions of the Coal Measures are given in Hull (1860), Fox-Strangways (1907), Mitchell and Stubblefield (1948), Spink (1965) and Worssam and Old (1988). A detailed history of shallow and deep mining activities in the district can be found in Owen (1984).

5.2.1. Lower Coal Measures (Langsettian)

This division constitutes the beds between the base of the Subcrenatum Marine Band and the base of the Vanderbeckei (Bagworth) Marine Band. A comparison of borehole records (Figures 2 & 3) suggests that for *Sheet SK31NW*, in the east of the district, the Lower Coal Measures have a maximum thickness of about 290 m (combined logs for Blackfordby No.1 and Granville Colliery No.2). For *Sheet SK21NE*, to the west, the sequence is commonly faulted, making thickness estimations more hazardous, but a figure of 400 m can be suggested if the sub-Kilburn strata in the Cadley Hill Borehole and supra-Kilburn strata of the Ashley House Borehole are considered together. By contrast, the Lower Coal Measures of the Leicestershire Coalfield, in the adjacent Ashby district, are about 216 m thick (Carney, 1996). Fulton and Williams (1988) suggested that the westwards thickening occured at the Boothorpe Fault, but due to the removal of most of the Lower Coal Measures on the upthrown side of the fault this cannot be proved.

The strata crop out in the eastern part of Sheet SK31NW, but are largely concealed beneath the Middle Coal Measures and/or Triassic beds in the west of Sheet SK21NE.

On *Sheet SK31NW* the **Subcrenatum Marine Band** (Pot Clay Marine Band) is identified at 137 m depth in the Blackfordby No.1 Borehole (notes by J E Wright) as dark grey mudstones with *Gastrioceras subcrenatum*, *Lingula*, foraminifera and fish debris. Worssam and Old (1988) took the base of the Coal Measures to be the lower surface of a mudstone bed seen to rest on coarse-grained pebbly sandstone near Valley Farm [3445 1545]. On *Sheet SK21NE*, it was tentatively identified at 468 m depth in the Cadley Hill Borehole, as a dark grey mudstone with *Lingula* and possible goniatites.

The succeeding beds in *Sheet SK31NW* consist principally of grey laminated micaceous mudstones and siltstones with 2.5 m of pale grey fine-grained sandstone in the Blackfordby No.1 Borehole. A possibly equivalent sandstone bed between 68.9 and 70.9 m depth in the Blackfordby No.4 Borehole (SK31NW/105) is coarse-grained and pebbly, with quartz, sandstone and siltstone clasts. It is possibly the same as the coarse-grained yellow sandstone mapped by Worssam and Old (1988) near Valley Farm [3450 1525]. In Blackfordby No.4

Borehole the sandstone is overlain by further sandstones succeeded by 11 m of seatearth which may be a lateral replacement of the Smalleys and Belper Lawn seams seen in the Blackfordby No.1 Borehole. In *Sheet SK21NE* (Figure 2) the Belper Lawn, Smalleys and Alton seams commonly fail, making correlations between boreholes difficult to maintain. The 'quartz grit' at 838 m depth in the Grange Wood Borehole (SK21NE/28) may, however, correlate with the pebbly sandstone mentioned above.

The **Belper Lawn** and **Smalleys** are insignificant and discontinuous coal seams. In *Sheet SK31NW* they are represented in the Blackfordby No.1 Borehole by two thin seams of dirty, pyritous coal, separated by seatearth: the lower, Belper Lawn seam rests on a sandy and coarsely micaceous seatearth. In *Sheet SK21NE* the equivalent sequence is thicker and better-developed. For example, in the Cadley Hill Borehole the Belper Lawn, 1.1 m thick, rests on seatearth and dark mudstones which in turn are underlain by 7.6 m of pale grey sandstone. It is overlain by 5 m of grey mudstone capped by 0.6 m of coal which is equated with the Smalleys seam. The Belper Lawn to Smalleys sequence in the Bretby West No.3 Borehole is occupied by 4.5 m of seatearth, with the Smalleys seam succeeded by grey mudstones with the marine fossils *Dunbarella*, *Posidoniella* and fish fragments. These beds resemble the succession between the Belper Lawn and Holbrook coals of the Derby district (Frost and Smart, 1979, Figure 12), in which case, by correlation, the fossil horizon may equate with the **Honley Marine Band** in the Ashbourne and Cheadle district (Chisholm et al., 1988, Figure 16). Problems of correlation are caused by the condensed nature of this part of the Coal Measures succession, however, and it is equally possible that the marine band may correlate with one of the Smalley's marine bands in the Derby district.

The **Alton** seam, like the coals below, is discontinuosly developed in the east of the district. In *Sheet SK31NW* it is 0.2 m thick in the Blackfordby No.4 Borehole, and absent from the Blackfordby No.1 Borehole, where the sequence between the Listeri Marine Band and the Smalleys seam is occupied by 4.4 m of pale green, fine-grained sandstone. The available records for *Sheet SK21NE* suggest that the Alton seam is between 0.3 and 1.2 m thick. The **Listeri Marine Band** (Alton Marine Band) everywhere rests on the Alton seam, the two beds forming an easily recogniseable stratigraphical marker horizon. In *Sheet SK31NW* it is represented in the Blackfordby No.1 Borehole by black pyritous mudstone with *Lingula.* At the same horizon in the Blackfordby No.4 Borehole *Lingula* is abundant and accompanied by fish scales. In *Sheet SK21NE,* the record for the Bretby West No.3 Borehole shows that the Listeri Marine Band consists of about 5 m of dark grey mudstones with *Lingula* and fish debris. In the lower part of the interval, *Anthroconauta*, *Dunbarella*, and *Posidonia* also occur. By contrast, fossils were only recognised in 3 inches of measures forming the roof of the Alton seam in the Coton Park Borehole (SK21NE/29); they include *Dunbarella, Anthracoceras* and conodonts suggesting a comparison with the Listeri Marine Band seen in the Stanhope Bretby and Cadley Hill sequences (Notes by D C Greig accompanying the log). In the Grange Wood Borehole the marine band is replaced by grey sandstone.

Mudstones and seatearths between the Listeri Marine Band and the Hard Bed Band coal seam form a sequence between 8 and 12 m thick in *Sheet SK31NW.* The Blackfordby No.4 Borehole shows mussel-bearing mudstones and then, 7.6 m above the Listeri Marine Band, a marine band with fish scales and abundant *Lingula*. This marine band is not associated with a coal seam, and may be equivalent to the **Upper and Lower Parkhouse Marine Bands** of the Derby district (Frost and Smart, 1979, Figure 12); it is overlain by grey massive sandstones with thin siltstone and mudstone layers, replaced laterally by seatearth in the Blackfordby No.1 Borehole. In *Sheet SK21NE* the Listeri Marine Band is succeeded by 15-20 m of grey micaceous mudstone and siltstone capped by the seatearths of the Hard Bed Band.

The **Hard Bed Band, Norton** and **Upper Band** form a closely-related grouping of thin coal seams which are commonly represented only by seatearths. In *Sheet SK31NW* they are identified within a 4.5 m sequence in the Blackfordby No.4 Borehole: the seatearth of the Hard Bed Band is underlain by about 2 m of massive, pale grey sandstone which, according to Worssam and Old (1988), is equivalent to the hard, grey, silty, ganisteroid sandstone forming a low dip slope at Shell Brook [338 164]. At the latter locality Opencast Executive boreholes proved two thin coals identified by Spink (1965) as the Norton and Hard Bed Band seams. In the Blackfordby No.3 Borehole (SK31NW/106), immediately below a 2-inch seam correlated with the Norton, a pellety, clay-rich carbonaceous mudstone was determined by analysis to consist mainly of kaolinite, suggesting that it is a tonstein (Notes by R W Elliott, 1959, accompanying the borehole log). In *Sheet SK21NE* the seams define a 15 m sequence which, in the Bretby West No.3 Borehole, is dominated by grey to black micaceous mudstones and seatearth; a brown, ferruginous variety is additionally present below the Hard Bed Band seam. In the Cadley Hill Borehole, the 0.3 m coal correlated with the Norton seam is directly overlain by dark grey mudstones containing *Lingula* and fish scales which is probably the **Norton Marine Band**. In the Coton Park Borehole, the 0.2 m coal tentatively correlated with the Norton seam is succeeded by 8 m of mainly seatearth, above which the occurrence of *Lingula* in dark grey mudstones may suggest the appearance of the **Upper Band Marine Band** (cf. Frost and smart, 1979, Figure 12).

The strata between the Upper Band seam, or its equivalent seatearth, and the Kilburn seam can be divided into two lithological associations: the lower part, consisting of grey, silty, micaceous mudstones, is succeeded by an upper succession of thick sandstones and siltstones belonging to the **Wingfield Flags**. In *Sheet SK31NW,* the corresponding strata in the Blackfordby No.1 Borehole are 65 m thick. The Wingfield Flags, comprising the upper 33 m, mainly consists of grey laminated micaceous siltstone interbedded with fine-grained sandstone in which plant fragments, animal burrows and cross-bedding are all common. The outcrop of the Wingfield Flags is mapped as a low feature extending from the south of the sheet north-westwards to the outskirts of Blackfordby [327 180]; the lithologies are revealed by sandy soils containing brash of yellow to grey, fine- to medium-grained sandstone. The crop is separated from that of the Kilburn seam by a belt of clay-rich ground: in the Blackfordby No.1 Borehole, this upper succession is represented by the Kilburn seatearth which rests on green to dark grey mudstones containing *Carbonicola* and *Spirorbis.* At this level in the Blackfordby No.3 Borehole a mussel fauna, which includes *C. bipennis,* occurs together with ostracods and fish scales. This fauna was correlated by J E Wright (1958, notes accompanying the borehole log) with the base of the Communis Chronozone, which covers the measures just above and just below the Kilburn seam in the Leicestershire Coalfield. In the Granville Colliery Borehole, the rather meagre log shows only about 9 m of sandstone in the position of the Wingfield Flags. In *Sheet SK21NE* the Wingfield Flags are between 40 and 60 m thick. The Bretby West No.3 Borehole shows that the lower part of the unit consists of about 22 m of grey micaceous siltstone which is locally very sandy or carbonaceous. Above this comes about 5 m of pale grey sandstone, fining up to grey micaceous siltstone. This is in turn overlain by 18 m of grey sandstone characterised by abundant silty wisps, micaceous layers and slumped bedding. Succeeding this is 15 m of grey micaceous siltstone and sandy siltstone capped by a black, pyritous seatearth of the Kilburn seam. The log of the Grange Wood Borehole shows that the upper part of the Wingfield Flags consists of 30 m of purple-stained, plant-bearing sandstone with micaceous laminae and small-scale current bedding developed in certain parts. This is underlain by 9 m of purple, micaceous siltstone with sandy layers and plant remains.

The **Kilburn** (Heath End, Pistern Hill, Anglesea, D'arcy) coal forms the lowermost seam of the Productive Measures. In *Sheet SK31NW* the seam is absent in the Blackfordby No.3 Borehole; elsewhere it is between 0.8 and 1.3 m thick and generally of poor quality. The outcrop east of the Boothorpe Fault was proved mainly by Opencast Executive boreholes (Spink, 1965), there being no natural exposures. The Kilburn was opencasted at the Sandtop Lane site [335 177], and evidence of more ancient workings is suggested by the belts of disturbed ground following the outcrop to the east of the Boothorpe Fault. At the time of writing this report the seam, 0.8 to 1.3 m thick, was being extracted at the RJB Shellbrook Opencast Site [332 162]. The seam was worked underground east of the Boothorpe Fault, in the Woodville area, and from Granville Colliery in Swadlincote farther west. The overlying strata up to the Clod seam comprises 20 m of dark grey mudstones and siltstones. In the Blackfordby No.3 Borehole a sandstone interbed shows current bedding and contorted bedding; similar sandy beds were encountered in the Granville Colliery No.2 Pit (SK31NW/1) interbedded with coaly mudstones (Figure 3). In *Sheet SK21NE* the Kilburn seam is between .01 and 1.9 m thick and has been worked underground between Swadlincote, Coton Park and Overseal. It is separated from the Clod by 30-35 m of mudstones, with a thin sandstone-rich sequence in Coton Park and Ashley House (SK21NE/58) boreholes. In the Caldwell Hall Borehole (SK21NE/26) the equivalent strata comprise grey to dark grey micaceous siltstones with mussels in certain layers. The **Clod** seam is thin, impersistent and of little commercial significance. Where coal is absent, the Clod horizon can still be detected by the prominent thick mussel band which normally overlies the seam. In *Sheet SK31NW* the Clod is up to 0.5 m thick and is split into two leaves in the Blackfordby No.3 Borehole. Several horizons with mussels and fish remains occur in the 12 m thickness up to the seatearth of the Twelve Inch seam, but although *Anthroconauta* was recorded, the *Carbonicola pseudorobusta* fauna, which is typical of the 'Clod mussel band', was not found (Notes by J E Wright accompanying the borehole log). Faunal identifications from the Coalville district are, however, given by Worssam and Old (1988, p38), who suggest a correlation with the Pseudorobusta Belt, late Communis Chronozone. Sandstones below the seatearth of the Twelve Inch seam are identified with those giving rise to low features near Blackfordby [e.g. 3296 1675]. In *Sheet SK21NE* underground provings suggest that the Clod is either poorly developed or absent, but the horizon is recognised by its seatearth and overlying mussel band. The faunas are commonly fragmental, but the roof of the Clod in the Stanton House Farm No.9 Borehole (SK21NE/2) yielded *Carbonicola crista-galli, C. pseudorobusta* and *Anthraconauta candela* (Report NCB No.2089 by R H Hoare and M A Calver).

The Clod to Eureka sequence contains the Twelve Inch, Well, Stanhope and Joyces seams. The Stanhope, usually the thickest seam, combines with the Well farther east to form the Lower Main seam of the Leicestershire Coalfield. The seams crop out only in *Sheet SK31NW;* for example, recent site investigation reports to the east of Sharpswood Farm [315 196] indicate that the Well, Stanhope and Joyces seams are probably present hereabouts. The **Twelve Inch** seam is commonly less than 0.1 m thick in *Sheet SK31NW,* but in *Sheet SK21NE* attains 0.6 m in the Ashley House Borehole, where the overlying black mudstones contain mussel fragments and fish debris. The **Well** (Threequarter) seam may be the coal formerly seen in *Sheet SK31NW* under the railway arch at Woodville [3148 1929]; it is about 0.4 m thick in the Blackfordby No.3 Borehole and Granville Colliery No.2 Pit. In the west of *Sheet SK21NE* the Well is between 0.6 and 1.6 m thick (Figure 3). In the Caldwell Hall Borehole its roof consists of black pyritous and carbonaceous mudstones with an abundance of fish fragments. Mussels from the overlying grey mudstones at Granville Colliery contained *Anthraconauta ?minima* and *Carbonicola pseudorobusta* (Mitchell and Stubblefield, 1948, Table 1); further faunal details of this horizon in the Coalville district are given in Worssam and Old (1988, p.38). The **Stanhope** seam is 0.3 to 0.9 m thick in *Sheet SK31NW.* It has been worked underground throughout the western part of the sheet, and was formerly opencasted at the Boothorpe Brickworks [323 180]. Borehole records (Figure 3) show that the interval between it and the overlying Joyces seam is largely occupied by a 3 to 6 m bed of pale grey, fine-grained sandstone. In *Sheet SK21NE* the Stanhope is between 0.3 and 1.8 m thick. It was worked underground to the north of Church Gresley, and at the Coton Park/Ashley House prospects. The seam is split into upper and lower leaves to the south-west of the Coton Park Borehole, and in the Coalville district farther south (Worssam and Old, 1988, Figure 8). The succession between the Stanhope upper leaf and the Joyce's seam in the Linton Lane Borehole (SK21NE/107) is occupied by 7 m of pale grey, fine-grained massive to laminated sandstone similar to that seen in Sheet SK31NW. The **Joyces** (Joicey) seam is up to 0.3 m thick in *Sheet SK31NW;* in the Rawdon Pit Shaft (SK31NW/30) it is overlain by the 8 m seatearth of the Eureka seam. In the Rawdon East Borehole (SK31NW/29) the seam is overlain by a thin black cannelly mudstone. A few metres of silty, micaceous mudstones follow but develop a rootlet fabric upwards and are evidently part of the Eureka seatearth which here is about 6 m thick. In *Sheet SK21NE* the Joyce's seam reaches 0.9 m thick in the Ashley House Borehole, where it is overlain by 0.3 m of black, pyritous and cannelly mudstones. The latter become more silty and micaceous upwards, before being capped by 1 m of sandstone which underlies the 2.5 m seatearth of the Eureka seam.

The **Eureka** (Bottom, Yard of Leicestershire Coalfield) was named in the early 19th century at Robinson and Foreman's pit at Swadlincote, although it was actually discovered before this, in 1833, at the bottom of a pit at Moira (Hull, 1860, p.22). In *Sheet SK31NW* the seam, between 1.2 and 1.5 m thick, crops out between Blackfordby and Woodville. It was formerly opencasted to the south-east of the old Swadlincote and Woodville railway [319 184], and has been extensively worked underground. In the Hastings and Grey (SK31NW/34) and Granville Colliery No.2 shafts the overlying interval up to the seatearth of the Stockings seam is occupied by the 'Eureka Rock', which is a sequence of grey sandstones with subordinate mudstone partings totalling 12 and 18 m thick respectively. The sandstones do not form a continuous sheet, however, for they are missing from the Rawdon Pit Shaft, where 'strong blue bind' is recorded instead, and are represented by only 4 m of grey micaceous sandy siltstone beneath the 5 m thick Stockings seatearth in the Rawdon East Borehole. In *Sheet SK21NE*, the Eureka is between 0.8 and 2.8 m thick, the thickest proving being in the Ashley House Borehole where strong bright coal was mainly encountered. Above the seam the 'Eureka Rock' is present in some boreholes, but missing from others. In the Coton Park Borehole it is 10 m thick and consists mainly of grey, well-laminated micaceous sandstone interbedded with siltstone; wavy and slumped bedding were noted on the borehole log. Fox-Strangways (1907, p.40) reports that 'at Netherseal' the Eureka seam is commonly cut by sandstone washouts 'which run in confluent lines like the tributaries of a river'.

The **Stockings** (Two Yard, Low Main, Linton) seam has been mined throughout the exposed coalfield and at the Caldwell, Coton Park and Linton prospects in the concealed coalfield (Sheet SK21NE). In *Sheet SK31NW* the seam is between 1.7 and 2.4 m thick. It crops out at Woodville, to the east of the Blackfordby Fault, and farther south-west it is brought in again along the upthrown side of the Boothorpe Fault. It was formerly opencasted to the south-east of the Swadlincote and Woodville railway [318 184], being originally known hereabouts as the Raffaree or Shiloh Coal (Hull, 1860; Mitchell and Stubblefield, 1948). Mudstones principally overlie the seam, but a 4.6 m sandstone is intercalated in the Hastings and Grey Shaft. From the mussel band in the roof to the seam at Marquis Colliery [3095 1603], Mitchell and Stubblefield (1948) listed: *Carbonicola communis, C. crista-galli, C. ovalis, Naiadites flexuosa* and *N. triangularis* in addition to the ostracod *Celsina arcuata*. A similar faunal horizon in the Coalville district was attributed to the Crista-galli Belt, earliest Modiolaris Chronozone, by Worssam and Old (1988, p.38). In *Sheet SK21NE* the Stockings seam, between 1.4 and 2.2 m thick, is split into two leaves in the Linton Lane Borehole in the south-west of the district. *Niaidites* was found in the mudstones above the seam in the Caldwell Hall Borehole.

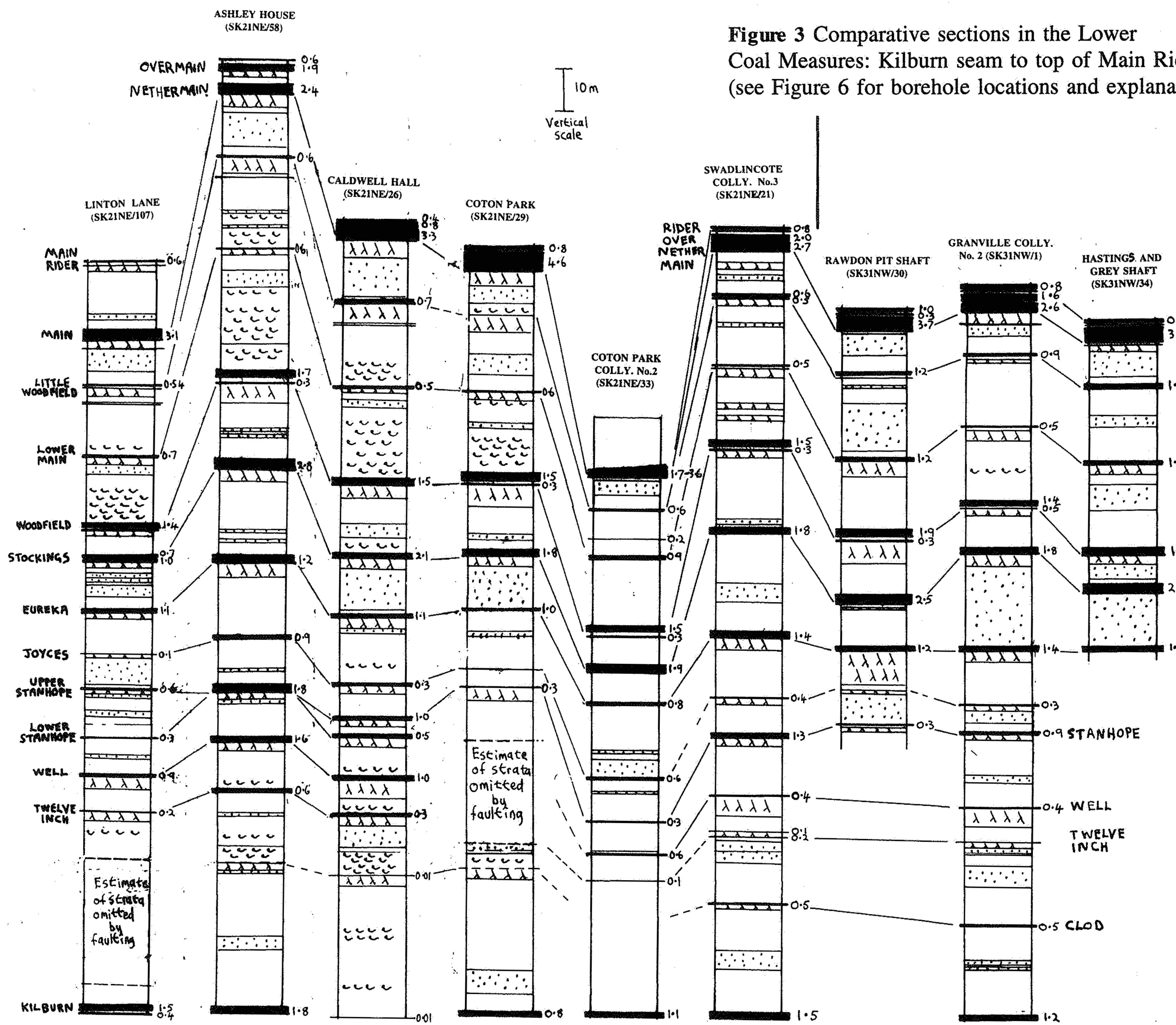
The **Woodfield** is commonly a split seam with a lower, much thinner leaf known as the Trencher. It was mined throughout the exposed coalfield, and at the Caldwell, Coton Park and Linton prospects in the concealed coalfield (Sheet SK21NE). In *Sheet SK31NW* the seam, between 1.8 and 2.0 m thick, crops out to the east of the Blackfordby Fault at Woodville. Underground provings show that it is separated from the Lower Main seam by 15-20 m of mainly mudstone, with a 5.5 m sandstone interval in the Hastings and Grey Shaft. Three metres above the seam in the Rawdon East Borehole is a thin coal overlain in turn by 3 m of black, pyritous mudstones with mussels, ostracods and fish debris. The diverse fauna collected from the Rawdon East Borehole and from Marquis Colliery (Mitchell and Stubblefield, 1948, Table 1) is as follows: *Carbonicola boltoni, C. communis, C. crista-galli, C. oslancis, C. ovalis, C. pseudorobustus*, and the ostracods *Carbonita fabulina* and *Celsina arcuata*. The assemblage is comparable with that in the top of the Middle Lount seam of the Leicestershire Coalfield, and is appropriate to the Crista-galli Belt, earliest Modiolaris Chronozone. Like the Middle Lount seam, the Woodfield includes, in places, near its top a 25 mm brown tonstein, described by Mitchell and Stubblefield

(1948, p.16) as an ironstone. In *Sheet SK21NE* the seam is between 1.4 and 2.8 m thick. In the Caldwell Hall Borehole the overlying 14 m of grey or black pyritiferous mudstones contains ostracods, fish debris and mussels identified in the log only as *Naiadites* and *Carbonicola.* Identifications from the same horizon at Netherseal, Cadley Hill and Granville collieries (Mitchell and Stubblefield, 1948, Table 1) showed the presence of the forms previously reported for Sheet SK31NW, with the addition of *Carbonicola obtusa C. rhomboidalis* Hind, *C.* cf *smithi* and *Naiadites flexuasa.* At the same level in the Stanton House Farm No.9 Borehole *Carbonicola pseudorobustus* and *C. rhomboidalis* Hind were found (Report NCB No.2089 by R H Hoare and M A Calver). Higher up the sequence a 2-3 m thick sandstone occurring within several metres of the Lower Main seam is shown in many borehole records.

The **Lower Main** (Shale, Slate) seam is between 0.4 and 1.2 m thick in *Sheet SK 31NW.* The c.15 m interval between it and the Little Woodfield seam is dominated by mudstones except in the Rawdon Pit Shaft, where the log records 11 m of sandstone ('grey rock' and 'stone'). In *Sheet SK21NE* the seam is impersistent, being split into two thin leaves at Swadlincote Colliery and elsewhere attaining a maximum thickness of only 0.8 m. The succeeding sequence of mudstones with impersistent sandstone beds thickens westwards, from 15 m and 10 m at Swadlincote and Coton Park Collieries to a maximum of 22 m in the Ashley House Borehole. The latter records dark grey pyritous mudstones with fish debris and mussels for 4.8 m above the seam, with a thin coal developed just below the seatearth of the Little Woodfield; the minor coal is shown to be split in the Caldwell Hall and Linton boreholes. The **Little Woodfield** seam is rather thin but has been worked underground in the exposed coalfield area. Around Moira, in *Sheet SK31NW,* it was formerly known as the Toad, because its surface is commonly studded with the pale brown impressions of *Carbonicola* (Fox-Strangways, 1907, p.40). Mitchell and Stubblefield (1948, Table I) record *Carbonicola* of the *ovalis* group in collections made from the Moira collieries. The Little Woodfield seam is 0.8 to 1.2 m thick, and is split into two leaves in the Rawdon Pit Shaft. The c.10 m of strata separating it from the Nether Main contains a persistent sandstone which attains 6 m in the Hastings and Grey Shaft. In *Sheet SK21NE* the Little Woodfield averages 0.6 m thick; it is split in the Linton Lane Borehole, and represented by a seatearth in the Rawdon East Borehole. In the overlying sequence sandstone is persistent, attaining 10 m in the Caldwell Hall and Ashley House boreholes.

The Main group comprises three closely-associated principal seams whose names, from the base, are the **Nether Main**, **Over Main** and **Main Rider**. Of the minor seams that are present, a thin coal below the seatearth of the Nether Main is distinguished as the Under Main around Netherseal (Worssam and Old, 1988, p.39), and as the Little Woodfield Rider in an exploration borehole at the Nadins Opencast site [2760 1942]. Hull (1860) noted that in the coalfield south of Moira the Over Main, being of superior quality, was worked in preference to the Nether Main while north of Moira, in the Newhall area (north of Sheet SK31NW), the reverse was the case. In the intervening area, at Church Gresley Colliery (Sheet SK21NE) for example, both seams were of medium quality and therefore were worked equally. Over the past century all seams of the Main group have been mined throughout the the coalfield.

Figure 3 Comparative sections in the Lower Coal Measures: Kilburn seam to top of Main Rider (see Figure 6 for borehole locations and explanation)



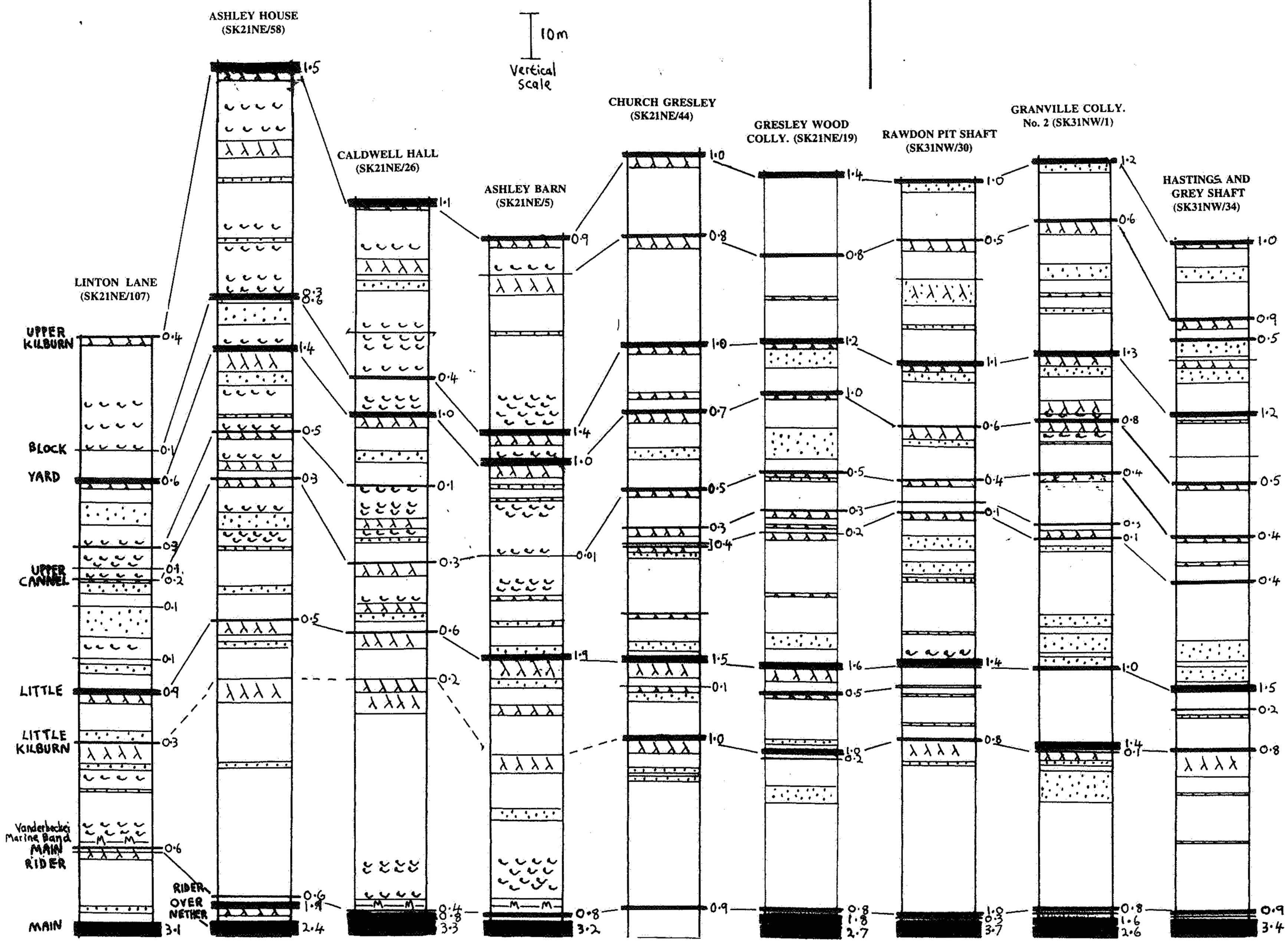


Figure 4 Comparative sections in the Middle Coal Measures: Main Rider to Upper Kilburn (see Figure 6 for borehole locations and explanation)

In *Sheet SK31NW* the Nether and Over Main seams unite in the Hastings and Grey and Rawdon Pit shafts, forming a single seam 3.4 and 3.7 m thick respectively which is surmounted by two thinner seams, the First and Second Rider. According to Hull (1860), at the Bath Pit [3097 1560] the Second Rider, 1.2 m thick, rests directly on the combined Nether and Over Main seams producing a single seam nearly 5.5 m thick. In the Rawdon East Borehole a single 1.0 m Rider is separated by a thin seatearth from the 3.9 m combined Nether and Over Main. The multiple seam sequence of the Granville Colliery No.2 Pit comprises: Nether Main; 2.6 m; 'bat', 0.3 m; Over Main, 1.6 m; seatearth, 0.6 m; Little Rider, 0.2 m; seatearth, 0.2 m and Rider, 0.8 m.

In *Sheet SK21NE* the principal variation is in the separation between the Nether and Over Main seams. In the north, this is given as 8 and 4 m in the Bretby Colliery No.5 (SK21NE/1) and Bretby Colliery No.3 (SK21NE/16) boreholes respectively, and only 0.5 m at Stanton Colliery (SK21NE/22), a little to the east. Within the small area of the Nadins Opencast Site [195 280] the exploration plans show that the Nether to Over separation increases north-westwards; a generalized vertical section for the site is given as follows:

Seam	*Thickness variation (m)*
Main Rider	0.5-0.9
Black mudstone	0.1-0.8
Over Main	2.0-2.8
Grey mudstone and siltstone	0.3-15.7
Nether Main	2.3-3.3

Variation is expressed on a more local scale at the Coton Park Colliery, where records state that the combined Nether and Over seam thickens from 1.7 m to 3.6 m in the headings. In the nearby Coton Park Borehole the seams are again united, but for a thin dirt parting; their aggregate thickness is 4.6 m, with a single 0.8 m Rider seam present above. The split between the Nether and Over seams is pronounced in the the Ashley House Borehole, where the sequence is: Nether Main, 2.4 m; mudstones with large plant stems, succeeded by seatearth, 5.4 m; Over Main, 1.9 m; black carbonaceous mudstone, 0.5 m; Main Rider, 0.6 m. The seams are close together again farther south in the Caldwell Hall and Linton Lane boreholes, but the latter shows greater separation for the Rider (0.6 m thick), with 16 m of grey silty mudstones silty sandstones and seatearths intervening between it and the Over Main.

5.2.2. Middle Coal Measures (Duckmantian-Bolsovian)

The base of the Middle Coal Measures is taken at the lower surface of the Vanderbeckei (= Bagworth, Clay Cross, Molyneux, Seven Feet) Marine Band. The Middle Coal Measures include the Westphalian B/C boundary, which is marked by the Aegiranum (Overseal) Marine Band, but continue above this to the top of the Cambriense (Top) Marine Band, after which they are succeeded by the Upper Coal Measures. Typical thickness values for the Middle Coal Measures are 310 m for Sheet SK31NW and 285 m for Sheet SK21NE. Comparative vertical sections through the Middle Coal Measures are given in Figure 4.

The **Vanderbeckei Marine Band** commences in or just above the roof of the Main Rider seam. Its top can only be precisely defined at the first incoming of mudstones with non-marine bivalves; otherwise only its minimum thickness is known. In *Sheet SK31NW*, faunas from the roof of the Main Rider collected from the 'Moira area' and at 'Newfield Pit, Moira' by W S Gresley were viewed at Leicester Museum by Mitchell and Stubblefield (1948, p.28), who listed the following: *Spirorbis, Lingula mytilloides, Dunbarella* cf *macgregori, Myalina compressa*, the gasteropod *Sphaerodoma* sp, the ostracod *Carbonita secans* and the productid *Productus (Cancrinella)* cf *undatus*. The same workers noted that from this horizon at the Marquis of Hastings Pit, Church Gresley, Molyneux (1869) had also reported *Aviculopecten fibrillosum* and, from Coton Park and Linton collieries (Molyneux 1878), *Aviculopecten papyraccus, Goniatites Listeri, Posidonia* sp and *Orthoceras* sp. They observed that this faunal assemblage compares favourably with that of the Clay Cross Marine Band of the Nottinghamshire and Derbyshire Coalfield. In the Rawdon East Borehole the Vanderbeckei Marine Band is 7 m thick. The upper 1.2 m interval, in which *Lingula* becomes less common and is accompanied by mussels including *Naiadites*, marks the transition to non-marine conditions represented by the succeeding 13 m of mussel-rich mudstones. The 11 m interval overlying this comprises mudstones coarsening up to sandstones and sandy siltstones surmounted by the seatearth of the Little Kilburn seam.

In *Sheet SK21NE* the Vanderbeckei Marine Band was formerly exposed above the Main Rider seam at the bottom gallery of Nadins Opencast Site [2772 1950]. It comprises 1.6 m of black to dark grey, massive to faintly laminated mudstone with small *Lingula* and pyritized planolites burrows. A palaeontological report (N J Riley) is currently in preparation. The full measured section is:

Description	*Thickness (m)*
Coal (Little Kilburn)	1.8
Sandy and silty seatearth, pale grey, with silty mudstone partings	0.8
Sandstone, pale grey, fine-grained, erosive base incorporating slivers of coaly plant material and large plant stems. Trough and planar cross-bedded in 1-2 m sets, showing current flow approx. from north to south. Large rootlet casts throughout	7.7
Siltstone, pale grey, with rootlets, interbedded on cm scale with black, plant-rich, highly carbonaceous to coaly siltstone	1.2
Siltstone, pale grey, laminated with rootlets	0.4
Sandstone, pale grey, fine-grained, with diffuse planar lamination, massive towards base	1.6
Mudstone, black, burrowed	0.1
Siltstone, pale grey, white or buff, with sandy laminae showing current-rippled tops and slump structure	2.0
Siltstone, pale grey to green-grey, blocky to well-laminated.	6.4
Mudstone, black, with abundant mussels	0.2
Mudstone, dark grey, massive to well-laminated with common ironstone layers and mussel bands	7.0
Vanderbeckei Marine Band	1.6

The thick sandstone in this section is inferred to crop out farther to the north, but is largely hidden by spoil heaps near Hall Fields Farm [2735 1966].

A greater thickness is attained for the Vanderbeckei Marine Band in the Coton Park Borehole where *Lingula* and many goniatites were found in the mudstone interval extending 4.5 m above the Main Rider, and mussels accompanied by the marine ostracod *Paraparchites* for a further 3.0 m above that (D C Greig *in* NCB Report No. 2553).

The **Little Kilburn** (Smith's, Smuts, Cannel) is a thin seam which persists across most parts of the coalfield. In *Sheet SK31NW* it is 0.7 to 1.4 m thick and is succeeded by 13 to 15 m of grey laminated micaceous mudstones with a thin coal, or split coal, intercalated towards the top. In *Sheet SK21NE,* the Little Kilburn varies between zero and 2.0 m thick. The seam was exposed at Nadins Opencast Site (Jones, 1995), where two leaves are present. The upper leaf is discontinuous, has a markedly undulatory base and no seatearth, indicating that it is not *in situ.* It is erosively overlain by 11.5 m of cross-laminated sandstone, interpreted to be a minor channel in which the current flow was to the ESE. In the Ashley House and Ashley Barn (SK21NE/5) boreholes the horizon of the Little Kilburn is represented by a seatearth only. Elsewhere the sequence above the seam, or where split above its upper leaf, commonly contains a further thin coal.

The **Little** (Five Feet, Four Foot) has been widely mined underground, though not exploited in the concealed western extension of the coalfield on Sheet SK21NE. In *Sheet SK31NW* the seam is between 1.0 and 1.5 m thick. In the Rawdon Shaft it is split, with a thin lower leaf, and its roof contains a mussel band with *Anthraconauta, Carbonicola aquilina, C. atra, C. fulva, C. phrygiana, Naiadites quadrata* and *N. triangularis* (Mitchell and Stubblefield, 1948, Table 1). The Little is succeeded by between 30 and 45 m of strata with, in the lower part, about 10 m of interbedded sandstones and siltstones. A thin coal locally overlies the arenaceous beds, for example in the Hastings and Grey Shaft. The Little seam is split in the Rawdon Pit Shaft and Granville Colliery No.2 Pit. In *Sheet SK21NE* the Little is between 0.5 and 1.9 m thick. It was exposed at Nadins Opencast Site (see measured section above, and Jones, 1995) and its much-faulted outcrop has been inferred from exploration records (Spink, 1965) east of Cadley Hill [2780 1898]. The seam is presently exposed just beneath the Trias in the backwall of a cutting behind a factory yard [2726 1938], where the section comprises 1.8 m of bright and dull banded coal, with common carbonaceous silty intervals containing plant remains, overlying at least 1 m of pale grey to buff mudstone with rootlet fabric. The Little is overlain by 15 to 40 m of strata comprised mainly of mudstones and siltstones, but with a persistent development of thin sandstones which typically occur near the base in the east of the sheet; many mussel bands are recorded in the Ashley Barn Borehole. Two thin coal seams, known at Nadins Opencast Site as the Little Rider (Lower) and Little Rider (Upper) are intercalated in the east, but are poorly developed in the western, concealed part of the coalfield.

The **Upper Cannel** is a persistent but generally thin seam across the district. In *Sheet SK31NW* it is between 0.3 and 0.9 m thick and separated from the overlying Yard seam by about 10 m of mudstones. Black, micaceous, pyritous mudstones with mussels occur in the roof of the seam. From a mussel band in Granville Colliery '155 feet above Little' (i.e.

below the seatearth of the Yard seam), Mitchell and Stubblefield (1948, Table 1) recorded: *Carbonicola acutella, C. affinis, C. aquilina, C. fulva, C. phrygiana, Naiadites quadrata* and *N. triangularis*. In *Sheet SK21NE* the Upper Cannel is commonly less than 0.3 m thick, but shows better development to the west and north, being up to 1.05 m at Nadins Opencast Site, where the seam is mostly of cannel coal (Jones, 1995). Coal exploration data enable its outcrop to be inferred in faulted ground to the east of Cadley Hill (Spink, 1965). To the north-east of here, at Nadins Opencast Site, Jones (1995) interpreted tha strata above the seam to comprise lacustrine mudstones cut by palaeochannels, one of which is represented by 6 m of cross-bedded sandstone deposited from north-easterly currents. Farther west, in the concealed part of the coalfield, the interval up to the Yard seam comprises 26 m of mudstones with mussel bands in the Ashley House Borehole. There is also a 0.3 m coal developed in nearby boreholes (e.g. Caldwell Hall), named as the Two Foot seam. This seam was correlated with the Threequarters Coal of the Leicestershire Coalfield by Spink (1965, p.43). Farther south, in the Linton Lane Borehole, the Upper Cannel is split into two leaves below the Two Foot seam (Figure 4).

The **Yard** of South Derbyshire is a persistent seam which is generally of little economic importance, although thicker to the west than in the eastern part of the district. In *Sheet SK31NW* the seam, between 0.5 and 1.0 m thick, was identified at outcrop during exploration for the Shellbrook Opencast Site [3315 1600]. From the mussel bed in the roof of the seam at the Granville Colliery and Bath Pit, Moira, Mitchell and Stubblefield (1948, Table 1) identified *Carbonicola aquilina, C. exigua, C. phrygiana, Naiadites* app., *Carbonita fabulina* and *C. scalpellus.* A simila fauna from this horizon in the Coalville district was attributed by Worssam and Old (1988, p.40) to the Phrygiana Belt, late Modiolaris Chronozone. The seam is succeeded by 10 to 13 m of mudstones and siltstones, commonly with a thin coal and/or seatearth in the lower part. A sandstone bed 2-3 m thick occurs below the seatearth of the Block seam in the Hastings and Grey Shaft and Granville Colliery No.2 Pit, and is more thickly developed farther east, where two sandstone beds totalling 4 m thickness are present in the Rawdon East No.1 Borehole. In *Sheet SK21NE* the Yard, between 0.1 and 1.0 m thick, has been encountered in shallow exploration boreholes (Spink, 1965) and site investigations, enabling its outcrop to be traced between Cadley Hill and Swadlincote. North of here it was opencasted at Nadins [286 198] and Hearthcote Road [291 195] sites. The seam is overlain by strata varying between 5 and 13 m thickness, mainly composed of mussel-bearing mudstones and siltstones; a sandstone bed is locally present near the top.

The **Block** (Snailhorn, Jack Dennis, Watson, Four Foot) seam has been mined in several parts of the district, although Hull (1860) stated that it was commonly friable, well-jointed and full of water. In *Sheet SK31NW* the seam, between 1.1 and 1.3 m thick, is presently being opencasted south-east of Norris Hill, at the Shellbrook Site [329 162]. Hull (1860) noted that the seam invariably occurs beneath a thick sequence of mudstones containing several ironstone layers; in boreholes these strata, 35 to 40 m thick, are comprised of mudstones and siltstones with thin sandstone beds in the middle part. Two thin, unnamed coal seams are intercalated in the south, at the Hastings and Grey Shaft, but the lower of these is represented by a seatearth in most other provings. The mussel bed forming the roof of the Block at 'collieries in the Moira area' yielded *Naiadites* of the quadrata group

(Mitchell and Stubblefield, 1948, Table I), In the Coalville district the same horizon has yielded a fauna attributed to the Atra Belt, Lower Similis-Pulchra Chronozone (Worssam and Old, 1988, p.40). In *Sheet SK21NE* the Block is between 0.1 and 1.6 m thick, the latter value being attained at the Hearthcote Road Opencast Site [291 195] where the seam was formerly worked. Exploration boreholes interpreted by Spink (1965) show the seam's crop to be folded and interrupted by faulting to the east of Cadley Hill [280 186]. From there it is inferred to extend north-eastwards, and was encountered in site investigations for the Civic offices at Swadlincote [2976 1972]. In the Ashley House Borehole, the Block is split into 2 leaves; the overlying sequence to the Upper Kilburn seam is occupied by 48 m of mudstones and siltstones with subordinate thin sandstones. Elsewhere a thin coal seam or equivalent seatearth horizon is present in addition.

The **Upper Kilburn** (Snailhorn, Four Foot, Dicky Gobbler) has been mined in the southern parts of the two map sheets. In *Sheet SK31NW* it averages 1.1 m in thickness, with little variation shown (Figure 4). Around Norris Hill its outcrop has been inferred from coal exploration records for the Shellbrook Opencast Site [329 161]. Underground provings show that elsewhere the seam typically overlies 1-2 m of grey, silty and sandy seatearth, and it is in turn overlain by 35 to 40 m of mudstones and siltstones. In the Coalville district these strata contained mussel bands which yielded a fauna appropriate to the Atra belt, Lower Similis-Pulchra Chronozone (Worssam and Old, 1988). Four thin but persistent coal seams, numbered **P44** to **P41**, occur in the sequence; they lie at a similar horizon to the Excelsior Coal of the Leicestershire Coalfield, and were suggested by Spink (1965, Fig.3) to be splits of that seam. Mussels from the roof of the P41 seam in the Hanginghill Farm Borehole (SK31NW/141) included *Anthraconaia pulchella* and *Anthracosia sp* (Worssam and Old, 1988, p.40). The 13 m or so of strata that intervene between the P41 and P40 seams include a thin sandstone, named the Hill Farm Sandstone by Worssam (1977). The field notes of Fox-Strangways show this bed to have been worked at outcrop to the west of the Moira Fault, in a small quarry [3076 1603] now covered by waste. Further outcrops occur on the hill top farther south [311 158], and the sandstone is brought in again across the Moira Fault to the west of Norris Hill [3262 1626], forming a low feature which can be traced south-eastwards to the edge of the map sheet. The top of this sandstone therefore forms a convenient, mappable horizon at which to place the base of the 'Pottery Clays Formation', described below. In *Sheet SK21NE* the upper Kilburn is between 0.1 and 1.4 m thick. It crops out from beneath Trias cover at Castle Gresley and extends north-eastwards, where it was formerly exposed in workings at Gresley Wood [2881 1901]. Faulting may bring the seam in again to the west of Church Gresley, but there is little subsurface information available to confirm this. The 28 to 37 m of strata above the Upper Kilburn seam in the Church Gresley Colliery contain the P44-P41 seams; these are inferred to crop out on the slopes between Church Gresley and Swadlincote, with associated sandstones revealed by low features and debris in foundations [2970 1934]. At the High Cross Opencast Site [286 175) Jones (1995) identified a 2 m sandstone above P41, which was correlated with the Hill Farm Sandstone of Worssam (1977). It is a grey, very fine-grained, erosively-based sandstone, cross-laminated in places and with upright *in-situ* tree trunks preserved. The sandstone grades up into mudstone and then into the palaeosol of the P40 seam. In the concealed coalfield to the west (Figure 5), P42 and occasionally P43 are missing, as shown by the Botany Bay Borehole (SK21NE/27). The Hill Farm Sandstone is again seen in many boreholes below the seatearth of the P40 seam.

'Pottery Clays formation' (informal name).

These strata, up to 140 m thick, commence at the top of the Hill Farm Sandstone or, in boreholes where the sandstone is absent, their base is taken at the floor of the P40 seam. The type section for the formation is in the BGS Hanginghill Farm Borehole (Figure 5), on Sheet SK31NW, which was drilled to the Upper Kilburn seam in order to constrain the stratigraphy of this economically valuable sequence of fireclays and coals (Worssam, 1977). The P40 and P39 seams are distinctive in boreholes throughout the two map sheets in being separated by a 1 to 3 m seatearth. Surmounting P39 are the black, pyritous mudstones of the Maltby (Two Foot) Marine Band, which marks the first of 7 marine incursions recorded up to the base of the Barren Measures.

Pottery Clays in Sheet SK31NW

The **Maltby** (Two Foot) **Marine Band** is represented in the Hanginghill Farm Borehole by 1.7 m of dark grey, pyritous mudstones with *Glomospira sp., Lingula mytilloides, Anthraconaia sp., Myalina compressa* Hind, *Naiadites sp.* and cf. *Geisina sp.* (Worssam, 1977, p.4). The crop of the marine band and underlying **P39-40** seams occurs within a zone of steepened dips on the western (downthrown) side of the Boothorpe Fault; the beds can be traced north-westwards from Willesley [3337 1500], and were formerly exposed close to the fault in the north-eastern part of the Granville Opencast Site, near Swadlincote [3125 1905]. Present-day exposures in the cutting of a derelict factory yard, about 40 m to the east of the Granville site [3132 1897], showed strata inferred to lie above the Maltby Marine Band. They comprised carbonaceous and coaly mudstones with a 0.8 m bed of fine- to medium-grained sandstone; the beds were sheared and fractured, their dip of 42° SW being due to the close proximity of the Boothorpe Fault. The P39/Maltby Marine Band horizon is brought in again to the west of the Moira Fault, and crops out close to the Rawdon Pit Shaft [3122 1626] where it was intersected at 7 m depth. Farther west it was encountered in the southern part of the Haywood Opencast Site [309 162], and it represents the lowest stratigraphical level to be excavated at the Donington Extension Opencast Site [305 176]. To the south, the crop of the marine band can be traced around the north-west trending Swainspark Anticline whose axis lies north of Gorsey Leys [163 159].

The **P38** and **P37** seams are impersistent in Sheet SK31NW, and in the Hastings and Grey Shaft are evidently washed out by grey sandstones with carbonaceous and coaly laminae. In the Hanginghill Farm Borehole, Worssam (1977, p.4) reported that mudstones above the P38 seam contain *Naiadites obliquis* Nix & Trueman and *Rhizodpsis sp.* (scale). The additional presence of the ostracod *Carbonita humilis* (Jones & Kirkby) strongly suggested a faunal horizon equivalent to the Clown Marine Band in the East Pennine Coalfield, even though, in the absence of marine fossils, it could not be designated a true marine band. The Clown has, however, been identified in the Acresford No.6 Borehole, to the south of the present district (Worssam and Old, 1988, p.34). Succeeding P37 is a closely-spaced grouping of coals that includes the **P36-33** seams. They were collectively termed the 'Thick

Group' during the exploitation of the Donnington Pipeworks area (Spink, 1965, p.67), and one seam in particular, the **P34** or 'Ell' seam, is the most persistent and thickest, at between 0.3 and 1.1 m. These coals and intercalated, generally thin, seatearths, closely parallel the crop of the Maltby Marine Band described above between the Willesley and Granville opencast sites. They were formerly revealed in the eastern part of the Albion Opencast Site [317 179] and, to the west of the Moira Fault, in the Milk Hill [311 187], Ensor's [305 184], Donington Extension [304 176] and Haywood [309 166] sites, among others. The succession commencing above the P34 seam and extending upwards to P31 contains seatearths of considerable thickness and quality, many of which were given local names by miners. The stratigraphical context of this terminology, given in the vertical sections of Mitchell and Stubblefield (1948, Figure 4), is of some importance since the records for many of these sites no longer exist and completion plans, if available, commonly do not indicate the seatearth (fireclay) thicknesses. For Sheet SK31NW, the following sequence is based on the sections of Mitchell and Stubblefield, and various opencast completion reports:

Seam	*Named Fireclay Horizon*	*Approx. Thickness (m)*
P31 (Derby)		
	Marl	1.0
	Crucible Clay/Main Fireclay/ Derby Fireclay	1.0-3.0
	Bottle Clay	1.2-3.7
P32 Rider		
	Seatearth, no name	0-1.8
P32	-	-
P33		
	Deep Fireclay/White Clay	Together =
	Deep Clunch/Brown Clay	1.5-4.0
P34 (Ell)		

Information bearing on the thickness and quality of the P32-36 seams and intervening fireclays worked before 1973 at the Haywood Opencast Site is given by Worssam and Old (1988, p.41).

The **Haughton Marine Band**, resting on the P33 seam, comprises 1.7 m of dark grey pyritous mudstones with foraminifera, including *Hyperammina sp.*, in the Hanginghill Farm Borehole (Worssam, 1977). Elsewhere in Sheet SK31NW, the horizon of this marine band is commonly occupied by a seatearth (Figure 5); for example, Worssam and Old (1988, p.42) reported it to be absent from the succession formerly exposed at the Willesley Clay Pit [326 154]. Nevertheless at Sutton's Pit, now incorporated into the south-western side of the Donnington Extension Opencast Site [307 167], Mitchell and Stubblefield (1948, Table I) recorded *Orbiculoidea* cf. *nitida* from this horizon. Similarly, the Union Lodge Nos.1 and 4 boreholes (SK31NW/142 & 145) show that the 2.2 m of dark grey mudstones resting on P33 contain *Productus, Lingula, ?Tomaculum, Orbiculoidea*, crinoid debris and foraminifera. The **Sutton Marine Band** is identified about 0.8 m above the Haughton Marine Band in these two Union Lodge boreholes, overlying 0.2 m of coal representing the P32 seam. It consists of 0.8 m of dark grey pyritous mudstones with *Lingula* and forams.

The marine band was formerly thought to be absent from this part of the South Derbyshire Coalfield (Worssam and Old, 1988, p.34), and while it is possible that the Union Lodge faunas represent an areally restricted marine embayment it is more likely that the deposits of a widespread marine incursion were severely modified by the pedogenesis that developed the thick seatearths of the Derby Fireclay. These occupy most of the succeeding interval up to the P31 seam (see above), with a sandstone bed intercalated at the Willesley Clay Opencast Site [330 156] .

Overlying the **P31** seam, the **Aegiranum** (Overseal) **Marine Band** was intensively studied in the Hanginghill Farm Borehole (Worssam, 1977, p.4), where it comprises 6.53 m of grey mudstone with an abundant fauna of marine brachipods and foraminifera. It is similarly well-developed in the Union Lodge No.1 Borehole, where it is represented by 3.4 m of grey pyritous mudstones with *Crurithyris, Lingula,* ostracods, productids and gastropods. The horizon is overlain by up to 20 m of mudstones and seatearths with common sandstone beds. The 0.9 m sandstone formerly seen in the Hicks Lodge Opencast Site occurred 7 m above P31 and rested with a load-casted base on the mudstones (Worssam and Old, 1988, p.42). This sandstone was said to floor the seatearths and coals of the **P29/30** (Soup Kitchen) seams, whereas a short distance to the east, in the Willesley Clay Opencast Site [330 156] these seams rest on mudstones and are directly overlain by a 9 m thick sandstone bed. The sandstones above and below the P29/30 seams are probably continuous with those giving rise to low features in ground extending north-westwards towards the Albion Opencast Site [3188 1725]. One of these beds intersected in the Hanginghill Farm Borehole, about 1 m above the Aegiranum Marine Band, consisted of 2.6 m of grey, fine- to medium-grained sandstone resting on a sharp base. The Aegiranum Marine band and overlying beds were formerly revealed in most of the large opencast areas north of, and including, the Donnington Extension Site. A most extensive listing of the faunas from these various exposures is given in Mitchell and Stubblefield (1948, Table II).

The **P28** to **P23** seams commonly occur within several metres of vertical section; they comprise a closely-spaced grouping of 0.2-1.0 m-thick coals interbedded with seatearths and mudstones (Figure 5). Farther west the sequence thickens to about 20 m in the Union Lodge Nos. 1&4 boreholes, where 6.7 m of pale grey, medium-grained sandstone occurs above P27. This may be a lateral equivalent of the highly lenticular channel sandstone seen at the base of the present working face of the Donnington Extension Opencast Site [3062 1760]. The sedimentology of the highly variable sequence exposed here will be the subject of a separate report (B W Glover, in prep.). A further exposure of the combined P27 and P28 seams was seen by the edge of the lake on the western side of the flooded Albion Opencast Site [3131 1741], as follows:

Description	*Thickness(m)*
Mudstone, dark grey, silty	1.0+
Coal, dull and bright bands, with strong bedding-parallel planar fabric in part defined by yellow and dark grey variegation	0.88
Coal, dull and bright bands, with horizontal fissility defined by abundant slickensided foliae	0.56

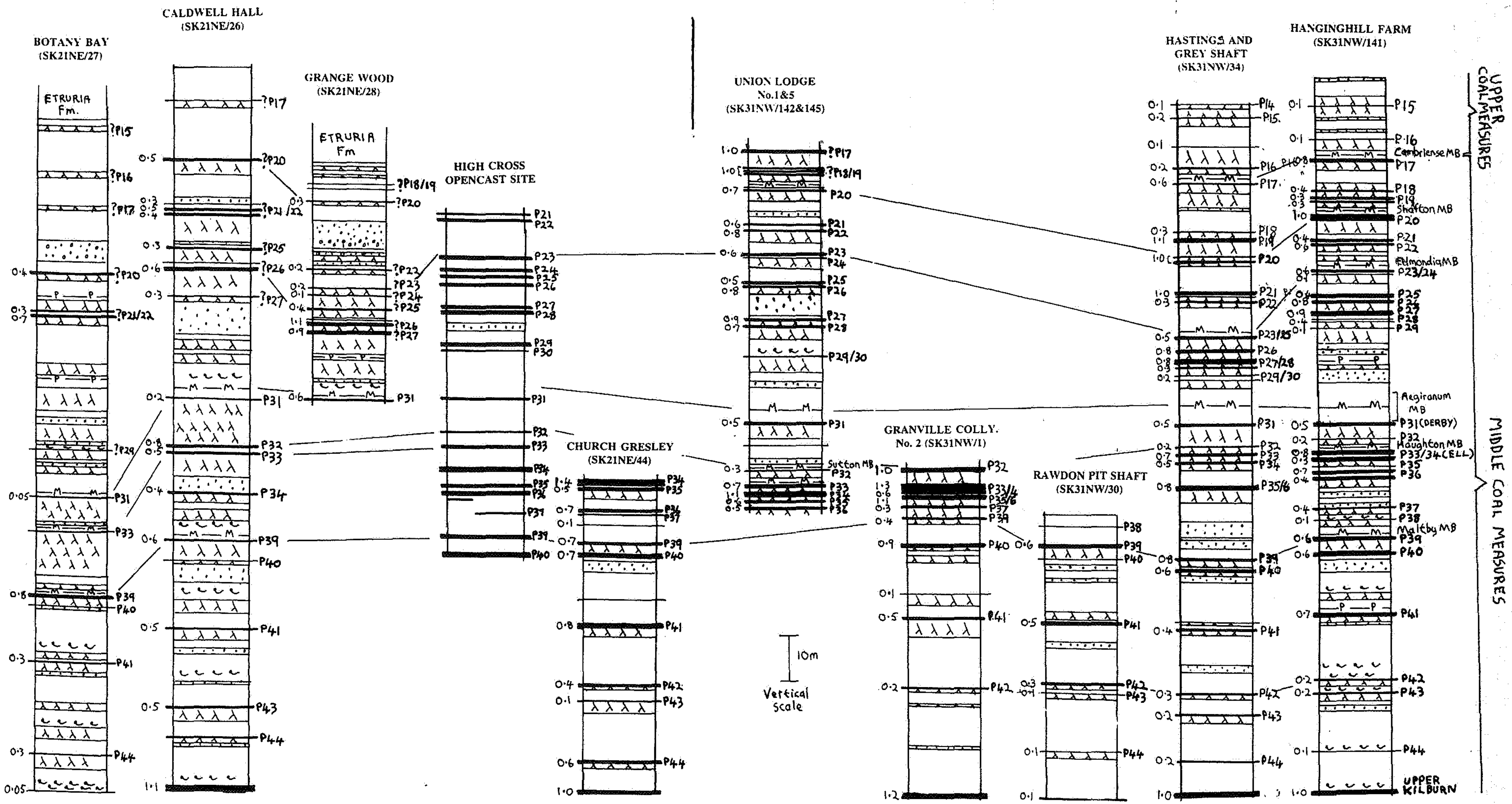
Coal, dull and bright bands, with fissile and slickensided layers	0.80
Mudstone, pale grey, with sporadic rootlets. Top part incorporates aligned coal slivers from overlying seam	1.0+

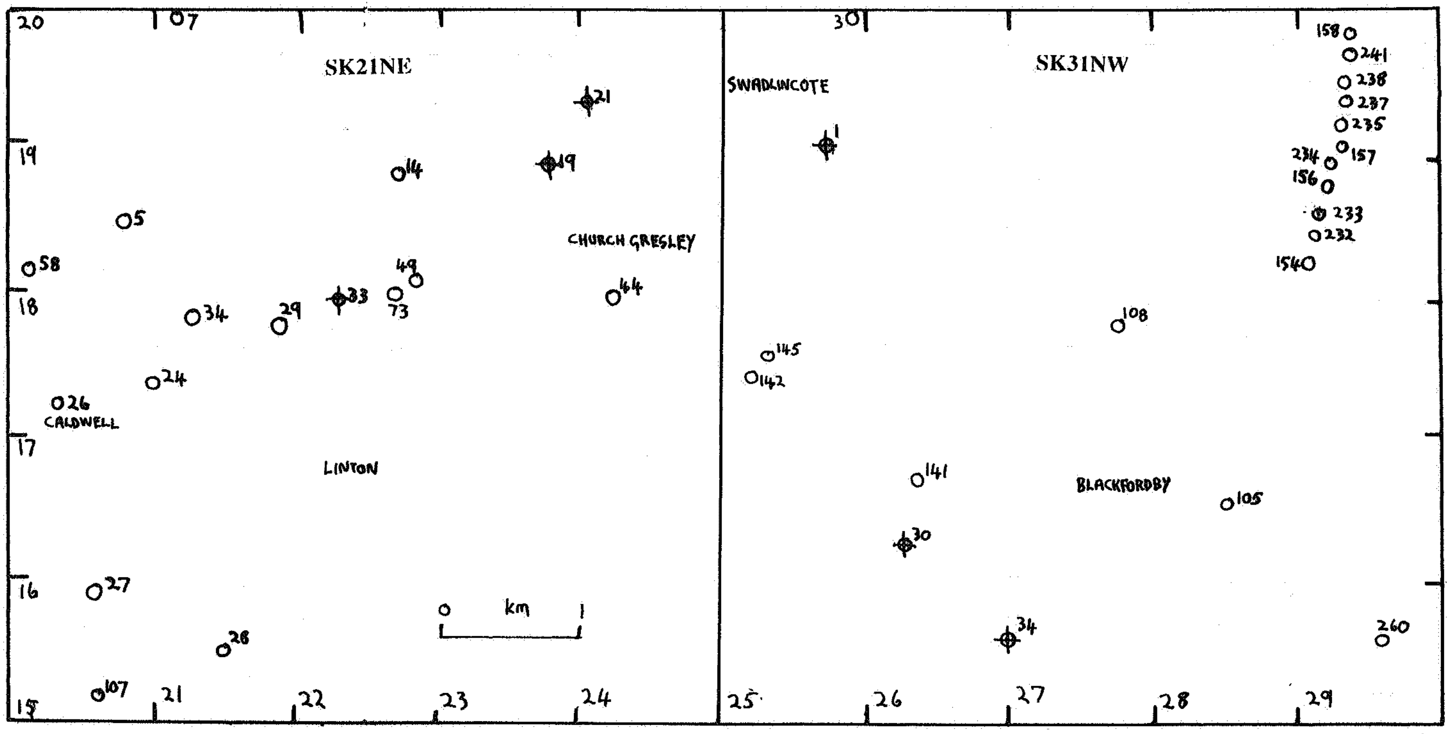
The fissile fabric and complex lower surface of this seam suggest that it had experienced northwards movement along bedding-controlled planes before lithification. On the inaccessible northern continuation of this face, two further thin seams (?P29/30) occurred below the coal, with a 2-3 m sandstone bed intercalated lower down. On the opposite, eastern side of the lake, an isolated and landslipped occurrence of sandstone interbedded with siltstone showed abundant ripple-drift lamination indicative of current directions from east to west.

Tonsteins overlying the P27 and P26 seams are both kaolinite-rich. The P27 tonstein is noteworthy in containing radioactive zircon suggestive of a correlation with the Sub-High Main tonstein (Spears 1970) or Supra-Wyley Yard tonstein (Williamson, 1970), for which a volcanic origin has been postulated (R K Harrison *in* Worssam, 1977).

The **Edmondia Marine Band** overlies the P23 seam; in the Hanginghill Farm Borehole it comprises 0.2 m of dark grey, pyritous mudstones with the foraminifera *Glomospira sp., Glomospirella sp., Tolypammina sp.,* fish debris and abundant plant remains (Worssam, 1977 p.4). Former exposures in the Willesley Clay Pit (Worssam and Old, 1988, p.42) showed that the marine band was locally washed out by 6 to 9 m of cross-bedded siltstone deposited by south-east flowing currents [3224 1530]. The overlying 12 to 15 m sequence contains the seatearths and 0.3-1.0 m coals of the **P24-20** seams: they principally crop out between the Hicks Lodge Opencast Site and Albert Village [~309 184]. Resting on P20, the **Shafton Marine Band** is represented in the Hanginghill Farm Borehole by 0.76 m of grey laminated mudstones containing *Ammodiscus sp.,* sponge spicules, *Hirondella sp.,* and a palaeoniscid scale (Worssam, 1977, p.3). It was also identified as a c. 2 m interval of dark grey mudstones with ribbed shell fragments (but no obvious marine fossils) in the Union Lodge No.4 Borehole. A tonstein from the P20 seam in the Hicks Lodge Farm Opencast Site is described in Worssam (1977, p.5). A similar layer occurs in the P20 seam the Union Lodge Nos. 4 and 5 boreholes, but on analysis was proved not to be a true tonstein, nor was a tonstein found in this position in the Hanginghill Farm Borehole. The **P19-P17** seams and their associated seatearths occur within a 7 to 10 m section at the top of the Middle Coal Measures. The sequence overlying the P19 seam at the northern edge of the Hicks Lodge Opencast Site [3232 1556] includes two beds, 0.2 and 6 m thick, composed of a distinctive buff to pale grey coarse-grained sandstone (Worssam and Old, 1988, p.42). Their outcrop can be traced northwards beyond Sweethill, and one sandstone is partially exposed in a series of small overgrown quarries [3251 1600, 3192 1670]. The pronounced feature-forming bed mapped to the east of Hanging Hill [316 168] appears to be an extension of this sandstone; no sandstone was encountered at the expected level in the Hanginghill Farm Borehole, but the 1.5 m thick silty seatearth sequence below the P19 seam may be a lateral equivalent. The P19-P17 seams were formerly worked at the Moira Opencast Site [317 162], Hepworth Lom [312 180] and Ensor's No.5 Pit [307 181].

Figure 5 Comparative sections in the Middle and Upper Coal Measures: Upper Kilburn to top of Coal Measures (see Figure 6 for borehole locations and explanation)





EXPLANATION OF LITHOLOGIES

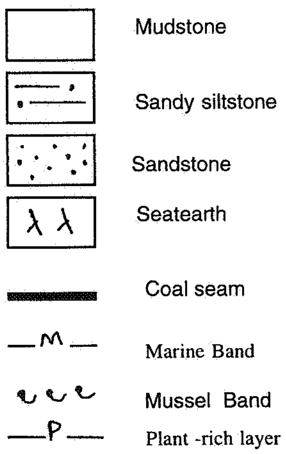


Figure 6 Explanation of symbols and borehole locations in Figures 2-5, and Figure 11

The P17 seam is surmounted by the **Cambriense** (Top) **Marine Band**. It is represented in the Hanginghill Farm Borehole by 0.13 m of ironstone with rootlet fabric, containing *Lingula mytilloides* and foraminifera incuding *Glomospira sp., Glomospirella sp.,* and *Tolypammina sp.,* sponge spicules, *Orbiculoidea sp.* and *Aviculopecten* cf. *delepinei* Demanet. The marine band was also identified at the top of the Union Lodge No.5 Borehole (SK31NW/146), as 0.8 m of dark grey, pyritous, silty mudstone with foraminifera.

Pottery Clays in Sheet SK21NE

The principal exposures of the **Maltby Marine Band**, and overlying beds occurred in Robinson and Dowler's Clay Pit [295 166]. Mitchell and Stubblefield (1948, p.20, Table I) reported 8 cm of hard shale with *Lingula mytilloides*, *Megalichthys* and 'fucoid markings', succeeded by mudstones with (revised names, Worssam and Old, 1988 p.41) *Curvirimula sp*, *Anthracosia* cf. *acutella*, *Anthracosia spp* and *Naiadites spp*. In the concealed coalfield farther west, the Caldwell Hall Borehole recorded mudstones at 270.7 m depth with *Lingula* and *Myalina*, the latter being typical of the Maltby Marine Band in the Nottinghamshire and Derbyshire Coalfield (Notes by D C Greig accompanying the borehole record). The outcrops of the **P39** coal, the Maltby Marine Band, and an overlying sandstone bed are inferred on the sloping ground to the north of Church Gresley, although there is little subsurface evidence to sustain this interpretation.

The succeeding sequence with the **P37-P33** seams and associated seatearths is between 12 and 20 m thick. The strata principally crop out along the slope to the north of Church Gresley but there is little borehole or surface evidence to locate the various seams with precision. The **P34 (Ell)** seam was proved at 9.6 m depth at Church Gresley Colliery and its outcrop can thus be inferred to the west and north. The former clay pit bordering George Street [2913 1840] revealed a particularly thick coal which may be the P34 seam (Field slip of G H Mitchell, 1939), within the following sequence:

Description	*Thickness (m)*
Shale	6.1
Coal (?P34)	1.7
Grey shale	1.2
Coal (?P35)	0.5
Grey clay	3.0
Coal	?

A further clay pit just off the Church Gresley village square [2920 1815] is now infilled and built over. The field slip of G H Mitchell (1939) recorded that of the three coal seams present the upper two, with an aggregate thickness of 1.3 m, were separated by an inch of 'dirt'; the thickness of this combined seam suggests that it is probably the P34 coal. The P33-34 seams are brought in to the east of the Newhall Fault: a road cutting at Swainspark [2972 1716] showed exposures of buff, laminated sandstone. This bed, which forms a low feature hereabouts, may be intercalated between the P33 and P31 seams.

In the concealed coalfield to the west, many of the P37-33 seams fail and the interval is principally occupied by seatearths with subordinate sandstone beds.

The **Haughton Marine Band**, resting on the P33 seam, was formerly exposed at Robinson and Dowler's Pit [295 166], where Mitchell and Stubblefield (1948, p.20) recorded an occurrence of *Lingula mytilloides.* To the west it was proved in the Botany Bay Borehole as 0.6 m of grey mudstone with *Lingula* and a productid; it is overlain by almost 6 m of seatearth extending up to the P31 seam.

The **P31 (Derby)** coal, with the overlying **Aegiranum Marine Band**, were formerly exposed at Robinson and Dowler's Pit. The 'few feet' of highly fossiliferous dark grey shales (Mitchell and Stubblefield, 1948, p.21) contained a rich and diverse fauna listed by those authors and also by Worssam and Old (1988, p.41). Above these beds came 7 m of shales with many ironstone bands and nodules, some of the latter yielding marine fossils of *Crurithyris.* The six-inch ironstone ('Main Stone') surmounting these shales contains *Lingula* at other locations and thus marks the top of the marine band. It is in turn overlain by a 2-3 m thick sandstone. Sandstone beds at this stratigraphical level, intercalated with seatearth and mudstone, are common in the concealed coalfield to the west. The Aegiranum Marine Band was noted by B C Worssam in the western wall of Robinson and Dowler's Clay Pit [2905 1664], and re-appears east of here at Swainspark [2975 1722], where its location is constrained by workings in the Donnington Extension and Church Gresley opencast sites. The marine band is repeated by faulting northwards, and was formerly seen by B C Worssam in the northern highwall of the Railway Works Opencast Site [2950 1809]. North of here, the high ground around the Church Gresley football pitch is probably underlain by seams at or below the level of P31; for example, the following is a tentative correlation of seams encountered in a site investigation borehole (SK21NE/177):

Description	*Thickness (m)*
Grey silty clay and ironstone	4.6
Coal, black and shaly (?P31)	0.5
Mudstone/grey clay	6.0
Mudstone/siltstone, grey	0.7
Sandstone, yellow and grey	1.9
Siltstone, grey	0.9
Sandstone, yellow and grey	1.2
Mudstone, black (?Haughton Marine Band)	0.3
Coal, black, shaly (?P33)	0.7
Mudstone, grey	2.6
Coal, black, shaly (?P34)	1.3
Mudstone, grey	0.7
Coal, black, shaly (?P35)	0.6
Mudstone, grey	3.6+

The stratigraphically highest outcropping beds of the Pottery Clays formation on Sheet SK21NE comprise the 30 m sequence of mudstones and seatearths containing the **P29-P21** seams. These strata are preserved within the Mount Pleasant Syncline (Section 8.2), and were formerly worked at the High Cross Opencast Site [2880 1725]. Farther south, in the

Robinson and Dowler's Clay Pit [2948 1603], Worssam and Old (1988, p.41) recorded the highest seams as being P25/26 and P27/28; these were interleaved between two sandstone beds which can be followed as features in fields to the south-east of the pit.

Strata between the **P21** and **P17** seams are proved at depth in the concealed coalfield to the west. The correlation of these seams is highly tentative, however, since many of the marine bands either fail or were not identified in the boreholes (Figure 5). The 6.1 m bed of coarse-grained, cross-bedded sandstone below the P20 seam in the Grange Wood Borehole is in a similar stratigraphic position to the erosive sand body which was observed above P19 at the Hicks Lodge Opencast Site, on Sheet SK31NW (see above). However, in the Botany Bay Borehole the same sandstone facies appears above P20, at 352 m depth, according to Worssam and Old (1988, Figure 10).

5.2.3. Upper Coal Measures (Bolsovian)

The horizon marking the base of the Upper Coal Measures is taken at the top of the Cambriense (Top) Marine Band. The overlying beds are a continuation of the Pottery Clays formation. They are unconformably overlain by Triassic or Permo-Triassic strata across most of the district, and by the late Carboniferous Barren Measures in the south-western part of the concealed coalfield on Sheet SK21NE.

Sheet SK31NW

The Upper Coal Measures have a minimum thickness of about 34 m. They occur within a north-west elongated syncline to the east of the Moira Fault [320 158], and as an outlier capping the hilly area of Littleworth [310 180]. A further outlier to the west of Littleworth [305 175] was removed during expansion of the Donnington Extension Opencast Site.

The sequence in the Moira Pottery Clay Pit [316 162] comprised seatearths and mudstones which included the P14 to P13 seams when visited by Worssam and Old (1988, p.43). Since then the quarry has been deepened and seams down to P26 extracted. When visited by the present writer, the highest part of the sequence, exposed in the south wall of the pit [3160 1600] was as follows:

Description	*Thickness (m)*
Clay, yellow and cryoturbated	1.8
Coal (?P12)	0.5
Coaly mudstone	0.3
Coal interbedded with coaly mudstone (?P13)	0.4
Mudstone, pale grey, blocky	0.7
Coal, with dull and bright bands (?P14)	1.0+

Two sandstone beds intercalated above the P17 and P16 seams form low features around Hanging Hill. In the disused quarry north-west of Hanginghill Farm [3122 1653], exposures of the lower bed show a grey, medium- to coarse-grained thinly-bedded feldspathic sandstone at least 4 m thick. Individual bedding units up to 0.3 m thick are bounded by sharply-defined partings; they are either internally massive or show cross-bedding indicative of current flow towards the south-south-west or south-east. The sandstone capping Hanging Hill [31301673] is also a coarse-grained variety, and probably correlates with the sandstone capping the hill-top at Littleworth Colliery farther north [3100 1775]. These sandstones are lithologically distinctive, to the extent that Mitchell and Stubblefield (1948, p.22) thought that they were unconformable upon the Coal Measures, naming them the 'Moira Grits' and even suggesting that they may be correlated with the Halesowen Formation, rather than being a coarse-grained facies of the Middle Coal Measures (Fox-Strangways, 1907). The former view was initially endorsed by B C Worssam (*in* Worssam et al., 1971), but was later discounted (Worssam and Old, 1988, p.34), particularly as it was shown that identical sandstones form part of the Middle Coal Measures sequence. For example, exposures in north of the Willesley Clay Pit [3223 1543] showed that coarse-grained sandstone resting on the P19 coal forms a channel-fill body conformable within the local sequence. The term 'Moira grit' was therefore discontinued.

Sheet SK21NE

Mudstones and seatearths tentatively correlated with the Upper Coal Measures comprise the upper c.20 m of strata below the Etruria Formation in the Botany Bay Borehole (Figure 5), and also probably the Linton Lane Borehole. By contrast, only a few metres of these beds can be accomodated below the Etruria Formation in the Grange Wood Borehole (Figure 5).

5.3. Barren Measures (Bolsovian - Stephanian)

This division does not crop out, but has been proved at depth in the south-western part of the concealed coalfield on *Sheet SK21NE*. The strata represent a distinctive 'red bed' association of sandstones and mudstones, which elsewhere in central England is considered to range from Bolsovian to Stephanian age. The collective name 'Barren Measures' is used here informally, as a term of convenience for this lithological grouping, and it is recognised that in other parts of the UK beds of this age are not entirely barren of coal seams (e.g. Corfield et al., 1996).

The sequence was subdivided into three components by Worssam and Old (1988. p.43). The lower of these, the Etruria and Halesowen formations, are retained here but the upper unit, formerly known as the Keele Formation, is renamed as the Whitacre Member of the Meriden Formation, in line with the nomenclature for the Barren Measures of the Warwickshire district proposed by Bridge et al., (in press.).

In parts of the UK it has been found that the Coal Measures and Barren Measures are diachronously interbedded (e.g. Besly, 1988). The sequences proved in the present district show no indication of interbedding, but there are two lines of evidence which suggest that the basal Barren Measures unit, the Etruria Formation, may be unconformable upon the Coal Measures. First, comparisons between the relevant boreholes (Figure 5, and Figure 10 of Worssam and Old, 1988) indicate that different levels within the Middle and Upper Coal Measures occur at the base of the Etruria Formation, suggesting prior tilting and/or erosion of the Coal Measures. A hiatus in sedimentation that would accompany such an erosional interval is furthermore suggested by the marked change in depositional environments and oxidation states of the strata on either side of the junction. Second, seismic sections extending into the south-western part of this district show reflectors of presumed Middle to Upper Coal Measures age being truncated at the contact with the Barren Measures, although further work is needed to constrain the interpretation of these profiles (Oral communication, NJP Smith). The sub-Etruria hiatus, known regionally as the Symon Unconformity, was originally recognised by Whitehead et al. (1928) near Wolverhampton. Its significance to the tectonic evolution of central England during the late Carboniferous is discussed by Corfield et al. (1996), among others.

5.3.1. Etruria Formation (Bolsovian)

Complete sections through this formation show respective thicknesses of 43, 34.1 and 26.3 m in the Linton Lane, Grange Wood and Netherseal Rosliston boreholes. Where overlain by Triassic strata the formation is at least 44.7 m thick in Caldwell No.2 Borehole and 29 m in the Botany Bay Borehole, both located near the western margin of the district. That the base of the Etruria Formation may be irregular and erosive upon the Upper Coal Measures has already been suggested. However, this may not entirely account for the thickness variations since it is shown in the Coventry district (Bridge et al., in press) that in places the junction with the overlying Halesowen Formation can also be an unconformity.

The Etruria Formation consists mainly of reddish brown, unbedded mudstone with purple, yellow, green and blue-grey mottles. A 4 to 7.5 m bed of coarse-grained sandstone occurs near the middle part of the unit at Grange Wood, Caldwell 2 and Linton Lane. The latter borehole additionally records 'seatearth' horizons up to 9 m thick; for example the interval between 386 and 395 m depth is comprised of purple and brown calcareous mudstone with common ochreous patches, desiccation cracks, listric surfaces and rootlet traces. These lithologies are similar to the brunified alluvial palaeosol facies of Besly and Fielding (1989). At Grange Wood they are probably represented by the equally thick beds of reddish-brown, yellow and purple mottled marls with abundant listric surfaces. The base of the Etruria Formation is sharp upon the grey Coal Measures mudstones. The latter have developed red, purple or yellow mottling, and contain brick-red ironstone nodules, over several metres below the contact. Such features, combined with the common absence of coals, are attributed by Worssam and Old (1988, p.43) to penecontemporaneous oxidation and are compatible with the unconformable relationship of the Etruria Formation discussed earlier.

5.3.2. Halesowen Formation (Stephanian)

The incoming of this formation is marked by a pronounced colour change, to purple-grey and greenish grey as opposed to the reddish brown and ochreous lithologies of the underlying Etruria Formation. The only complete section through the unit is in the Grange Wood Borehole, where a 69.1 m thickness is recorded; in the Linton Lane Borehole it is at least 58 m thick beneath Triassic cover. At Grange Wood the lowest 45 m consists of purple, purplish grey and green-grey, locally very coarse-grained grained, micaceous and feldspathic sandstone. The basal sandstone, which is also the thickest at 21.6 m, may correlate with the '100-foot' sandstone which is persistent at the base of the Halesowen Formation farther south in the Coventry district (Eastwood et al., 1923). Purple, green and grey micaceous laminated siltstones and mudstones form subordinate interbeds but increase in importance upwards and are dominant in the upper 13 m of the formation, The Linton Lane Borehole records three possible sedimentary cycles. The lowest, between 378 and 360m depth, is dominated by purple-grey, medium-grained and locally cross-bedded sandstones. They are succeeded abruptly by purple-grey, massive to laminated mudstones and siltstones, with ferruginous concretions and listric textures locally developed. These are erosively overlain at 354 m by purplish grey sandstones of the third cycle; these may comprise most of the uncored 18 m interval beneath the Trias.

In the Grange Wood Borehole the topmost bed of the Halesowen Formation comprises 0.1 m of purple, fine-grained limestone with green mudstone partings. Erosion of this bed is suggested by the description of 'calcareous fragments' in the basal sandstone of the overlying Meriden Formation.

5.3.3. Meriden Formation (Stephanian)

The component of the Meriden Formation represented in this district is identified with the *Whitacre Member* of the Warwickshire Coalfield, Coventry district. As defined by Bridge et al. (in press.), the Whitacre Member consists of mudstones and subordinate sandstones in its lower part, but becomes increasingly arenaceous towards the top.

In this district the Meriden Formation is recorded only from the Grange Wood and Netherseal Rosliston boreholes, where the respective minimum thicknesses are 38 m and 29 m. At Grange Wood the sequences commences with 7.3 m of medium-grained pale purple sandstone with mudstone clasts and, at the base, calcareous fragments. This is then overlain by 22 m of predominantly dark red-brown micaceous siltstone, commonly calcareous and nodular, and in places with *Lepidodendron* remains. Towards the top of this sequence are intercalated two conglomerate beds, each about 1 m thick, which contain coated quartz pebbles or angular quartz fragments, and clasts of purple limestone and calcareous sandstone. The upper 9 m of the Meriden Formation is dominated by beds of dark red-brown to green, medium- to coarse-grained, locally pebbly sandstones. Many sandstones contain layers rich in mudstone clasts, which are commonly concentrated along the basal bed surfaces.

6. TRIASSIC

The lithostratigraphical subdivision of the Triassic rocks in this district is based on the scheme of Warrington et al. (1980), as modified by Charsley et al (1990). The two principal divisions comprise a basal Sherwood Sandstone Group and an overlying Mercia Mudstone Group.

6.1. Sherwood Sandstone Group

In this district the Sherwood Sandstone Group (Warrington et al., 1980) comprises three units: a discontinuously-developed *Moira Formation* at the base, succeeded by the *Polesworth Formation* and *Bromsgrove Sandstone Formation.*

6.1.1. Moira Formation

The Moira Formation comprises subangular conglomerates ('breccias') in association with mudstones, siltstones and sandstones. It unconformably overlies the Coal Measures, and forms a series of discontinuous outcrops along the basal boundary of the Sherwood Sandstone Group. The combined evidence of borehole data and field mapping shows that the top surface of the unit is broadly planar, and that the thickness variations observed within the Moira Formation are in part due to irregularities of the basal surface. Additionally, Brown (1889) has shown that at least locally in Sheet SK31NW there is an angular unconformity developed between the Moira Formation and overlying strata of the Polesworth Formation. The Moira Formation is therefore regarded as an unconformity-bounded unit, representing sequences that infilled hollows on the Carboniferous landsurface, but which were affected by earthmovements before being onlapped by the Polesworth and Bromsgrove formations.

These beds were originally called the 'Breccia and Marl of Moira' on the One-inch Geological Sheet 155 (Atherstone, since re-named Coalville), published in 1899, although in contemporary Geological Survey memoirs (Fox-Strangways, 1900, 1905, 1907) the rocks were referred to as 'Permian breccias' or 'Permian marls'. In the present report the name 'Moira' is retained because it is in common use, even though these strata do not crop out in Moira itself. The term 'breccia' is not appropriate, however, since on-going work both here and in the map sheets to the north (Barclay, 1996), indicate that 'breccia' is not always the dominant lithology, and that where rudaceous beds are present many of the pebble or cobble-grade clasts show rounded or partly-rounded corners rather than being truly angular (see also the descriptions in Worssam and Old, 1988, p.55). The angularity that so impressed the earlier workers may in part reflect the extremely low *sphericity* of most clasts, which is a distinctive feature of the unit. The degree of angularity may also be geographically controlled, however, for it is reported to increase, in direct proportion to the 'breccia' content of the formation, from north to south (Brown, 1889, p.22). The earlier studies recognised a 'Hopwas Breccia' variant, which differed in containing a small percentage of limestone clasts, and the deposits of the present district were referred to as 'Moira or Hopwas Breccia' by Mitchell and Stubblefield (1948, p.1). The practice of using Moira Breccia around the South Derbyshire and Leicestershire Coalfields and Hopwas Breccia in the Warwickshire Coalfield area was adopted by Hains and Horton (1969); it is followed here as in the district to the south (Worssam and Old, 1988, p.51).

The age of the Moira Formation is not precisely known since these beds are generally lacking in dateable fossil remains. In the West Midlands the equivalent strata, called the Barr Beacon Beds and the Hopwas Breccia, were thought to be Permian in age by Smith et al. (1975). Recently, however, a comparative palaeomagnetic study of samples from the

Enville Formation, Hopwas Breccia and Kidderminster Sandstone of the West Midlands has concluded that the Hopwas Breccia is probably of early Triassic (earliest Scythian) age, and that very little time had elapsed between its deposition and that of the overlying Kidderminster Sandstone (=Polesworth Formation) (Oral communication, J H Powell). In the present district, the sedimentological contrasts, and the fact that the Moira Formation presents an angular and erosional unconformity with the overlying Polesworth Formation, are both indicative of a significant time-lapse between the two units, even though this is not diagnostic of age and may have occurred in the earliest part of the Triassic.

Details: Sheet SK31NW

The Moira Formation has a maximum thickness of about 8 m on this sheet. It typically occurs in discontinuous, narrow outcrops along the break of slope representing the Carboniferous/Triassic junction. Although the unit is very poorly exposed, its presence is commonly revealed by red, sandy or clayey soils strewn with subrounded rock fragments.

The most significant outcrop of the unit occurs around the base of the Trias-capped hill between Woodville and Swadlincote [311 195]. The northerly spur of Triassic strata, shown on the reprinted 1976 edition of Sheet 141, was subsequently removed during the expansion of the *Hillside Quarry (Wragg's Clay Pit).* Early excavations into the western side of the Triassic outcrop revealed in full the stratigraphical relationships of the Moira Formation, and these were described and illustrated photographically by Brown (1889, Plate I). It was shown that the Moira formation exhibits a strong angular unconformity with the overlying 'Bunter' beds (Polesworth Formation), for example the dip measurements of Brown (1889, p.7) demonstrated that whereas the Polesworth Formation was sub-horizontal the Moira Formation dipped 23° to the NE050. The underlying Coal Measures were only seen in strike section, and appeared to be in angular continuity with the Moira Formation, although there is ample evidence elsewhere for unconformity along that particular junction. In the section measured by Brown (1889, p.8), the variation within the 8 m thickness of Moira 'Breccia' was as follows:

Description	*Thickness (m)*
Soil and disturbed ground	1.2
Bunter [Polesworth Formation]:	
Pebbly conglomerate with a few thin beds of coarse sandstone	1.5-2.4
Moira Breccia:	
Sandstone, buff, friable	1.2
Clay, red and grey, sanding upwards	0.5
Sandstone, grey with red tints, thinly-bedded and rippled	1.0
Clay parting	0.01
Breccia, with middle clay and sand parting	1.0
Sandstone, with clay parting and small angular rock fragments	0.2
Clay, red, with 90 mm breccia bed near top	3.3
Sand, grey and argillaceous with sporadic angular pebbles, grades down to:	0.2
Breccia, with basal very hard, ferruginous 'cank' stone, latter eroded and impersistent	0.6-0.9
Coal Measures:	
Clay, dark purple and variegated, with large haematite nodules	1.8
Dark pyritous shales, etc.....	

Farther east, on the northern side of the hill, Brown (1889, p.9) described a further section in a clay pit, close to *Sharpswood Farm.* This quarry is now landscaped and occupied by a Residential Home [3118 1963]. The section formerly exposed, augmented by provings in a shallow well in the floor of the brickyard (information from Fox-Strangways, 1905, p.28) is as follows:

Description	Thickness (m)
Bunter [Polesworth Formation]:	
Sandy clay and coarse-grained sandstone	0.6-1.0
Conglomerate with clay galls, cross-bedded	0.4
Moira Breccia:	
Sand, grey and argillaceous	0.2
Marl, red and indurated	0.4
Fine-grained breccia	0.1
Marl, red and variegated, with sandstone layer near top	0.5
Breccia, with thin argillaceous parting	1.2
Clays, red and green variegated, with white sandstone beds	3.6 approx
Breccia	1.0 approx
Well extension:	
Clay, red	1.0
Breccia	2.4
Coal Measures etc	

The Coal Measures immediately below the Moira Formation were described as 'hard and blue' in the well (Brown, 1898, p.9) and thus do not appear to have suffered secondary reddening at this location.

During the present re-survey, about 1 m of subangular conglomerate, representing a 'breccia' bed of the Moira Formation, was exposed above red and grey mottled Coal Measures mudstones in a newly-deepened ditch along the *southern margin of Hillside Quarry* [3107 1974], between the two localities described above. The conglomerate clasts are between 5 to 70 mm in dimension and are separated by a matrix of red, very poorly-sorted, friable, muddy or silty sand. Most of the clasts have red rims and tabular or discoid shapes; they have a preferred parallel orientation which suggests that the deposit overall shows a crude sub-horizontal stratification. Although of extremely low sphericity, the clasts nevertheless generally possess rounded-off corners. One pyramid-shaped clast with four exceptionally smooth, faceted surfaces strongly resembles a *dreikanter*: other clasts are partly-faceted, or have bedding planes smoothly etched out, and certain volcanic clasts have weathered-out carbonate amygdales, giving them a pock-marked appearance. The clasts therefore may have been exposed to weathering agencies for some time, perhaps on a pediment surface, before being scoured off and rapidly redeposited during sheetflood events. The clast lithologies include coarse-grained feldspathic sandstone, limestone, foliated vein quartz and green cleaved mudstone, the latter of probable Cambrian age. A significant proportion also comprise thinly-bedded to laminated, cleaved, volcaniclastic rocks inferred to have been derived from the Precambrian succession of Charnwood Forest. In particular, one clast of porphyritic dacite shows in a thin section (E67775) large phenocrysts of quartz and only partly-altered plagioclase in a fine-grained, slightly cleaved leucocratic groundmass, a texture diagnostic of an ultimate derivation from an outcrop of the Sharpley Porphyritic Dacite (Carney, 1994, p.47), the nearest present-day exposure of which is in

Charnwood Forest 13 km to the east-south-east. Brown (1889, p.26) reports that Professor Bonney also attributed certain clasts in these beds to the Peldar-Sharpley area of Charnwood Forest. The reader is referred to the latter account for further details of clast lithologies.

On the *south-eastern outskirts of Woodville,* the early mapping showed a narrow belt of Moira Formation at the base of the Bromsgrove Sandstone outcrop. Augering confirmed only unconsolidated red sand, but the subdued concave feature at the base of the hill is taken to be developed on a mudstone-dominated facies of the Moira Formation. Its presence in a similar position to the south, near Blackfordby House [3274 1836], is revealed by fields containing brash of bright red mudstone and siltstone, with flakes of purple siltstone and sporadic subangular rock fragments. To the south-east, a former excavation by the roadside in Blackfordby [3296 1799], recorded on the 1974 field slip of B C Worssam, showed 'breccia' resting on red-stained Coal Measures mudstone; the formation is inferred to feather out to the east of here.

Narrow Triassic outliers which include the Moira Formation crop out on the western, downthrown side of the Blackfordby Fault. In the *Boothorpe Pottery Works* [316 185], former exposures sketched by Brown (1889, p.6) show the 'Permian' (Moira Formation) resting upon Coal Measures and being then overstepped by the 'Bunter' (Polesworth Formation) beds. The base of the Polesworth Formation was described as erosional, but with a slight angular unconformity caused by the Polesworth Formation dipping at 4°S and the Moira Formation at 5°S. At the same locality, Fox-Strangways (1905, p.29) stated that "the Bunter sandstone......fills in depressions of the breccia"; the latter author described the following section:

Description	*Thickness(m)*
Bunter [Polesworth Formation]:	
Sandstone, friable and pebbly	2.4
Moira Breccia:	
Sandy breccia or conglomerate	0.8
Breccia, purple, with sandstone bed in upper part	1.7
Marl, purple, with white and grey layers	1.5
Coal Measures	
Grey mudstones, steeply dipping	

The south-easterly continuation of these beds was formerly revealed beneath the Polesworth Formation, in a section on the southern side of the *Albion Opencast Site* [3190 1775]. The 1968 field slip of B C Worssam notes 4.5 m of red, sandy, well-bedded breccia with angular fragments present throughout. The Moira Formation is inferred to pinch out not far to the south of here, but comes in again to the south-east, around *Drift Farm* [3258 1707], described in the next section, and near *Wood Farm* [3355 1545]. The latter outcrop's north-west orientation is suggestive of a structural control by the nearby Boothorpe Fault, but on earlier maps (B C Worssam, in MS) the fault was depicted as passing beneath the Moira Formation, which was shown as unfaulted. The interpretation now favoured is that the Moira Formation is preserved on the downthrown, south-western side of the Boothorpe Fault whose true position, revealed during this survey at the nearby Shellbrook Opencast Site [330 163], is about 340 m farther to the north-east than originally mapped.

The south-easternmost outcrop of the Moira Formation forms gentle slopes at the base of the Triassic outcrop *south-east of Valley Farm* [347 154]. Its presence was revealed by augering and by subangular rock fragments around newly-dug post-holes. Evidently, the rudaceous component of the formation is predominant hereabouts, there being almost 16 m of subangular conglomerate proved in boreholes drilled through the continuation of this outcrop in the adjacent map sheet (Carney, 1996).

The south-westernmost outcrop, south of Gorsey Leys [30 15] on the eastern outskirts of Overseal, forms a low hill upon which are developed red, sandy or clayey soils strewn with subangular pebbles. Details of temporary exposures in this area are given by Worssam and Old (1988, p.54).

Details: Sheet SK21NE

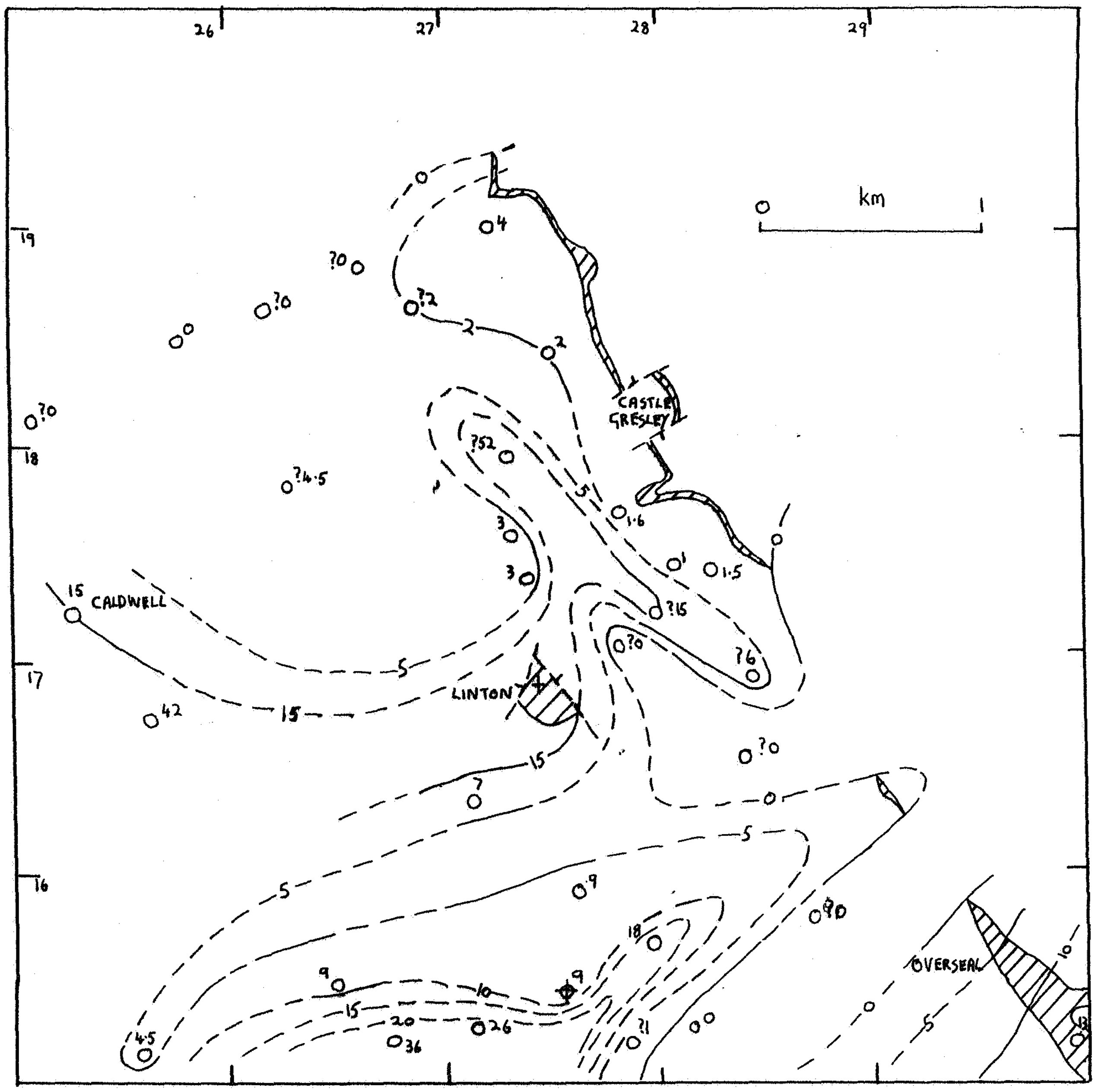
The Moira Formation crops out in three places along the base of the Triassic escarpment between Overseal [298 155] and Council Farm [2726 1932]. Its other exposure, in Linton [275 168], is at the apex of a triangular horst bounded to west and east respectively by the Netherseal and Overseal faults. Underground provings show that over most of the mapped sheet the unit is only a few metres thick, or is absent, but that it locally attains thicknesses of up to 50 metres (Figure 7).

On the outcrop at *Overseal*, the Poplars From Borehole (SK21NE/59) proved 13.1 m of red-brown argillaceous sandstone with 'pebbles' overlying Coal Measures.

The small outcrop mapped to the north-west was originally exposed in the highwall of Robinson and Dowler's Clay Pit [2907 1640], but no descriptions of this are known.

The most extensive outcrop commences north-west of Mount Pleasant [2827 1739] and runs along the base of the Triassic escarpment as far as Council Farm [2726 1932]. The Moira Formation hereabouts forms a subdued concave feature generally covered by sandy soils and thin head washed down from the overlying Polesworth Formation. At *High Cross Bank* exposures in a well [2818 1748] described by Fox-Strangways (1905, p.25) showed what is interpreted as the Moira Formation ('purple gravel' or 'pox gravel') beneath only 5.7 m of strata resembling the Polesworth Formation; about 50 m to the south-east of the above locality a further proving was made, of 2.1 m of 'pox gravel', at a depth of 10 yards (= 9m), or about 80 m above OD. This is at odds with the base of the Trias being at 31 m OD only 180 m due east, in the High Cross Bank Borehole (SK21NE/63), and indicates that a westerly-throwing fault must intervene between the two localities. In Figure 14, this structure is shown as the southerly extension of the Coton Park Fault, which in part controls the junction between the Polesworth and Bromsgrove formations hereabouts

In the north side of the railway cutting, south of *Castle Gresley* [2801 1780], augering proved a bright red mudstone thought to represent part of the Moira Formation. The latter's continuation to the north-west is demonstrated by provings of about 1 m of 'mingled marl' and 'very hard mingled rock' at 27.7 m depth in Cadley Hill Colliery No.1 Borehole



Isopachyte, value in metres, dashed where highly speculative

Borehole, with Moira Formation thickness in metres

Outcrop of the Moira Formation

Figure 7 Isopach map of the Moira Formation in Sheet SK21NE

(SK21NE/8), and by 4.1 m of 'gravel' above Coal Measures at 24.5 m in the Cadley Hill Colliery No.4 Borehole (SK21NE/11).

Former exposures sketched by B C Worssam (in MS, 1974), during the widening of the *Cadley Hill Road* [2753 1904], showed at least 3 m of gently-dipping subangular conglomerate of the Moira Formation in sharp vertical contact with tightly folded Coal Measures. The orientation of the field sketch is uncertain, but the relationships shown are consistent with the margin of the Trias outcrop being controlled by a north-westerly fault throwing the Moira Formation down to the west.

At *Linton* village the outcrop of the Moira Formation is covered by urban development but its presence is revealed in gardens by red clayey or sandy soils with subangular fragments of ?Cambrian mudstone and quartzite. A former exposure, described by Hull (1860, p.59) in a 'lane at Linton', showed the Moira 'Breccia' faulted against younger Triassic sandstones and mudstones. It consisted of 'a mass of loose pebbles, angular or otherwise', which included 'Light green and indurated slate', said to be from Charnwood Forest, 'grits' of various types, 'dark brown and purple sandstones....., chert, feldspar, trap and quartz'. Some of the clasts were as much as 13 cm dimension. Coleman (in Brown, 1889, p.12) added that in a well at Linton 42 ft 6 in (12.9 m) of Moira 'Breccia' were found overlying the Coal Measures.

Several boreholes in the west of the sheet have proved Moira Formation below strata of the Polesworth Formation. The accounts are not all reliable, however, because the sinkings were part of a coal exploration programme and many were drilled open-hole until the base of the Trias was reached. Furthermore, even where coring had been done the descriptions are couched in antiquated terminology, with only passing reference made to the Triassic cover. Reliance is therefore often placed on the driller's 'feel' for typical Moira Formation lithologies, which would have constituted an important datum before the Coal Measures were entered. The better records allow an isopach map to be constructed (Figure 7), which like Figure 14 of Worssam and Old (1988) shows apparent west-south-west trending axes of thickening interpreted to be the courses of channels incised into the Coal Measures and infilled by the Moira Formation.

The record for the thickest underground proving of the formation, at Coton Park Colliery, refers to 171' 11" (52.4 m) of 'Grits, clays and binds with haematite nodules, breccia etc.' That this is probably not Etruria Formation is indicated by the fact that it rests on Middle Coal Measures just above the Main group of seams, whereas elsewhere the base of the Etruria Formation only comes in considerably higher up, at about the level of the Middle/Upper Coal Measures boundary. This proving may be that mentioned by Gresley (1886, p.3), as the 'Coton Park and Linton Colliery', where a 'nodule of hard haematite' was likened to clasts found elsewhere in the Moira 'Breccia'. In addition to being haematitic, these commonly contain the impressions of Carboniferous plants and mussels and are therefore derived, secondarily, by the incoporation of material from weathered and oxidised Coal Measures. The style of this oxidation suggests furthermore that these clasts were derived from the weathered zone below the Barren Measures (Section 5.3). Farther west, a note in the log of the Caldwell No.2 Borehole records 42.6 m of Moira 'Breccia', but again there are no adequate supporting descriptions. Close by, in the Caldwell Hall Borehole, 15 m of Moira Formation was described in the log as 'medium purple sand'. One of the better descriptions of the Moira Formation is in the Grange Wood Borehole, where the Coal Measures are overlain by 9 m of red, green or purple coarse-grained argillaceous sandstone with rounded to angular pebbles of sandstone, igneous rock and 'marl'. The topmost bed shows an upwards increase in the degree of clast roundness suggesting that Moira Formation may have been reworked at the base of the Polesworth Formation.

6.1.2 Polesworth Formation

The Polesworth Formation mainly consists of poorly cemented, coarse-grained pebbly sandstones and matrix- or clast-supported conglomerates. The larger clasts typically comprise well-rounded 'Bunter' pebbles whose composition and origin is discussed by Worssam and Old (1988, p.56). The unit corresponds to the Bunter Sandstone or Bunter Pebble Beds of previous workers (Fox-Strangways, 1905). Its present name was first coined by Warrington et al. (1980, p.38) and the type area designated by Worssam and Old (1988, p.56) as the outcrop between Polesworth and Warton, on the eastern side of the Warwickshire Coalfield. The Polesworth Formation belongs to a distinctive early Triassic (Scythian age) association of coarse-grained sedimentary rocks. These lithologies have been recognised throughout the English Midlands, but they commonly form basal infills to isolated Triassic depositional basins and so are seldom seen in demonstrable lateral continuity on a regional scale. This mode of occurrence has prompted Warrington et al. (1980, p.38) to recommend that the strata should be assigned local formation names in their various areas of outcrop. Thus the Polesworth Formation represents the strata within or fringing the Hinckley and Needwood basins of deposition, and is equivalent to the Kidderminster and possibly the Wildmoor formations of the Worcester Basin, and to the Nottingham Castle Formation of the South Nottinghamshire Basin (Warrington et al., 1980, Table 4; Worssam and Old, 1988, Table 3).

A coherent sequence is difficult to establish for the Polesworth Formation, since its outcrops are strewn with pebbles and cobbles regardless of the underlying lithology. Non-conglomeratic sandstone beds have been mapped at the surface, but commonly cannot be followed laterally for more than a few hundred metres. Most of the better-documented boreholes show that true conglomerates form less than 50 per cent of a given section, and that within the sequence as a whole there are all gradations between conglomerate, pebbly sandstone and medium- to coarse-grained sandstone devoid of pebbles.

In the present district the Polesworth Formation thins towards the east, its feather-edge occurring a few hundred metres to the east of the Boothorpe Fault in Sheet SK31NW. Its principal outcrop, in the western part of Sheet SK21NE, lies within a zone of syn-Triassic subsidence and growth-faulting along the eastern flank of the Needwood Basin (Worssam and Old, 1988, p.112), and here the unit may be unconformable on the Bromsgrove Sandstone (Section 6.1.3). An isopach map (Figure 8) demonstrates that the formation thins over a north-westerly 'high', but that overall it thickens westwards into the Needwood Basin, a trend which is continued in the area to the south (Worssam and Old, 1988, Figure 15).

Details: Sheet SK31 NW

The Polesworth Formation varies between zero and 10 m thick on this sheet. It principally occurs within narrow, tectonically-controlled outliers on the downthrown, south-western margin of the Boothorpe Fault. The small exposure in a disused quarry *south-east of Boothorpe Hall* [3216 1745] shows the following north-eastwards dipping sequence:

Description	*Thickness (m)*
Conglomerate, buff to grey, poorly sorted and supported by a coarse sand matrix. Pebbles are up to 0.1 m size. Faint imbrication suggests currents to S190°. Channelled base on:	0.2+
Sandstone, buff, medium- to coarse-grained, cross-bedded with foreset dip to NE/065°	0-0.2
Sandstone, buff, medium- to coarse-grained, massive with sporadic 'floating' pebbles, erosive base on:	0.4
Sandstone, buff, coarse-grained with sporadic small pebbles, laminated to thinly bedded	0.5+

To the north-west, the Polesworth Formation was formerly exposed in old workings now incorporated into the Albion Opencast Site. A section in the southern highwall of the former quarry [3190 1773] showed Triassic strata dipping at 20° to the north-east (B C Worssam in MS, 1968) as follows:

Description	*Thickness (m)*
Sand, coarse-grained, with pebbles (weathered Polesworth Formation, above main face)	3-4.5
(Unexposed section............	3.0)
Sandstone, red-brown, fine-grained	0.6
Mudstone, dark red	0.3
Sandstone, yellow-brown to pink, massive	1.5
Sandstone, yellow, with angular clasts and mudstone partings	1.2

Farther to the north-west, the *Boothorpe Pottery Works* [316 185] formerly exposed 8 feet (2.4 m) of 'soft pebbly sandstone' (Fox-Strangways, 1905, p.28), here correlated with the Polesworth Formation, overlying the Moira Formation.

To the north-west of Woodville, former exposures at the *Hillside Quarry* (Wragg's Clay Pit) are described in the previous section on the Moira Formation. Only about 2.4 m of conglomerates and coarse-grained sandstones of the Polesworth Formation were exposed, but enough was seen to indicate that these beds, being sub-horizontal, rested with strong angular unconformity upon the Moira Formation (Brown, 1889, Plate I).

Details: Sheet SK21NE

The Polesworth Formation varies from about 46 to 170 m in thickness. These are approximate estimates, based mostly on borehole records of uncored and consequently poorly documented Triassic sections. There is barely sufficient data to construct an isopach diagram (Figure 8), but this nevertheless shows significant thickening of the formation towards the south-western corner of the sheet. This trend, reflecting the infilling by the Polesworth Formation of the Needwood Basin, is continued farther south in to the Coalville district, where Worssam and Old (1988, Figure 27) also show a syn-Triassic growth component along the Netherseal Fault (Worssam and Old, 1988, Figure 27). The latter structure brings the Polesworth Formation to crop at Linton. Farther north its throw is transferred to the Coton Park Fault which bounds the Polesworth Formation outcrop to the north-west and south-east of Castle Gresley.

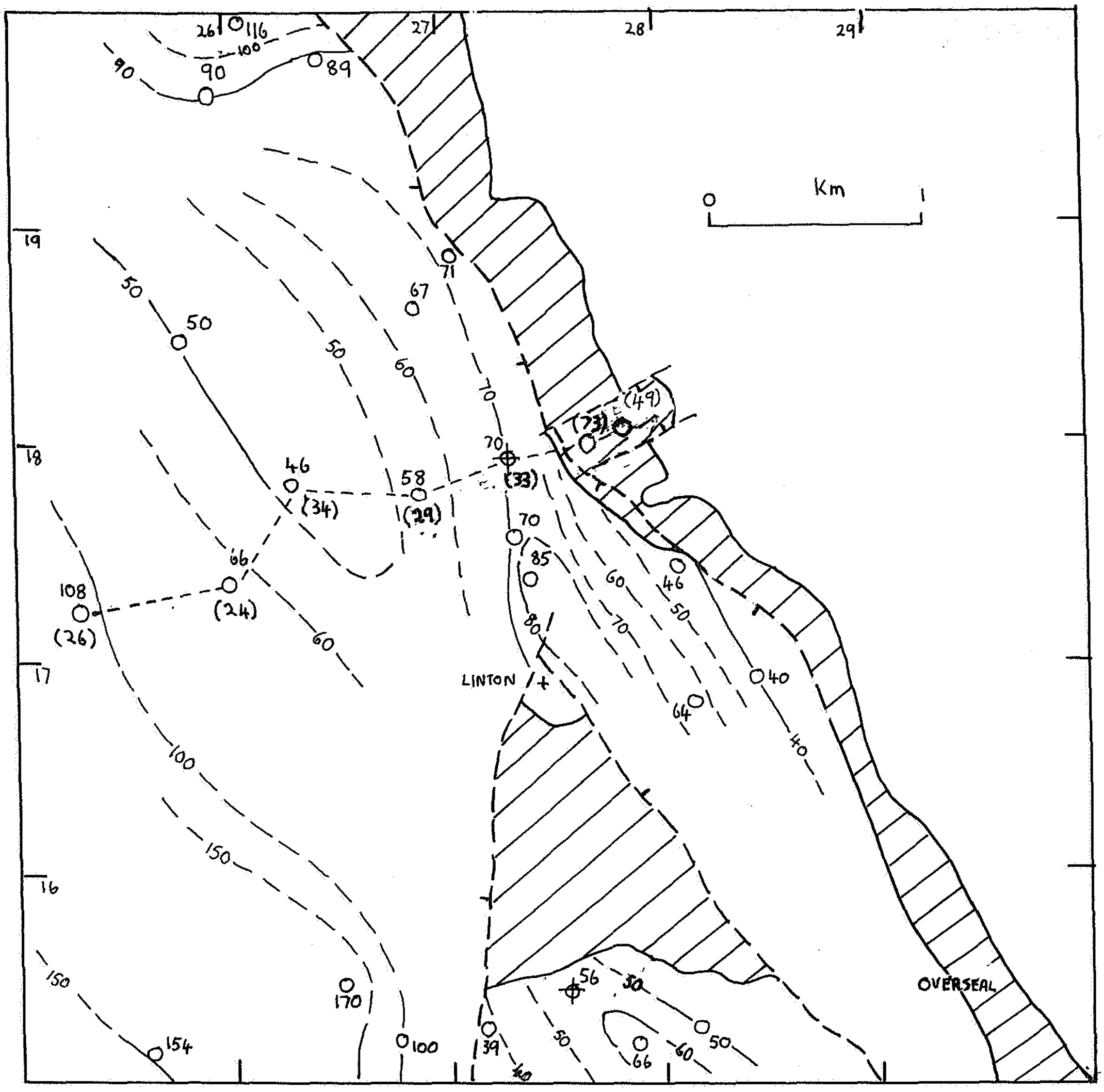
Figures 8 and 9 show that this margin of the Needwood Basin is complex, with differential thinning of the Polesworth Formation occurring over a north-west trending topographic ridge on the underlying Coal Measures The borehole sections (Figure 9) show that the Polesworth Formation thins to less than 50 m over this ridge, before thickening up farther east within a north-westerly trough located on the downthrown, south-western side of the Coton Park Fault (Figure 8). Thus in the Coton Park Grange Farm Borehole (SK21NE/70), within the trough axis, the Polesworth Formation is about 85 m thick. In the north of the map sheet the Polesworth Formation thickens up to 116 m in the Bretby West No.3 Borehole, perhaps suggesting the *en echelon* continuation of the Needwood Basin.

To the *south-east of Castle Gresley* the basal Polesworth Formation beds dip about 5° west and form rubbly exposures of buff, pebbly, coarse-grained sandstone above the railway cutting south of the castle [2795 1782]. Here the base of the Polesworth Formation is at 80 m above OD, whereas in the Castle Hill Borehole (SK21NE/50), 150 m to the south-west, it is only 29 m above OD. A fault, inferred to be the southerly extension to the Coton Park Fault, is therefore inferred to intervene between these two localities.

South-east of High Cross Bank the Polesworth Formation outcrop narrows, probably due to flexuring of strata near to the tip of the Coton Park Fault. Such a structure is suggested by the south-westerly dip of 16° formerly seen by Fox-Strangways (in MS) near the crest of the ridge which underlies this outcrop [2943 1735]. Along this ridge towards Overseal [295 154], ground underlain by the Polesworth Formation typically gives rise to sandy soils with abundant fragments of coarse-grained sandstone and rounded pebbles; sporadic mudstone layers are also indicated by augering.

North-west of Castle Gresley, the Polesworth Formation outcrop forms a prominent ridge whose crest overlooks the A444. To the south-east of Cadley Hill, old sandstone workings are in part responsible for the steepness of the north-east facing escarpment developed hereabouts. One of these quarries [2762 1884] exposes a 6 m strike section showing buff, coarse-grained sandstone or pebbly sandstone in medium to thick cross-bedded sets. Individual beds commonly show centimetre-scale internal bedding and are erosively-based. Foreset dips are between 5 and 10° towards the west or west-north-west (272-290°), and the structural dip is 15° west-north-west.

The north-westerly continuation of these beds is next seen in a roadside cutting along the lane to the *west of Council Farm* [2721 1930]. Here the structural dip is 22° to the west, and the beds are successively exposed in dip section, to give the measured thickness of



—— – – 50 Isopachyte, value in metres, dashed where highly speculative

46 Borehole, with Polesworth Formation thickness in metres

Outcrop of the Polesworth Formation

Figure 8 Isopach map of the Polesworth Formation in Sheet SK21NE. The boreholes linked by the dashed line are summarised in Figure 9.

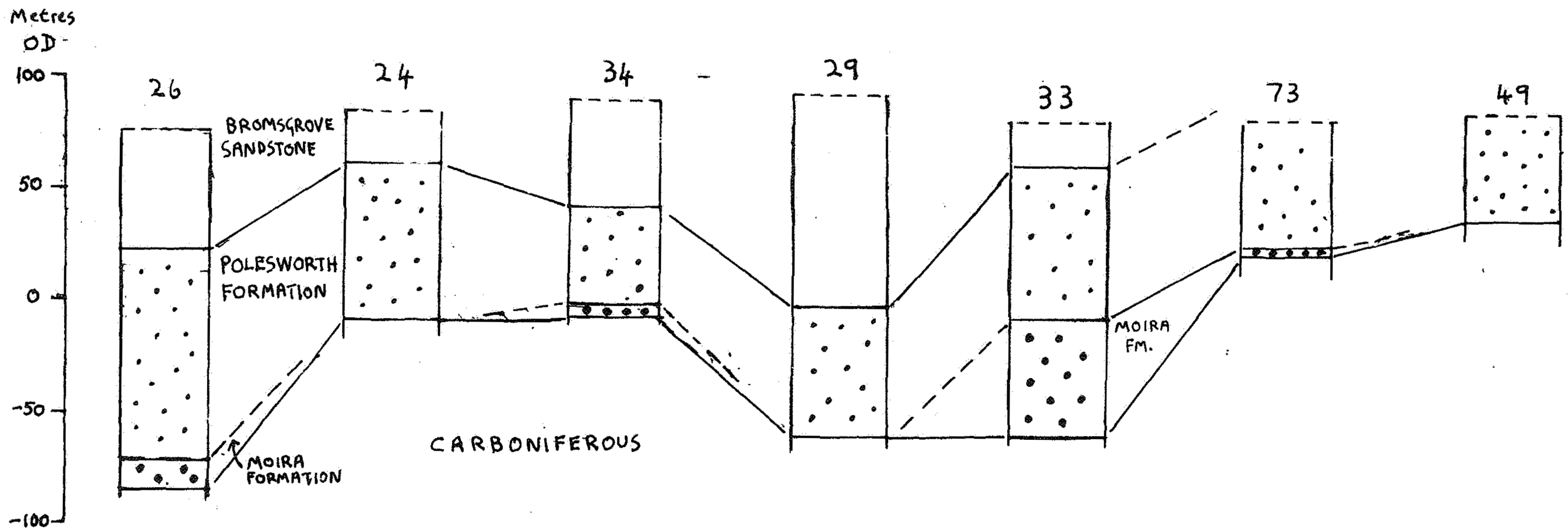


Figure 9 Representative thicknesses of the Polesworth Formation and Bromsgrove Sandstone in Sheet SK21NE (the borehole locations are shown in Figure 8)

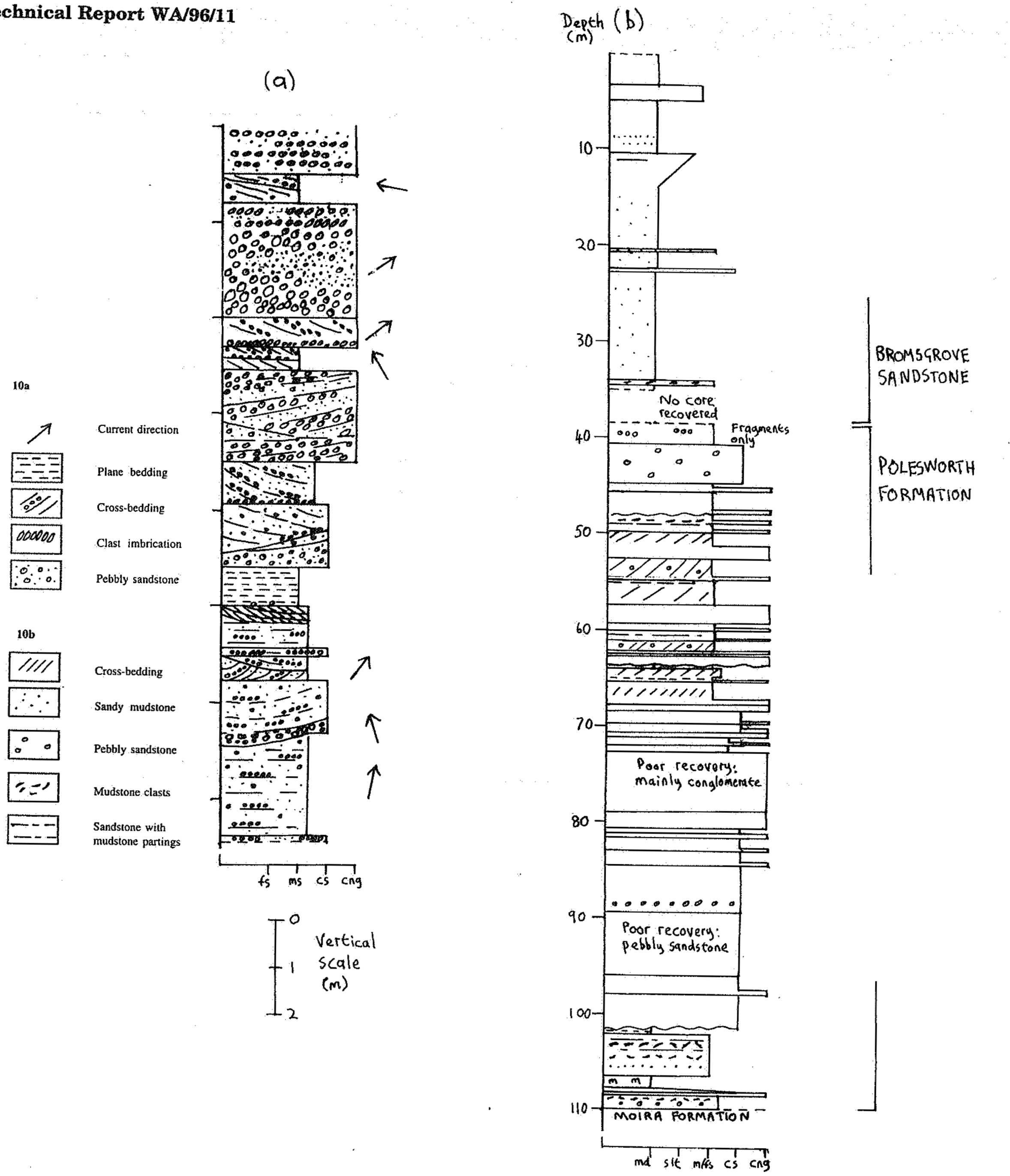


Figure 10 a) Log of a measured section in the Polesworth Formation near Council Farm [2721 1930], **b)** Vertical section through the Polesworth Formation in the Coton Park Village Borehole (from archived record) about 15 m depicted in Figure 10a. The sequence is predominantly composed of thick to very thickly bedded (0.2-2.2 m), coarse-grained, pebbly to conglomeratic sandstones. The dominant sedimentary structure is cross-bedding, either planar or with curved, trough-like forms, representing profiles through straight-crested or sinuous-crested sand or gravel dunes respectively. Very low-angle cross-bedding, or horizontal bedding, suggests the presence of low-profile ?longitudinal bar forms or upper-phase flow conditions in a minority of beds. Foreset bedding is in part defined by pebble stringers which thicken down the foreset, indicating avalanching and/or the winnowing of arenaceous material in strong currents. Pebble lags are also developed along the erosive bases of some cross-bedded foresets. The general absence of aggradational structures, such as ripple-drift lamination or mudstone suspension beds, suggests a proximal fluvial channel environment in which the tops of gravel dunes were scoured by later currents. The well-structured nature of most beds is further evidence for a fluviatile environment, although the very poorly stratified bed third from the top in Figure 10a resembles the deposits of unconfined, gravelly sediment-flows, and could suggest the input of material from a nearby alluvial fan (e.g. Blair and McPherson, 1994). The well-rounded pebbles mainly comprise grey, medium-grained quartzite, with minor proportions of a dacitic volcanic lithology. Clasts with lower degrees of rounding and/or sphericity consist of buff ?Carboniferous sandstone and white, crumbly fragments of calcretic carbonate; intraformational clasts were not recognised. Cross-bed azimuths indicate northerly current flows and low degrees of sinuosity in the lower part of the section, but become more diverse in the particularly coarse-grained upper part.

It is noted that the structural dip of the above sequence, were it to continue westwards, would be enough to carry the Polesworth Formation stratigraphically beneath the Bromsgrove Sandstone. However in the Cauldwell Lane Borehole (SK21NE/71), which is located only 40 m west of the Polesworth Formation outcrop, the latter's top is 45 m below ground level (i.e. at 26 m above OD). This proves that the Polesworth/Bromsgrove junction is actually faulted, probably by the northerly extension of the Coton Park Fault. The plans for the Cadley Hill Colliery Drift (SK21NE/85) show a further fault to the east whose surface expression within the Polesworth Formation outcrop may be a break in slope, as seen for example to the east of the sewage works [2730 1915].

The outcrop *south-east of Linton* occurs within the triangular horst block formed by the Netherseal and Overseal faults. The pebbly sandstones form low ridges, with south-south-easterly dip slopes, and the intervening slacks represent outcrops of coarse-grained sandstone with relatively fewer, and smaller pebbles. An exposure of the latter variety, dipping 3° to the south, was recorded by B C Worssam (1966-71, in MS) in a former sand pit to the east of Woodside Farm [2765 1564].

The Coton Park Village Borehole (SK21NE/69) presents one of the few well-documented sections through the whole of the formation (A. Horton, in MS), which here is 73 m thick. The summary log (Figure 10b) indicates that fine-grained lithologies are restricted to sporadic thin beds of red and green laminated mudstone or siltstone. A lower series of coarse-grained to conglomeratic sandstones can be distinguished between 102 and 68 m depth, overlain by fine- to medium-grained sandstones with thin (0.1-0.6m) conglomerate layers up to the contact with the Bromsgrove Sandstone at 40.5 m depth. Many of the thin conglomerates probably represent pebble-rich lags formed at the erosive bases of thicker beds, as demonstrated in the exposed section described above. The fine- to medium-grained sandstones are commonly dull brown to reddish-brown or grey-green, with micaceous laminae and cross-bedding developed in some beds.

6.1.3 Bromsgrove Sandstone Formation

This formation consists of sandstone-rich sequences thickly interbedded with mudstone- and siltstone-rich sequences. The unit overlies the Polesworth Formation in the west, but oversteps eastwards on to the Moira Formation and Coal Measures. In parts of the English Midlands the Bromsgrove Sandstone is unconformable on the Polesworth Formation, a relationship attributed by many (e.g. Warrington et al., 1980, p.38) to tectonic movements in the intervening period. The Bromsgrove Sandstone is conformably overlain by the Mercia Mudstone Group, although the passage between the two is somewhat gradational and the boundary line on the map is arbitrarily drawn at the incoming of thinly-bedded mudstones, siltstones and sandstones of the Sneinton Formation. Bromsgrove sandstones commonly have mixtures of rounded and subangular grains and are slightly micaceous, with varying contents of interstitial clay minerals. They are mainly distinguished from those of the underlying Polesworth Formation by their finer grain size and paucity of pebbles and/or conglomeratic beds. The content of mudstone and siltstone beds is also much greater in the Bromsgrove Sandstone: for example the sandstone:mudstone ratio is estimated at 1:2 in the adjoining Coalville district (Worssam and Old, 1988, p.60).

The Loughborough geological sheet (No.141) represents the meeting point between two contrasting lithostratigraphical schemes of subdivision of Early to Middle Triassic strata. The principal area of contention involves the Lower Keuper Sandstone and Waterstones divisions of the earlier nomenclature. In the Nottingham district, Charsley et al. (1990) assigned all of these strata to a unit called the Sneinton Formation. This constitutes a typically laminated to thinly-bedded sequence of sandstones, siltstones and mudstones placed at the base of the Mercia Mudstone Group, a scheme which is in keeping with the original supposition of Warrington et al. (1980), that around Nottingham the Waterstones (their Colwick Formation) and underlying sandstones and mudstones (Woodthorpe Formation) represent marginal, and basal, facies of the Mercia Mudstone Group. By contrast, in the Coalville district, adjoining the present map sheets to the south, only the Bromsgrove Sandstone was differentiated: beds of equivalent lithology to the Sneinton Formation were suggested to be thinly developed and, although identified in boreholes, their distribution was not shown on maps and they were included within the topmost part of the Bromsgrove Sandstone by Worssam and Old (1988).

In the Bromsgrove Sandstone of the adjoining Coalville district, the alternations between sandstone, siltstone and mudstone are interpreted as fining-upward alluvial channel cycles. Near the top of the formation the cycles are thinner and the sandstones become progressively more micaceous, marking the incoming of the Waterstones (=Sneinton Formation) facies (Worssam and Old, 1988). The Bromsgrove Formation is considered to be mainly of Scythian age, with Anisian-age beds represented in the upper transition to the Sneinton and Radcliffe formations of the Mercia Mudstone Group (Warrington et al., 1980).

At outcrop, sandstones of the formation give rise to subdued features and the intervening mudstones and siltstones to slacks or hollows. Many of the sandstones shown on the map are probably composite beds, containing layers of siltstone and mudstone, and so the mapped units are only a rough guide to lithologies actually present.

Details: Sheet SK31NW

The Bromsgrove Sandstone overlies the Polesworth Formation in small outliers between Swadlincote [311 195] and Norris Hill [326 169], but overlaps the Polesworth and Moira formations to rest directly upon Coal Measures in the main outcrop to the north-east.

In the north-east, the Bromsgrove Sandstone underlies a dissected and moderately steep-sided plateau which attains a maximum elevation of 184 m above OD. The base of the Bromsgrove Sandstone is mapped at a concave break in slope, coinciding with a change to clayey ill-drained ground typical of the Coal Measures, at a general elevation of around 145 m in the north, near Short Hazels Farm [3320 1990], and 135-140 m farther south near Prestop Park [3460 1730].

Sandstones of the unit weather easily and so are poorly exposed. Brash in the fields, derived from the better-cemented strata, are typically of buff or red, fine- to medium-grained, or rarely coarse-grained, slightly micaceous sandstone and argillaceous sandstone. In the slacks between the sandstone features, red silty or sandy mudstone occurs as lumps in freshly-ploughed fields and is also confirmed by augering.

Sandstone is revealed in a small roadside exposure north of the crossroads at *Smisby* [3483 1917], where the following section was measured:

Description	*Thickness (m)*
Sandstone, buff, fine- to medium-grained, thinly bedded to laminated or cross-laminated, with a 7 mm layer of pale green mudstone 20 mm above the base	0.3+
Sandstone, buff to pale pink, micaceous, fine- to medium-grained, with massive layers 50-100 mm thick separated by finely cross-laminated sandstone, foresets inclined to NW340°	0.27
Sandstone, buff, fine-grained, thinly bedded to laminated, with a 7 mm layer of green mudstone	0.15+

Poor exposures of buff, cross-bedded sandstone were also seen in the road cutting on the northern outskirts of *Blackfordby* [3313 1823]: foreset inclinations were towards the south-east (160°).

The Bromsgrove Sandstone was proved in a series of boreholes for an alternative alignment of the M42, extending from Annwell Place [3404 1825] to Heath Farm [3439 1989]. A summary of the lithologies encountered is given in Figure 11 which is, however, based on the drillers' descriptions. The dominant lithology is red or buff sandstone with subordinate mudstone layers, but parts of the formation (e.g. in Boreholes 232 and 233) consist of thinly interbedded mudstone and siltstone, which dominate over sandstone. These more argillaceous sequences suggest that facies typical of the Sneinton Formation (= Waterstones) may be interdigitated within the Bromsgrove Sandstone hereabouts.

To the *west of the main outcrop*, on the hill to the east of Swadlincote [311 195], auger sampling shows the principal Bromsgrove Sandstone lithologies consist of red or green argillaceous sandstone interbedded with red mudstone. Farther to the south-east, where the Bromsgrove Sandstone crops out on the downthrown, south-western side of the Boothorpe Fault, exposures in the small quarry to the south-west of Drift Farm [3258 1707] were largely overgrown at the time of the present survey, but B C Worssam (MS, 1974) measured the following:

Description	*Thickness (m)*
Clay, greenish-grey	0.3
Clay, dark red	0.6
Moira Formation:	
Sandstone, greenish-grey to purplish-red, with mainly subangular pebbles of quartzite and fine-grained sandstone	0.3
Sandstone, even-grained, greenish-grey but weathers to yellowish-brown	0.6

During the present survey, rubbly exposures in red or buff, fine- to medium-grained, thinly bedded sandstone, typical of the Bromsgrove Sandstone, occurred near the top of the quarry face.

Details: Sheet SK21NE

A minimum thickness of about 95 m for the Bromsgrove Sandstone was proved in the Coton Park Borehole, drilled through the outcrop (Figure 9). Farther south, a complete sequence was proved below the Mercia Mudstone Group, with maximum thicknesses varying from 100 m in the Netherseal Rosliston Borehole, to 76 m in the Grange Wood Borehole and about 58 m in the Caldwell No.2 Borehole. These boreholes were not cored through the Bromsgrove Formation, and so yield little reliable lithological information. The paucity of data also precludes construction of a meaningful isopach diagram, although there is enough information to suggest that in the south, where the full sequence is encountered, the Bromsgrove Sandstone thickens eastwards, towards the Netherseal Fault. The same trend is shown in the adjoining Coalville district (Worssam and Old, 1988, Figure 16).

Structure contours on the base of the Bromsgrove Sandstone (Figure 12), show that this is an irregular surface, the main feature being a north-west trending ridge developed on the underlying Polesworth Formation. This may be a rejuvenation of the uplift axis responsible for thinning of the Polesworth Formation (see preceding section), and is interpreted (Section 8.3) as a manifestation of syn-Triassic movement intervening between the Polesworth

Formation and deposition of the earliest beds of the Bromsgrove Sandstone. One further possible indication of a syn-Triassic non-sequence at this boundary is the observation of Worssam and Old (1988, p.61), that in the Coalville district the basal sandstone of the Bromsgrove Sandstone is commonly a distinctive pebble bed with mudstone clasts and vertebrate fossil remains. In the present district, notes accompanying the log of the Caldwell No.2 Borehole (G Barrow, 1913, in MS) mention that at 281 feet (85.6 m) depth a '10 inch band of conglomeratic sandstone in which the pebbles are often sub-angular' was found; this was taken to mark the base of the Bromsgrove Sandstone.

The Bromsgrove Sandstone outcrop gives rise to a subdued topography near the northern margin of the map sheet. Low features around *Breach Farm* [2645 1884] are formed by thin (1-2 m) sandstone beds, also indicated by brash of buff, fine-grained sandstone in fields. These are interbedded with red silty mudstone, augered in the slacks between these features. Farther north, near Stapenhill Fields Farm, drift largely masks the bedrock but the few outcrops are mudstone-dominated [257 195]. This is proved in several shallow boreholes (e.g. SK21NE/136), which show up to 3 m of red-brown silty to very sandy mudstone with layers of green siltstone and fragments of green sandstone. That this represents the lower part of the Bromsgrove Sandstone is indicated by the log of the *Bretby West No.3 Borehole*, which shows the top of the Polesworth Formation to lie only 21.3 m below the surface. In this borehole the Bromsgrove Sandstone sequence (chiselled samples only) is as follows:

Description	*Thickness (m)*
Clay, red, with small pebbles	3.0
Sand, greenish-buff, coarse-grained	3.0
Clay, red	3.0
Clay, red, with much green siltstone	3.0
Siltstone, green	3.0
Clay, dark red, and green siltstone (on Polesworth Fm.)	6.1

Farther south the sequence includes five mappable sandstone beds, each up to 4 m thick, whose outcrop forms the prominent north- and east-facing ridge *between Ashleigh House [2565 1800] and Linton [2720 1700].* Sandstone dip slopes indicate that the sequence is inclined at 2-3° to the south-south-west. Brash in the fields commonly consists of red or buff, friable, fine- to medium-grained and slightly micaceous sandstone, with the slacks between the sandstone features composed of red and green mudstone, proved by augering. Former exposures in the railway cutting (now backfilled) to the west of Linton included 'coarse sandstone with pebbles' at one locality [2697 1714] on the field slip of Fox-Strangways. A small quarry nearby, to the *north-west of Grange Farm* [2712 1719], showed the following sequence (B C Worssam in MS, 1966-71):

Description	*Thickness (m)*
Sandstone, yellow, medium-grained, laminated	0.3
Mudstone, red and green mottled	0.6
Sandstone, red-brown, undulating base	0.1
Mudstone, dark red	0.1+

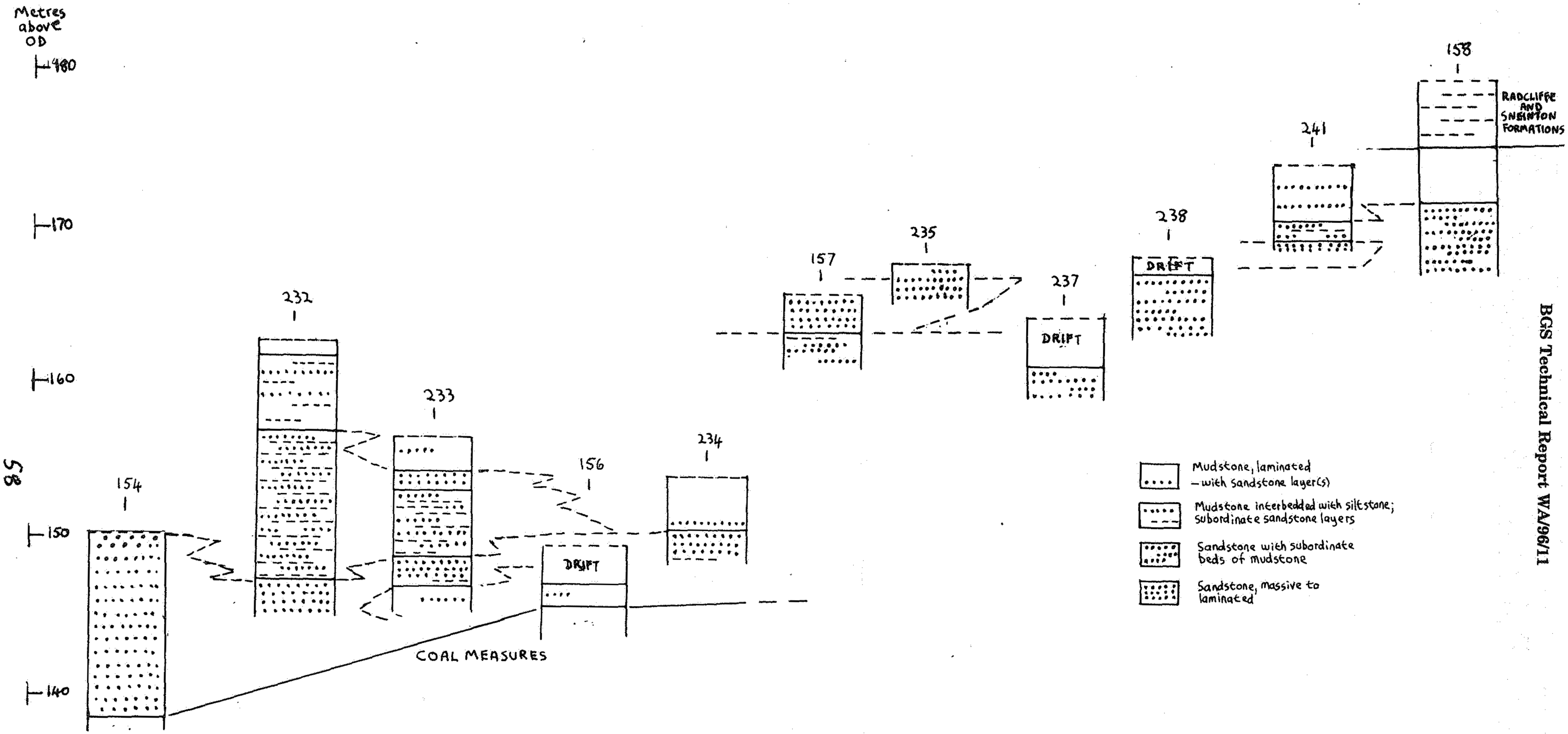
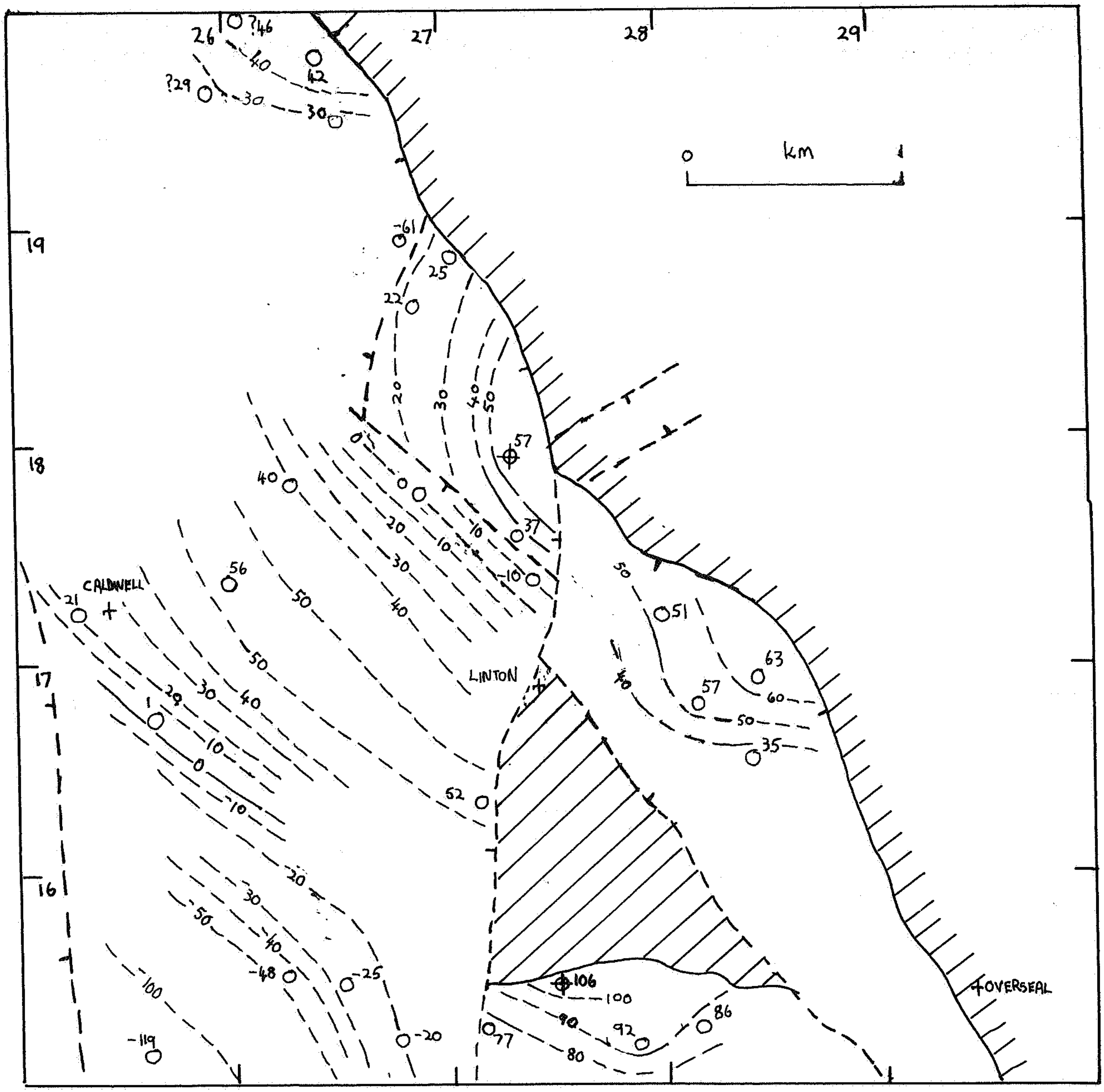


Figure 11 Partial vertical sections through the Bromsgrove Sandstone in Sheet SK31NW (the borehole locations are shown in Figure 6)



--- 30 Structure contour, value in metres relative to OD

○56 Borehole, with base of Bromsgrove Formation in metres relative to OD

Outcrop of the Polesworth Formation or Moira Formation

Figure 12 Structure contour map for the base of the Bromsgrove Sandstone/top of the Polesworth Formation in Sheet SK21NE

Part of the above sequence was formerly exposed in an old quarry in a cottage garden to the *south-east of Grange Farm* [2734 1704]. On the south-east side of this quarry, B C Worssam (in MS, 1966-71) noted 1.8 to 2.4 m of medium-grained sandstone in 0.3 m cross-bedded layers alternating with similar or slightly thicker layers of soft uncemented sanstone. On the south-western quarry face, one sandstone bed contained mudstone pebbles. A well in the floor of the quarry showed a further 3 m of massive sandstone. In *Linton village*, a roadside cutting [2732 1682] exposed the highest bed of the Bromsgrove Sandstone that has been mapped hereabouts; it consists of 1.5 m of pink to red, medium-grained, massive sandstone resting sharply on red and green laminated siltstone. This sandstone is truncated by a fault and a different bed may be brought in about 30 m up the hill; it is intermittently exposed as buff to pink, medium-grained micaceous sandstone, massive but with 0.15 m plane-laminated layers. The sandstone coarsens downwards, and at the base is poorly-sorted with common large spherical grains of probable aeolian origin.

To the *south of Linton*, the contact between the Polesworth and Bromsgrove formations is exposed within an uplifted triangular horst block bounded by the Netherseal and Overseal faults. The base of the Bromsgove Sandstone (mapping of B C Worssam) was taken at the first fine- to medium-grained, argillaceous, non-pebbly sandstone. Sandstones of the unit form low features, the sequence as a whole consisting of regular alternations between buff to red, fine- to medium-grained, argillaceous and rarely highly micaceous sandstones and red silty or sandy mudstones. The *Netherseal Colliery No.4 Borehole* (SK21NE/79) is typical of many underground provings (e.g. Figure 10b), in showing that the lower part of the Bromsgrove Sandstone contains thickly-interbedded mudstones, as follows (re-classification by B C Worssam):

Description	*Thickness(m)*
Marl or clay, red	1.8
Sand, grey, soft	0.9
Sandstone, grey	1.6
Marl, red	2.0
Marl, red, strong	2.4
Polesworth Formation.......	

One of the thickest cored sequences through the formation, which also has an adequate descriptive log, is that in the *Coton Park Grange Farm Borehole* (A. Horton, in MS), as follows:

Description	*Thickness (m)*
Uncored:	
Sand, brown, fine-grained, sub-rounded quartz grains	**1.5**
Mudstone, red-brown, becoming sandy downwards	4.5
Cored:	
Mudstone, reddish-brown, sandy with greenish-grey patches	3.7
Sandstone, pale grey to buff, fine-grained, micaceous, with one mudstone layer	**1.8**
Mudstone, reddish-brown	0.1
Conglomerate, red and yellow mudstone clasts in coarse-grained yellow sandstone matrix	**0.5**

Sandstone, greenish-grey to buff, medium- to coarse-grained, micaceous with subordinate red mudstone layers	**1.5**
Mudstone, red-brown, sandy with green and grey layers	3.7
Sandstone, greenish-grey, fine-grained, with layers of mudstone and mudstone-clast conglomerate	**5.5**
Mudstone, red-brown with green silty layers	0.5
Sandstone, pale greenish-grey, commonly fine-grained and argillaceous but with medium- and coarse-grained layers, latter with mudstone clasts	**12.4**
Mudstone, red-brown, sandy and micaceous	0.1
Sandstone, grey, very coarse-grained, with some well-rounded small quartz pebbles and mudstone clasts; gypsiferous cement in top 0.4 m	**1.0**
Conglomerate of Polesworth Formation..........	

The *Netherseal No.3 Borehole* was cored through the Trias, but the documentation is poor. The log shows alternations between 'hard grey rock' or 'sand rock' (thickness range 0.3 - 12.0 m), interpreted as sandstone, and 'red marl' or 'rocky marl' (thickness range 0.1-9.0 m), together with some beds up to 7 m thick composed of 'brown rock with beds of marl' (i.e. sandstone with mudstone layers and partings): out of a total thickness of 95 m for the Bromsgrove Sandstone in this borehole, approximately 70 per cent consists of sandstone.

6.2. Mercia Mudstone Group

6.2.1. Sneinton Formation (Sheet SK21NE)

The Sneinton Formation was named by Charsley et al. (1990) for the sequence of laminated mudstones, siltstones and sandstones, basal to the Mercia Mudstone Group, which was formerly referred to as the 'Waterstones'. The latter was recognised in boreholes in the Coalville district (Worssam and Old, 1988, Figure 18) but was not differentiated with certainty at the surface, save for observations of some laminated and silty beds near the base of the Mercia Mudstone. In the present district the passage beds between the Bromsgrove Sandstone and Mercia Mudstone are poorly exposed but nevertheless include laminated and fine-grained lithologies suggestive of a correlation with the Sneinton Formation. The sequence, which crops out within a narrow belt of undulating ground between Caldwell and Linton, is about 13 m thick.

The base of the Sneinton Formation is mapped at a concave slope-break at the top of the Bromsgrove Sandstone, which marks a change to a more undulating and subdued topography. The upper boundary of the unit, against the Radcliffe Formation, is taken as the top surface of a prominent sandstone bed.

Augering in fields to the north of Caldwell [2525 1763] reveals red, sandy or silty mudstone, commonly micaceous and with thin sand-rich layers. Discontinuous beds of fine-grained, argillaceous sandstone form low features within the lower and middle part of the formation, and a more prominent sandstone, about 2 m thick, is mapped below the junction with the Radcliffe Formation. A partial exposure of this bed in the stream to the south-west of Caldwell [2520 1706] shows buff, medium-grained micaceous sandstone overlain by red and green laminated mudstone. The continuation of this bed to the east was formerly seen in the railway cutting [2667 1687] as a 1.4 m massive sandstone beneath red mudstone (MS of B C Worssam, 1974).

Borehole provings are poorly documented for this part of the sequence. The report attached to the log for the Caldwell No.2 Borehole, sank near the top of the Radcliffe Formation, records that the first 84 feet (25.6 m) were chiselled "and the debris on the ground shows it was a red shaly marl with thin soft sandy bands, a kind of passage rock between the Keuper Marl and the sandstone", the latter being a reference to the underlying Bromsgrove Sandstone.

6.2.2. Radcliffe Formation

The Radcliffe Formation was defined by Elliott (1961) as a sequence of laminated and colour-variegated mudstones and siltstones with sporadic beds of fine-grained sandstone and cemented siltstone at the base of the Merica Mudstone. The unit is considered to be of mainly Anisian age (Warrington et al., 1980).

Details: Sheet SK31NW

The Radcliffe Formation is the youngest Triassic unit on the sheet. It is inferred to crop out in the north-east as a c. 8 m thick capping to the Bromsgrove Sandstone. Beds of the Sneinton Formation were not recognised, but may be thinly developed towards the base of the Radcliffe Formation or interdigitated with the Bromsgrove Formation (see Section 6.1.3). Auger samples and brash in the fields consist of red, silty or sandy mudstone. A borehole proving (SK31NW/158) shows the following sequence:

Description	*Depth (m)*
Soil	0-0.5
Mudstone, red-brown, with layers of siltstone	0.5-4.3
Mudstone, red and grey, sandy	4.3-5.3
Mudstone, red, thinly laminated, silty	5.3-7.6
Bromsgrove Sandstone:	
Sandstone, pale grey, fine-grained, laminated, with thin layers of laminated micaceous mudstone	7.6-13.0
(end of hole)	

The above sequence illustrates the gradational nature of the passage downwards into the Bromsgrove Sandstone, which itself contains a diversity of arenaceous and finer-grained beds hereabouts (Figure 11).

Details: Sheet SK21NE

To the south of the sandstone feature which marks the top of the Sneinton Formation, flakes of hard, pink, slightly micaceous mudstone and siltstone were observed as brash in fields [258 168] and as debris from a post [2577 1668]. These lithologies are indicative of finely laminated beds being present. Former diggings for brick clay [2612 1687, 2632 1670] also revealed red-brown interlaminated micaceous siltstone and mudstone, according to the field notes of B C Worssam (MS, 1974). Brash and auger samples show that red to pink, laminated micaceous mudstone and siltstone also dominate the outcrop south of Linton; during the present survey, diggings in a roadside cutting near to the old railway bridge [2692 1629] revealed dark red, laminated and micaceous mudstone.

6.2.3. Gunthorpe Formation *(Sheet SK21NE)*

Elliott (1961) originally divided the strata between the Radcliffe and Edwalton formations of the Mercia Mudstone into the Carlton and Harlequin formations, separated by a resistant bed known as the 'Plains Skerry'. The difficulty of sustaining this division in regions where the Plains Skerry was not easily distinguishable, compelled Charsley et al. (1990) to establish a single mappable formation, the Gunthorpe Formation, to encompass the Carlton and Harlequin Formations. Their scheme is the one followed here.

The Gunthorpe Formation consists of interbedded red-brown and grey-green mudstone or silty mudstone and siltstone. These lithologies are commonly massive, but contain intercalations of fine-grained sandstone and indurated (dolomitic) siltstone which occur at many stratigraphical levels and can be feature-forming.

The base of the Gunthorpe Formation is gradational by interdigitation with the Radcliffe Formation. It is conformably overlain by the Cotgrave Sandstone Member, basal to the Edwalton Formation.

Constructions based on the prevailing southerly regional dip of 2-5° over the outcrop suggest that the Gunthorpe Formation is about 73 m thick in this district.

Details

The Gunthorpe Formation is little-exposed. In fields it is indicated mainly by ploughed brash or by auger samples, as a red-brown or green, silty and slightly micaceous mudstone. The low feature extending south-south-westwards from Longlands Farm [26100 1636] is formed by a thin bed of cemented green siltstone, seen as abundant brash in the fields hereabouts.

Cored boreholes through the unit are restricted to the older provings, which unfortunately are poorly documented. In the Netherseal Rosliston Borehole the principal lithology, occupying sequences up to 18 m thick, consisted of "red and white marl with thin beds of rock", the 'rock' probably representing layers of cemented siltstone, of the type described above, rather than being sandstone. Subordinate lithologies included "brown rocky marl", and gypsum was noted in the lower 10 m of the section. In the Netherseal Rosliston Borehole, the main lithology was described as "brown clay" or "red and blue marl".

6.2.4. Edwalton Formation *(Sheet SK21NE)*

The Edwalton Formation was named by Elliott (1961), who defined its base as the lower surface of the Cotgrave Sandstone Member (formerly the Cotgrave Skerry). The top of the formation, which is not exposed in the district, is defined by a further sandstone, the Hollygate Sandstone Member. It has been tentatively assigned a Carnian age by Warrington et al. (1980).

The formation is poorly known in this district, but elsewhere mainly consists of red-brown and grey-green siltstone and mudstone, which is typically blocky or poorly laminated. Beds of sandstone and siltstone occur at various stratigraphical levels, and where indurated give rise to low, scarp-like features. The Edwalton Formation is about 50 m and 46 m thick in the Coalville and Nottingham districts respectively (Worssam and Old, 1988; Charsley et al., in prep.), and at least 20 m is recognised in the present district.

The Edwalton Formation is the youngest bedrock unit to crop out in the district. Its recognition is, however, dependant on the correlation of the prominent sandstone cropping out near Botany Bay as the Cotgrave Sandstone Member.

Above this sandstone, the Edwalton Formation is largely covered by Drift deposits. Augering of the ground to the west of Botany Bay Farm [2575 1533] indicates that red-brown blocky mudstone or sandy mudstone is the dominant lithology.

Cotgrave Sandstone Member

The Cotgrave Sandstone forms a prominent, scarp-like feature extending west of Botany Bay [2605 1550] before being truncated by a north-south-trending fault near to the western margin of the map sheet. East of Botany Bay the sandstone feature becomes progressively obscured by the Drift deposits centred on the hill occupied by Park Farm [2695 1515]. The sandstone is estimated to be about 2.4 m thick.

The fields along the sandstone feature commonly contain brash of grey or buff, fine-to medium-grained sandstone. No exposures were available during the present survey, but B C Worssam (MS, 1974) recorded from a cess-pit by Botany Bay Farm [2610 1548] thin slabs of fine-grained ripple-marked silty sandstone, and *in situ* exposures showing layers of friable red-brown sandstone and red mudstone.

To the west of the fault referred to above, the continuation of the Cotgrave Sandstone is mapped south-east of Caldwell based on the auger proving of red sand on the slopes above the stream [2514 1699]. Although this continuation of the outcrop is conjectural, it is supported on the adjacent map sheet (SK21NW) by a note indicating ripple-marked sandstone about 350 m along strike to the north-west.

7. QUATERNARY DEPOSITS

7.1. Till

Diamictons representing the melt-out products of former ice sheets, form scattered outcrops across the district. They typically consist of heterogeneous, stony and sandy clays and are likely to include both ground moraines (lodgement tills) and flow tills. Some of the earlier geological surveys in this region mapped till outcrops largely on the occurrence in soils of exotic brash, of which the rounded 'Bunter' pebbles are perhaps the most prominent. The present study found that brash is at best indicative, and at worst a misleading criterion on which to base drift boundaries. For example, augering reveals that such brash commonly reflects the presence of thin (~0.2-0.4 m) deposits of sandy head or till *remanie*, which are too small and intricate to be mapped separately. In this study, therefore, the mapping of till boundaries has been mainly constrained by augering combined with the observation of small-scale features.

Red-matrix tills are the only types represented in this district. They contain material of mainly Triassic or Carboniferous derivation, indicative of deposition from ice that advanced from the north and west (e.g. Rose, 1994). The till outcrops are now largely restricted to small patches that are principally preserved across Triassic bedrock. Their presence is commonly revealed by a concave break in slope, generally no more than 1 or 2 m high, surrounding a flat-lying, plateau-like surface with abundant rock fragments dispersed in the soil.

Details: Sheet SK31NW

The main till outcrop overlies the plateau-like surface developed on Triassic rocks in the north-east of the district, to the north of Stonehouse Farm [333 193] around Holmleigh [347 198], and west of Holywell Farm [345 181]. Augering of this ground typically shows a red or red-brown sandy clay, with some admixed yellow or grey sand in places. An excavation west of Several Woods Farm [3377 1985] showed till with a matrix of red sandy clay enclosing Bunter pebbles and fragments of Triassic and Carboniferous sandstone, ironstone, dark grey limestone and chert. Brash in fields to the north-east of Holmleigh [3490 1995] showed, in addition to 'Bunter' pebbles, fragments of Carboniferous Limestone and coarse-grained feldspathic sandstone of probable Millstone Grit derivation.

Details: Sheet SK21NE

Patchy developments of red-matrix till are present in the southern part of the sheet. On the outcrop to the west and south of Botany Bay Farm [252 153], red or red brown clay with stones was augered by B C Worssam (in MS, 1974). To the east, the Netherseal Rosliston Borehole records 21.6 m of drift: this presumably includes till towards the base, which may be represented by the 5.6 m of 'brown clay' recorded in that position.

Limited outcrops of red till occur to the east of Linton [270 167], forming a province which extends eastwards to include the till formerly exposed along the northern highwall of Robinson and Dowler's Clay Pit [2915 1675]. At the latter locality, B C Worssam (in MS, 1974) recorded a mixed deposit, up to 5 m thick, consisting of smooth brown clay with 5-10 mm-size erratics interleaved with 0.4 m layers of clayey silt showing fine to contorted, varved lamination.

7.2. Glaciolacustrine Deposits *(Sheet SK21NE)*

These lithologies represent the suspension deposits of former glacial lakes developed either beneath or along the margins of the ice sheets.

Glaciolacustrine deposits, identified principally by augering, occur in the fields surrounding Park Farm. The mapped outcrop boundaries suggest that they overlie red-matrix till occupying the lower ground. They are overlain by glaciofluvial sand and gravel deposits capping the hill at Park Farm [270 152], and in the nearby Netherseal Rosliston Borehole may be represented by lithologies described as brown sandy clay, between 5.8 and 16.1 m depth.

Augering carried out by B C Worssam (in MS, 1974) showed that the deposit consists of brown to grey, or red-brown silty clay which is devoid of rock fragments or pebbles.

7.3. Glaciofluvial Deposits

Deposits of unconsolidated sand and gravel occur at various elevations scattered throughout the district. They are commonly developed in close association with till deposits, and have been mapped above and below the latter. The sands and gravels are interpreted as the deposits of river channels or outwash fans derived from melt waters that either flowed beneath or discharged from the front of the ice sheets. Glaciofluvial deposits typically give rise to brown, sandy soils strewn with abundant rock fragments and pebbles.

Details: Sheet SK31NW

Very restricted developments of brown and red, pebble-rich sand occur below red-matrix till north-east of Tithe Farm [3392 1913], and cap a separate body of till north-west of Holywell Farm [3433 1834]. The latter outcrop is an outlier of the larger development of glaciofluvial deposits centred on Ingles Hill Farm [3450 1775], at 163 m above OD ; abundant fragments of flint accompany 'Bunter' pebbles in the fields hereabouts. In the south-western corner of the sheet glaciofluvial deposits underlie a low, flat-topped hill [350150] at about 138 m OD. They are a continuation of the sand and gravel deposits which in the adjoining sheet to the east attain a thickness of 9 m (Carney, 1996).

Details: Sheet SK21NE

Glaciofluvial deposits form scattered outcrops across the western part of the sheet. The deposit capping the hill at Park Farm [270 152] appears to be mainly gravel, based on the abundance and size of the 'Bunter' pebbles in many of the surrounding fields, and the occurrence of gravel in a cutting to the west of the farm [2685 1532]. Consideration of the topographic contours around the hill suggests that the deposits may be about 10 m thick hereabouts. This is borne out by the record of the Netherseal Rosliston Borehole, although this indicates a mixed deposit consisting of 'sand and gravel', 'red clay' and 'red sandstone' down to 5.8 m depth.

Glaciofluvial deposits occupy the low-lying ground in the north-west of the map sheet. An isolated outcrop at about 70 m above OD comprises the reddish brown coarse-grained pebbly sands which form a terrace-like feature on the valley side to the south-west of Cadley Hill Farm [1880 2700]. On ground lower than 62 m, around Royle Farm [2530 1900], a flat-topped outcrop consists of coarse-grained yellow sand with abundant 'Bunter' pebbles, flints and fragments of red or buff Triassic sandstone. The subdued, scarp-like features that follow the contours around this hill are attributed to separate beds of sand and gravel, rather being associated with river terrace development. In the continuation of these deposits around Stapenhill Fields Farm [2545 1955], augering showed brown, pebble-rich coarse-grained sand and gravel in some parts, and medium-grained sand devoid of pebbles elsewhere. Debris from a former sewerage trench [2527 1957] consisted of coarse-grained, partially-cemented sand intricately admixed with Mercia Mudstone. This may indicate a cryoturbated contact between the glaciofluvial deposits and bedrock. A borehole at the same locality (SK21NE/141) showed the following sequence of deposits:

Description	*Thickness (m)*
Sand, dark brown and orange-brown, medium-grained, silty and clayey in part with gravel lenses reducing with depth	1.4+
Clay, black, yellow-green and grey, with dark orange-brown mottles, silty and sandy with gravel lenses	0.2
Sand and gravel, pale to dark orange-brown with black silty layers	1.1
Sand, grey and orange-brown, medium- to coarse-grained, locally silty, with gravel lens	2.3+

To the south of Stapenhill Fields Farm [2552 1940], a further borehole (SK21NE/139) shows 0.6 m of grey-orange clay underlain by 2.5 m of intercalated sand and gravel. This rests on at least 1.75 m of blue-grey clay with sand and silt laminations, seen to the end of the hole at 5.25 m depth.

7.4. River Terrace Deposits *(Sheet SK 21NE)*

These deposits consist of unconsolidated sand and gravel. Their deposition followed the final withdrawal of the ice sheets, which ushered in a phase of vigorous stream incision that established the present Trent drainage system. As the rivers cut down into glacial deposits and underlying bedrock, each phase of aggradation and rejuvenation left behind the deposits of former floodplains, which are now seen as terraces perched on the valley sides.

The deposits occur as three small outliers, whose tops are about 60 m above OD, to the north-west and north of Stapenfields Farm [250 196, 250 200, 254 198]. The terrace edges are somewhat degraded, but are more sharply-defined than the margins of the glaciofluvial outcrops close by, with which they may otherwise be confused. Soils on the terraces are typically sandy, and strewn with 'Bunter' pebbles and flints. Augering to the north of Stapenhill Fields Farm [254 194] showed the upper part of the terrace deposit to be composed of yellow, buff and grey medium-grained sand with admixed clayey and organic-rich material.

The two westernmost terraces continue into the adjacent sheet (SK21NW) but were mapped as glaciofluvial deposits. The terrace interpretation presented here is based mainly on morphology, in particular the sharp-sided nature of the features formed by these deposits. Since most of the low-lying ground in Sheet SK21NW is mapped as the second Trent terrace, the terraces described here, being at a greater elevation, are tentatively correlated with the third Trent terrace.

7.5. Alluvium

Alluvium represents the detritus recently deposited by fluvial activity along the valleys of modern drainage systems. Typically it consists of gravel, sand and silt or clayey silt. The upper parts of alluvial sequences are commonly dominated by clay or silty clay, which represent the fine-grade material that settled out after the most recent flooding events.

Details: Sheet SK31NW

The principal alluvial tracts occur where stream valleys widen towards the southern margin of the map sheet. Along the course of the Shell Brook [3379 1650] black or grey clay and silty clay was commonly augered or exposed in river banks; the fineness of these deposits is attributed to low-energy deposition of mud-grade material washed from the Coal Measures outcrop.

Details: Sheet SK21NE

The main alluvial areas border the trunk and tributary streams which rise on the higher ground around Church Gresley and Swadlincote, and cut westwards through the ridge formed by the Polesworth Formation at Castle Gresley [2800 1775] and Cadley Hill [2725 1915]. East of the ridge the valley alluvium is largely obscured by mining and urbanisation, whereas to the west, the valleys widen into alluvial plains up to 300 m wide [2700 1835].

At Castle Gresley, a newly dug drain through alluvium occupying a narrow valley cut through the Triassic ridge showed the following sequence:

Description	*Thickness (m)*
Head, consisting of dark grey, pebbly clay and sand	0.5+
Gravel; abundant pebbles in grey to buff sandy matrix	0.5
Clay, dark grey and organic-rich, massive, with admixed sand and sporadic pebbles	1.2+

Grey, clay-rich ground was commonly augered on the alluvial plain to the north-west of here. In a stream bed [2690 1868], a fuller sequence was measured (B C Worssam, in MS, 1974) as follows:

Description	Thickness (m)
Clay, grey	0.6-1.0
Gravel, clayey, with pebbles	0.3-0.6
Clay, red (?Bromsgrove Sandstone).....	

Farther north, boreholes for a sewage trench (e.g. SK21NE/132) showed up to 2.8 m of dark grey to brown, organic-rich clay overlying Mercia Mudstone Group [2628 1925]; the deposit becomes more gravelly towards the basal contact with Mercia Mudstone, at 2.8 m depth. Nearby, some boreholes showed a discrete gravel layer, up to 1.0 m thick, below the clay.

7.6. Head

Head is a deposit formed mainly by processes of solifluction and gelifluction. Although colluvium or surface hill wash, included here as head, has largely been produced by the stripping of vegetation by arable farming, solifluction and gelifluction are processes that mainly operated during the periglacial phases of the late Devensian. The nature of the head mainly depends on the lithology of the bedrock or superficial deposits developed upslope. It is generally a poorly-structured deposit but can retain relic shear zones in some circumstances. These may adversely affect its geotechnical properties and be a potential hazard to construction.

Deposits of head mainly occur along the lower parts and base of certain of the steeper valley slopes. The up-slope boundary of the head is commonly a subdued concave slope-break, but its distal boundary is arbitrarily placed at the point where it is considered to merge with the flat-lying alluvial fill of the valley floors. Where the latter is absent, as in the narrower and less-mature steep-sided valleys, head deposits, rather than alluvium, infill the floors of the valleys and are exposed in the river banks.

Details: Sheet SK31NW

Head deposits commonly fill the valleys of narrow streams draining the Triassic outcrop in the north-west. Typical exposures in stream banks south-east of Tithe Farm [3418 1889] consist of buff, massive clayey sand with large cobbles and fragments of Triassic sandstone. A borehole nearby (SK31NW/156) shows 2.29 m of grey-brown mottled sandy clay with pebbles, interpreted as head, resting on weathered Bromsgrove Sandstone.

Details: Sheet SK21NE

On this sheet, head mainly comprises aprons of pebbly sand or silt, representing material moved down from the glaciofluvial sands and gravels cropping out on the hill centred on Royle Farm. To the south of the farm [257 188], augering in head commonly revealed a buff, loamy deposit with pebbles. Blue-grey clay was found beneath posts farther to the east [2588 1874], suggesting a close association between head and lacustrine alluvial material in the centre of this valley.

8. STRUCTURE

8.1. Pre-Carboniferous Structure *(Sheet SK 31 NW)*

In the Rotherwood Borehole, Cambrian strata of the Stockingford Shale Group dip at 60-70° and are affected by a "strong cleavage" (Worssam and Old, 1988, p.19) oriented at right angles to bedding. Such structures are not found in the overlying Carboniferous rocks, and are therefore indicative of Lower Palaeozoic deformation. The Stockingford Shales have also experienced mild recrystallization, with white mica crystallinity indices appropriate to the upper part of the Diagenetic Zone (e.g. Merriman et al., 1993). The degree of recrystallization and cleavage development is greater than that seen in the equivalent rocks of the Nuneaton Inlier (Bridge et al., in press).

The age of this deformation and metamorphism is not precisely constrained. A sample of "well cleaved" Cambrian rock from the Rotherwood Borehole gave a K-Ar whole rock age of 477±19 Ma (Evans, 1979, p.36). This cannot be a depositional age, though in view of the low degree of recrystallization it may be a hybrid age, reflecting mixed populations of detrital as opposed to fabric-forming mica in these samples. Regional considerations suggest that the deformation of these rocks probably occurred during one of the Caledonian events, dated at end-Ordovician or mid-Silurian (440-420 Ma), or at the time of the early Devonian (c. 400 Ma) 'Acadian' deformation (dates from Soper et al., 1992).

8.2. Carboniferous Structure

8.2.1. Dinantian Structure

Crustal extension in earliest Dinantian times led to rifting and the formation of the Widmerpool Half Graben to the north-east of this district (e.g. Ebdon et al., 1990). The evidence of the Rotherwood Borehole indicates that the present district was not submerged until a later episode of rifting and subsidence, in latest Asbian to Brigantian times. This initiated the widespread marine transgression which deposited the Carboniferous Limestone sequence seen in the borehole.

8.2.2. Namurian Structure

The Rotherwood Borehole indicates a non-sequence at the top of the Dinantian, with only the latest three stages of the Namurian (Kinderscoutian, Marsdenian and Yeadonian) being represented (Worssam and Old, 1988, p.23). The hiatus suggests an early Namurian regression which was possibly consequent upon uplifts along the south-western shoulder of the Widmerpool Half Graben. Renewed subsidence was followed by the deposition of a Namurian sequence which was considerably more attentuated than that seen farther north in the Derby district (e.g. Frost and Smart, 1979, p.15). Namurian isopachytes constructed for this region suggest that the Marsdenian-Yeadonian overstep proceeded southwards, towards the Wales-Brabant Barrier, and was a response to early Silesian thermal sagging that was in part controlled by the reactivation of structures with Charnoid trends, such as the Boothorpe Fault of Sheet SK31NW (Fulton and Williams, 1988, Figure 14.6). This local structural control is perhaps indicated on Figure 2, by the marked westwards thickening of the sequence between the Cumbriense and Subcrenatum marine bands between Sheet SK31NW (all boreholes to the east of the Boothorpe Fault) and SK21NE/14.

8.2.3. Westphalian Structure

Fulton and Williams (1988, p.190) note that early Westphalian A sedimentation, between the Subcrenatum Marine Band and Kilburn seam, was similar in style to that prevailing during the Namurian, with eustatic rises in sea-level leading to episodes of delta abandonment and marine incursion. For the present district, local structural control is suggested by the decrease in the sandstone component of the Wingfield Flags eastwards, across the Boothorpe Fault (Figure 2).

Above the Kilburn seam, the style of sedimentation changed to one marked by thicker coals, finer-grained sandstones and relatively fewer marine bands, characterising the Westphalian A/B strata up to the base of the Pottery Clays Formation. Fulton and Williams (1988) envisaged subsidence to have been slow and steady, with superimposed short-period bursts of cyclic subsidence resulting in rapid changes from subaerial to subaqueous conditions. Activity along the Boothorpe Fault, causing thickness variations between the Woodfield and Lower Main seams, was detected by Fulton and Williams (1988, p.192) to the south of the present district. Mobile tectonic conditions prevailing over the western part of this district, in Sheet SK21NE, are similarly indicated by marked changes in interseam thicknesses, the local attenuation or disappearance of the sandstone overlying the Eureka seam and the splitting of the Stanhope seam to the south-west (Figure 3). These variations may in part reflect activity along the precursors to the many faults formed during the Variscan earth movements (see below).

The change in Coal Measures sedimentation above the P40 seam led to deposition of the Pottery Clays formation. The facies exhibited by these strata suggest slower subsidence, with relatively long periods of subaerial exposure and pedogenesis indicated by thick seatearths. The several marine incursions recorded within a sequence averaging about 100-120 m in thickness, as compared with about 200 m for the same section in the Derby district (Frost and Smart, 1979), suggests condensed sedimentation in a marginal marine environment.

8.2.4. Late Westphalian Structure

The incoming of the Barren Measures denotes a major change in sedimentation and tectonics within the Coal Measures basins. This stratal package is classified as an inversion megasequence by Corfield et al. (1996, p.20), who attribute its deposition to the onset of basin inversion in the foreland of the Variscan orogenic belt. Tectonism at this time alternated between periods of uplift (Etruria Formation) and those characterised by flexural subsidence (Halesowen Formation) due to crustal loading along the southern margin of the Wales-London-Brabant Massif. Although the Barren Measures were referred to collectively as the 'Westphalian C-D Molasse' by Corfield et al. (1996), those authors noted that only the Meriden (Keele) Formation can be considered as a true regional molasse type of deposit (Besly et al., 1993).

The underground provings of these strata are too sparse to show structural trends within the Barren Measures of this district. Borehole and seismic evidence that these strata rest unconformably upon the Upper Coal Measures has already been discussed (Section 5.3).

8.2.5. End-Carboniferous (Variscan) Structures

The culminating phase of the Variscan orogeny compressed the foreland basin, uplifting the Carboniferous strata differentially by combinations of block faulting and folding. Figure 13 summarises the structures formed at this time.

Faults

Many of the larger displacement faults have *north-westerly trends*, and are interpreted to be posthumous reactivations of older basement structures dating back to either the Caledonian or the Avalonian-Cadomian (Precambrian) deformational events (e.g. Turner, 1949; Lee at al., 1990). In Sheet SK31NW, the **Boothorpe** and **Blackfordby faults**, with respective downthrows of 260 m to SW and 100 m to NE, define a horst block along the south-western flank of the Ashby Anticline (Spink, 1965, Figure 6; Carney, 1996). The Boothorpe Fault is a major crustal structure which also gives rise to a linear gravity anomaly (Spink, 1965, p.72). It was not exposed at the time of the present survey, but observations at the Shell Brook Opencast Site [330 163] show that on its upthrown side, the Coal Measures strata 'roll over' with steepening south-westerly dip, towards the fault plane. This suggests a normal throw for the fault, which is also the interpretation of Fulton and Williams (1988, Figure 14.12). A reverse throw for the Boothorpe Fault was suggested by Spink (1965, p.72), on the basis of borehole evidence near Measham Colliery, to the south of the present district, but a re-interpretation of the local structure led Worssam and Old (1988, p. 110) to conclude that a normal throw was more likely. Over much of the Boothorpe Fault the strata dip away from the fault plane (i.e. to the south-west, see below); however for the sector occurring within Hillside Quarry [309 195], Brown (1889, p.7) demonstrated that the Coal Measures dip 25° to the north-east, suggesting either that the strata have been backtilted on the downthrow side or, more likely, that the fault transects the limb of a fold structure.

In Sheet SK21NE, prominent north-west faults, mainly throwing to the south-west, extend from Overseal to the northern margin of the sheet. These faults occur in conjunction with fold basins and domes showing a similar elongation, and the two styles of structure together define a kilometre-wide linear belt. This broadly coincides with the north-eastern edge of the Triassic outcrop, suggesting that the latter is structurally controlled (see below). One of the principal faults, which in part defines the western edge of this structural belt, is the **Coton Park Fault**, which for its northern sector has a south-westerly throw of 192 m indicated on mine plans for the Woodfield and Stockings seams. Spink (1965, p. 72) considered that this fault may extend southwards, in to the Western Boundary Fault of the Warwickshire Coalfield. This is also the interpretation favoured by Fulton and Williams

- -76 Structure contour, Eureka seam, value in metres relative to OD (dashed where speculative)
- Structure contour on Woodfield seam
- Outcrop and incrop of the Eureka seam
- 60 Fault, dashed where speculative, tick on downthrow side; throw in metres where known
- Major anticline, syncline
- -153 Borehole, with height of Eureka seam in metres relative to OD
- Borehole, as above, proving Barren Measures
- 40 Dip of inclined bedding (to east of Boothorpe Fault)

Figure 13 Structure of the Coal Measures, based on mine plans for the Eureka and Woodfield seams. Structures shown to the east of the Boothorpe Fault are inferred from outcrop mapping

(1988, Figure 14.11), who portray the Netherseal Fault as the linking structure. The present study suggests that the Coton Park and Netherseal faults are probably not co-extensive, but that the latter may splay south-westwards from the Coton Park Fault; the throw is relayed from one fault to the other in a complex zone which also includes the northerly tip of the **Overseal Fault**. The Cadley Hill Colliery Drift intersected several north-west-trending faults, with throws to north-east and south-west of up to 90 m (Figure 13), as shown in underground plans for the Stockings seam. Information bearing on the extent of these faults is sparse, but their orientation suggests a Charnoid or eastern Caledonoid basement structural control hereabouts. Many of the larger throws are to the north-east, antithetic to the Coton Park and Netherseal faults. The overall structural configuration suggests that a complex horst block may lie to the north-west of Linton.

North-north-west to north-north-east trending faults. These exhibit the broadly northerly 'Malvernian' Precambrian basement trend (Lee et al., 1990). The most prominent structures are the **Netherseal Fault**, the sinuous **Newhall Fault** (Spink, 1965, Figure 6), which is the Coppice Side Fault of Mitchell and Stubblefield (1948, Figure 6), and the **Moira Fault**. The Newhall Fault dies out to the south but its throw is transferred *en echelon* fashion to the Moira Fault, whose magnitude of throw increases in the latter direction. The relay zone consists of several north-trending and east-throwing faults which dominate the structure in the south-western part of Sheet SK31NW. A general trend in the district is for the northerly faults to be terminated along, or deflected into, the courses of north-westerly faults.

Faults with *east-south-east* to *east-north-east trends* replicate the transverse basement structures which have been mapped farther east in Charnwood Forest (Carney, 1994). Throughout much of the district they have throws of up to 53 m, most commonly down to the north. The exception is the cross-fault seen on mine plans to the north of Caldwell, which has a northwards throw of 76 m (Figure 13).

Folds

Structure contours for the Eureka, Stockings and Woodfield seams (Figure 13) show that the exposed Coal Measures are contained within a gentle, south-east plunging syncline, termed the **Newhall Syncline** by Spink (1965, Figure 6). The north-eastern margin of the syncline is defined by the Boothorpe Fault, towards which dips in the Coal Measures commonly steepen. For example, south-westerly dips of up to 42° are recorded immediately adjacent to the fault south of Swadlincote [3125 1905], and up to 26° within a monoclinally-flexured belt of strata located 400 m south-west of the fault at the Willesley Clay Opencast Site [3300 1559]. The syncline loses definition southwards, within a complex area of northerly and easterly faulting, but its offset equivalent may reappear to the south-east, across the Moira Fault in the southern part of Sheet SK31NW, as the syncline adjacent to the Boothorpe Fault affecting beds at the Hicks Lodge/Willesley Clay opencast sites. To the west of the Newhall Syncline a complementary structure, the **Swainspark Anticline**, can be traced for a short distance across the district.

In Sheet SK21NE the Newhall Syncline and Swainspark Anticline are flanked on the west by the north-west-trending, kilometre-wide structural belt, previously described, extending north-west of Overseal. Folding is ubiquitous within this belt, though weakly developed to the north-west of Castle Gresley, where seam contours outline a broad circular basin (Figure 13). To the south-east, across an east-north-east trending fault line, the **Mount Pleasant Syncline** is a closed basin with north-westwards elongation parallel to local faulting. Farther south the **Overseal Syncline** (NB not the eponymous structure of Spink, 1965, Figure 6), with a northerly trend, is oblique to this faulting, a configuration which suggests a component of sinistral transcurrent movement along the structural belt (e.g. Wilcox et al., 1973, Figure 11). To the west, between the Netherseal and Overseal faults, seam contours shown by Mitchell and Stubblefield (1948, Figure 6) outline a north-west aligned series of closed structural basins extending south-eastwards from Linton.

In the western part of Sheet SK21NE, the few available seam contour plans indicate that the the Coal Measures dip towards the south or south-south-west. This structure, together with large displacements such as the Netherseal Fault, brings in the Barren Measures which incrop at the base of the Trias in the south-west of the district (Figure 13).

8.3. Syn- and Post-Triassic Structure

Faults of syn- to post-Triassic age are mainly rejuvenations of older, Carboniferous structures. Many of these had orientations which favoured reactivation during the phase of crustal extension that accompanied development of the Needwood Basin of Triassic deposition, the centre of which is located to the south-west of the present district. The distribution of syn- and post Triassic structures in Sheet SK21NE is shown in Figure 14, superimposed upon a structure contour map for the base of the Trias.

For *Sheet SK31NW*, Triassic strata cropping out in the north-east have a slight (~1°) overall southerly dip. Bedding within the Bromsgrove Sandstone is displaced by weak faulting near Scam Hazles Farm [3384 1840], indicating post-Scythian tectonism. The **Blackfordby Fault** also shows evidence of rejuvenation to the north-west of Blackfordby, where the Bromsgrove Sandstone is thrown down to the north-east, against the Coal Measures.

The initial post-Carboniferous movement of the **Boothorpe Fault** may have occurred in earliest Scythian times, as demonstrated at *Hillside Quarry*, where the Moira Formation shows tilting towards the north-east before deposition of the Polesworth Formation (Brown, 1889 and Section 6.1.1). Post-Scythian movement(s) are in part responsible for preserving the Trias within narrow slivers on the downthrown south-western side of the Boothorpe Fault: in the outcrop to the south-east of Boothorpe Hall [3216 1745], a structural dip of 17° to the north-north-east suggests that the Polesworth Formation was back-tilted during one of these movement phases.

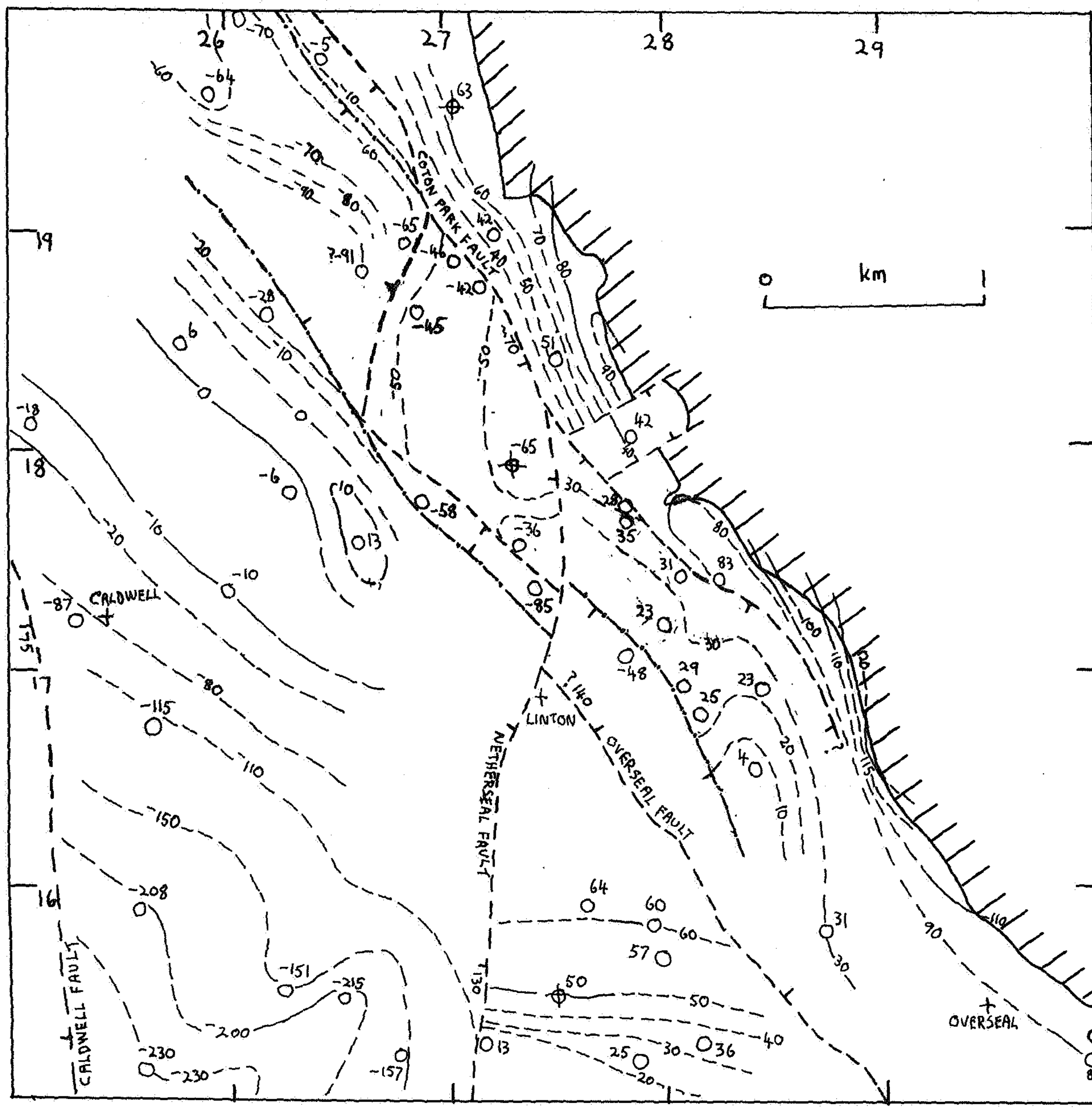
In *Sheet SK21NE*, the north-eastern margin of the Triassic outcrop (Figure 14) coincides with the prominent north-westerly belt of Carboniferous faulting and folding described in Section 8.2, suggesting an underlying tectonic control in Triassic or post-Triassic times. Field evidence for tectonism is the increased magnitude of south-westerly dip in the Polesworth Formation close to the north-eastern margin of its crop. This includes, for example, the 16° formerly seen (Fox-Strangways, in MS) to the south-east of High Cross

Bank [2943 1735], and between 15 and 22° measured in the present survey to the north-west of Castle Gresley [e.g. 2721 1930]. The tilting suggests monoclinal flexuring of the Trias above a rising basement block whose western boundary is represented by the west-throwing Coton Park Fault. Associated faulting is indicated by the faulted junction between Coal Measures and Moira Formation observed by B C Worssam in a cutting along the Cadley Hill Road (Section 6.1.1).

The **Netherseal**, **Overseal** and **Coton Park faults** demonstrably displace the Trias but record larger amounts of Carboniferous displacement, proving that they are rejuvenated Carboniferous structures. Worssam and Old (1988, p.112) suggest that the Netherseal Fault was an early Triassic (Scythian) growth fault, causing thickening of the Polesworth Formation on its western, downthrown side. Thickening trends for the Polesworth Formation in the present district (Figure 8) support syn-Triassic movements of the Netherseal and Overseal faults, but also show the presence of a north-west trending ridge and trough system. For example, the thinning of Polesworth Formation to the north-west of Linton, demonstrated by Figures 8 and 9, broadly coincides with the sub-Triassic ridge shown in Figure 14, while to the north-east there is a complementary sub-Triassic trough into which the Polesworth Formation has thickened. The ridge and trough system is parallel and coincident with intense Carboniferous faulting to the west of the Coton Park and Netherseal faults (cf Figures 13 and 14), indicating an underlying structural control over deposition of the Polesworth Formation. This early Triassic tectonism was possibly related to subsidiary flexuring and growth faulting aong the north-eastern rim of the Needwood Basin of syn-Triassic deposition (e.g. Worssam and Old, 1988, Figure 27). The thickness variations demonstrated for this district are therefore superimposed on an overall trend of syn-Triassic thickening towards the west or south-west, in the direction of the basin centre.

With a model of progressively incremental infilling of the Needwood Basin, the top of each sedimentary unit should be broadly planar, and dip basinwards. The structure contour map for the top of the Polesworth/base of the Bromsgrove Formation (Figure 12) demonstrates that this is valid for the south-western part of the district. To the north-east, however, this datum outlines a north-west trending ridge and complementary trough, and further shows that the top of the Polesworth Formation is flexured to the south-west close to the Coton Park Fault. Evidence from mapping suggests that the Bromsgrove Sandstone is not itself greatly flexured or faulted hereabouts, and dips to the south-south-west or west. The irregularities at its base are therefore attributed to syn-early Triassic faulting and flexuring following deposition of the Polesworth Formation, and indicate that the datum is also a surface of unconformity (see also, Section 6.1.3). A hiatus at this stratigraphical position is recognised elsewhere in the Midlands, and the relationships across it were briefly summarised by Warrington et al. (1980, p.38) who noted that the radical change in the style and provenance of sedimentation was indicative of intervening earth movements.

A continuation of faulting after deposition of the Mercia Mudstone Group is demonstrated by the Netherseal and Overseal faults and the northerly **Caldwell Fault**.



-65 Structure contour, value in metres relative to OD

-155 Borehole, with base of Triassic in metres relative to OD

Outcrop of pre-Triassic strata

130 Fault, dashed where speculative, tick on downthrow side; throw in metres where known, syn- to post-Triassic movement

Fault, as above, with possible early Triassic movement

Figure 14 Structure contour map for the base of the Triassic in Sheet SK21NE, showing the principal structures of syn- to post-Triassic age

9. OTHER INFORMATION

9.1. Mineral Resources

9.1.1. Coal

Coal has formed an important mineral resource in the district up to recent times. The earliest coalmining records show that exploitation of the exposed measures in the South Derbyshire Coalfield was well-established by the end of the thirteenth century, although the earliest known set of colliery accounts dates from the Elizabethan Period (Owen, 1984, p.19). Opencasting along the crop of the coal seams, on a 'cottage industry' basis, probably characterized the first phase of exploitation, but when it was realized that coal extended underground, these methods were for the most part abandoned and numerous 'bell' pits were sunk: this survey has found surface evidence of ground disturbed during these early phases of coalfield development, particularly to the east of the Goseley Estate [323 198], in Sheet SK31NW. Owen (1984) believes that by the fifteenth century, specialist collier groups within the area were developing deeper and better-equipped pits. The mining industry subsequently proceeded in a number of phases, corresponding to technical advances in deep mining and the changing socio-economic climate of the region, as documented in Worssam and Old (1988, p.123). Mining records show that development of the eastern part of the concealed coalfield from the Coton Park and Netherseal Collieries of Sheet SK21NE was under way by the turn of the century, but was not extended farther west until the 1960's, when the construction of underground drifts opened up small areas of extraction beneath Caldwell and Rosliston, the latter mainly lying outside the western boundary of the district. All underground collieries in the district are now closed.

The opencast working of seams of Middle to Upper Coal Measures strata above the P40 seam has occurred throughout this century, although mainly as a by-product of fireclay extraction (see below). During the present decade, however, opencast sites were established purely for the extraction of coal. Those presently working are the Shellbrook Site, on SK31NW, and Nadins Site, on SK21NE. A summary of all coal and fireclay opencast operations is given in Tables 2 and 3.

The coals worked in this district are mainly of high volatile, very weakly caking type (Coal Rank 802), though there are some coals of non-caking type (Code 902) and a small amount of weakly-caking type (Code 702).

9.1.2. Fireclay, clay

The area to the south of Swadlincote, in Sheets SK31NW and SK21NE, has been the UK's most important producer of *fireclay* this century. The history of fireclay extraction is closely associated with that of coal mining; for example, Owen (1984, p.278) notes that the early earthenware companies leased all minerals within 100 feet of the surface and paid royalties on both coal and clay. One of the earliest recorded clay mines was the Pool Works, to the west of Milk Hill [306 181], which was sited in 1825. The principal emergence of this industry probably occurred after 1860, however, since it is evident that the working of fireclay by opencast as well as underground methods was well underway by the turn of the century (Fox-Strangways, 1907, p.111). The quarries marked on the Ordnance Survey maps used by Fox-Strangways (MS 1892-95) are small (generally less than 100 m^2), but the size of opencast workings depicted on maps had greatly increased by the time of G H Mitchell's survey, in 1939, and details of the many quarries are given in Mitchell and Stubblefield (1948). Further expansion of the quarries occurred in the post-war years leading up to the early 1980's, but more recently the use of concrete for pipe-making has somewhat curtailed the demand for fireclay. The large fireclay stockpiles that had been established presently constitute a resource for the production of facing bricks, vitrified clay pipes and refractory products (Highley and Cameron, 1995). Those quarries currently with working faces are the Donnington Extension Site [3062 1760] and Albion Site [3188 1725], all of the other clay pits (Tables 2 & 3) being in various stages of restoration.

The principal fireclay lithologies are the seatearths of the c. 100 m-thick Pottery Clays formation. In the early days of exploitation the main resource constituted the seatearths between seams P34 (Ell) and P31, which underlie the Aegiranum Marine Band (Section 3.3.2); however many of the larger sites currently in operation or recently closed have worked the strata down to the P41 seam for fireclay. The fireclays are mainly used in the manufacture of clay pipes for sewage and surface-water drainage. They exhibit a wide range of compositions, with alumina ranging between 17 and 34% uncalcined according to Highley (1982), and a maximum of 35.6% proved in the Hanginghill Farm Borehole (Worssam, 1977). A detailed account of the fireclays, their composition and history of mining is given in Worssam and Old (1988, p.127).

Opencast Site - NGR	Seams exploited	Completed
Sandtop Lane 335 177	Kilburn	1946
Willesley Clay 331 156	P23-P40	1986
Hicks Lodge Farm 330 153	P23-P29	1967
Willesley Quarries 335 152	P19-P31	1971
Shellbrook 330 162	Kilburn, Clod, Yard to P39	Still working
Moira Pottery 317 162	P12-P26	1994
Albion 317 176	P27-P41	1982
Albion 314 174	P27-P40	Not yet backfilled
Albion Extension 314 185	?P29-P34	1976
Hepworth Lom 312 180	P17-P29	1992
Haywood 308 162	P35-P39	1976
Reservoir Works 309 166	?P33-P39	1965
Ashby Reservoir 308 169	not known	1965
Moira Road 308 171	not known	1966
Milk Hill 311 187	not known	1978
Hillside Quarry	not known	not known
Donnington Extension 305 173	P21-P40	Not yet backfilled
Donnington Plant 302 168	not known	1973
Boundary I & II 308 185	not known	1977
Granville 312 190	P31-P40	1988
Poolworks & Extn. 305 184	not known	1977

Table 2 Details of coal and fireclay opencast sites in Sheet SK31NW

Opencast Site - NGR	Seams exploited	Completed
Nadins 280 195	Main to Upper Cannel	Still working
Hearthcote Road 290 194	Block, Yard	1989
Queen St. 296 181	Seams unknown, up to P31	1972
Church Gresley 299 183	?P31-P40	1975
Church Gresley 299 176	not known	1975
Church Gresley 300 180	not known	1973
Railway Works 296 179	not known	1967
Railway Works 297 173	not known	1961
Robinson & Dowlers 296 165	?P25-P41	?1970's
High Cross 288 174	P21-P40	1994

Table 3 Details of coal and fireclay opencast sites in Sheet SK21NE

Clay for brick-making was sporadically worked in the Mercia Mudstone outcrop on Sheet SK21NE. Laminated micaceous mudstones of the Radcliffe Formation were quarried at a few sites to the west of Linton [e.g. 2612 1681], and mudstones of the Edwalton Formation near Botany Bay [2598 1517].

9.1.3. Sandstone

Small-scale quarrying of sandstone has been carried out, probably to obtain loose sand from the near-surface weathered zone.

In *Sheet SK31NW,* small quarries were opened on the crop of Lower Coal Measures sandstones west of Ashby-de-la Zouch [3435 1675, 3390 1570]. Former quarrying of the Polesworth Formation is seen near Sharpswood Farm [3118 1963] and Boothorpe Hall [3216 1745]. The Bromsgrove Sandstone has been worked east of Blackfordby [3351 1811] and near Smisby [3482 1935].

In *Sheet SK21NE* sandstone has been quarried at several locations along the east-facing escarpment developed on the Polesworth Formation north of Castle Gresley [e.g. 2762 1884]. Further former workings on the ridge formed by this unit are seen as shallow sand-pits to the north of Castle Gresley [2765 1840] and at High Cross Bank [2810 1765]. In the Polesworth outcrop south of Linton small disused quarries are seen near Sealwood Cottage [2818 1568]. The Bromsgrove Sandstone was worked north of Caldwell [2604 1821] and close to Linton [2717 1724, 1700 2734].

9.2. Water Supply

The major streams of the district drain northwards and westwards, into the River Trent system. In Sheet SK31NW, south-flowing streams, such as the Shell Brook, enter the Trent via the River Mease. Memoirs describing the groundwater supplies of Leicestershire and Derbyshire (Richardson 1929, 1931) contain much well and spring data, and discuss the properties of the principal aquifers. A review of factors influencing water supply and quality relevant to the district is also given in Worssam and Old (1988, p.130).

The principal aquifers of the district are the permeable sandstones and conglomeratic sandstones of the Sherwood Sandstone Group and, where present, the overlying Sneinton Formation (formerly the Keuper Waterstones) of the Mercia Mudstone Group. In the central Midlands region generally, the Sherwood Sandstone aquifer is commonly pumped from deep boreholes at distances as far as 20 km from the outcrop (Bath et al., 1987). In the present district this aquifer is part-confined by the relatively impermeable Carboniferous strata below, but is mostly unconfined at the top, and therefore particularly vulnerable to pollution; it is sealed only in the south of Sheet SK21NE, by capping mudrocks of the Gunthorpe and Edwalton Formations of the Mercia Mudstone Group. Triassic sandstone formations generally act as one aquifer, but can be a multiaquifer if significant mudstone interbeds are present, which is the case for the Bromsgrove Sandstone Formation. The Sherwood Sandstone aquifer is on the whole fairly porous (Lovelock, 1972), and it has a high value for specific yield. Carboniferous strata show some transmission of groundwaters and are regarded collectively as a minor aquifer, with locally important water-bearing beds represented by thick sandstone units such as the Wingfield Flags.

The recent underground mine abandonments may pose a potential hazard to underground water quality within or immediately adjacent to the South Derbyshire Coalfield. If the former workings are allowed to flood, the waters circulating through the partly-collapsed galleries will be susceptible to contamination by the leaching, and subsequent solution, of toxic chemicals concentrated within the Coal Measures strata. Local hydrological conditions may then create a potential for these contaminated waters to infiltrate underground aquifers, and in possible exceptional local circumstances gain access to domestic water supplies.

9.3. Artificially Modified Ground

This section describes ground that has been changed as a result of human activities, the impact of which is detectable by surface or subsurface investigation. It is intended to be a general description of the types of modified ground depicted on the accompanying 1:10 000 map sheet.

9.3.1. Worked Ground

Worked ground corresponds to areas where the ground is known to have been cut away by man. It includes quarries or pits, cuttings for railways, canals or roads and cut away landscaping.

9.3.2. Made Ground

This category of artificially modified ground comprises those areas where the ground is known to have been deposited by man. Road, rail, reservoir and screening embankments; flood defences; spoil (waste) heaps and constructional fill are the principal types of Made Ground in the present district. In the field, it commonly gives rise to large-scale anomalous features, upon which is developed an immature soil profile incorporating debris of rock and man-made waste.

Made Ground constitutes a potential hazard to development. Its geotechnical properties are dependant on its composition, which is usually difficult to determine unless comprehensive records have been kept. No attempt was made to retrieve such information during the present survey, so this report or its accompanying maps should not be regarded as accurate guides to the nature of the deposits.

In the Coal Measures outcrop, very old areas of made ground are identified by the presence of anomalous landforms in association with abundant colliery waste. Many such areas are of small extent, and are interpreted as heaps of spoil derived from nearby surface or subsurface mining operations and transported short distances by horse-drawn wagons. It is commonly difficult to distinguish this type of Made Ground from ground disturbed by shallow or surface mining: the boundaries drawn on the map should therefore be viewed with circumspection.

9.3.3. Worked and Made Ground

Worked and Made Ground is a category which covers those areas where the ground has been cut away and then had artificial ground deposited. It includes partly or wholly back-filled workings such as pits, quarries, opencast and landfill sites.

Landscaping operations have commonly obscured the older areas of cut and fill. Their boundaries, shown on the geological sheets, are mainly taken from old Ordnance Survey maps, supplemented by field observations, or opencast plans where available, and therefore may not accurately depict the maximum extent of the cuts immediately before they were infilled and landscaped. Worked and Made Ground carries the same potential hazard to development as Made Ground. The composition of the infilling material, and the design of the landfill, are usually impossible to determine unless comprehensive records have been kept. No attempt was made to retrieve such information during the present survey, and so this report and accompanying map should not be regarded as accurate guides to the types of artificial deposit involved.

9.3.4. Landscaped Ground

Areas where the original surface has ben extensively remodelled, but where it is impractical or impossible to separately delineate areas of cut and made ground, are included in this category.

9.3.5. Disturbed Ground

Disturbed Ground includes areas of ill-defined surface workings, and where ill-defined excavations, areas of subsidence and Made Ground are complexly associated with one another. During the present survey, Disturbed Ground was visually identified in fields by observing anomalous or hummocky small-scale features, which commonly are associated with angular unweathered or partially-weathered rock debris and man-made waste in the soil. In most cases, no attempt has been made to extrapolate Disturbed Ground into adjacent sites of urban development, or beneath roads and railways where it cannot be seen, but where it is nevertheless still probably present.

Disturbed Ground characterises areas that have commonly experienced several phases of mineral extraction, involving combinations of surface, shallow sub-surface and deep underground mining. Consequently a number of different processes contributing to ground instability may be operative within a single small area.

Disturbances reflecting surface workings represent a complex association between ground that has been cut away and ground that has been wholly or partially infilled by a variety of materials. The hazards posed by such areas will include the possibility of ground settlement above incompletely-filled excavations.

Disturbances caused by shallow subsurface workings are commonly developed in areas that formerly experienced mineral extraction by the bell-pit method. The pits were infilled by a variety of materials, including organic waste, and the ground around them can be weak and cavernous, resulting in excessive and uneven settlement when loaded. The possibility that some pits, or deeper abandoned mine shafts, were never completely infilled should also be taken into account when a site is developed in such ground.

General ground subsidence, caused by the progressive collapse of roadways and working faces in abandoned deep mines, has probably occurred throughout the undermined area to the west of the Boothorpe Fault. On *Sheet SK31NW*, ground cracking due to subsidence-induced earth movements reactivating old fractures has been reported in the vicinity of the Boothorpe Fault, in its southernmost sector around Norris Hill. Similarly, in *Sheet SK21NE*, well-defined escarpments up to 4 m high in Disturbed Ground north of Cappy Farm [2875 1822], and possibly farther south [2885 1775], are believed to be the result of differential subsidence caused by the collapse of underground workings whose boundaries were determined by fault lines in the Coal Measures. Subsidence is likely to prove a continuing problem in areas of the most recent mine abandonments, but is by no means confined to those areas and may still be a factor in some of the older mining districts. Advice about subsidence in specific areas, and mine plans showing the extent of undermining, can be obtained from the Coal Authority offices at Bretby.

10. BOREHOLES

This section summarizes information about those boreholes mentioned in the text and shown on the face of the accompanying 1:10 000 map sheet. The numbering system for these records commences with the map sheet number, followed by the number given to the borehole when it was archived (e.g. SK31NW/14). These records may be examined at the National Geological Records Centre of the BGS.

The surface elevation of each borehole refers to Ordnance Datum (OD), and is given in metres above sea level.

SK31NW/	NGR	ELEV	NAME	SUMMARY
1	3070 1907	~130	Granville Colliery No.2 Shaft	MCM,LCM
3	3091 1996	116	Granville Wood	LCM
29	3195 1730	129	Rawdon East No.1	MCM, LCM
30	31271626	~105	Rawdon Pit Shaft	MCM, LCM
34	3199 1559	~107	Hastings and Grey Shaft	UCM, MCM, LCM
105	3353 1654	115.6	Blackfordby No.4	LCM
106	3279 1685	131.9	Blackfordby No.3	LCM
108	3235 1827	136.1	Blackfordby No.1	LCM, Millst. Grit
141	3135 1672	127.1	Hanginghill Farm	UCM, MCM
142	3019 1743	122.7	Union Lodge No.1	MCM
145	3031 1760	126.7	Union Lodge No.4	MCM
146	3029 1762	128	Union Lodge No.5	UCM, MCM
154	3406 1826	150	M42	Bromsgrove Sandstone, LCM
156	3422 1880	150	M42	Head, Bromsgrove Sandstone, LCM
157	3430 1808	166	M42	Bromsgrove Sandstone
158	3438 1888	180	M42	Radcliffe/Sneinton Fm., Bromsgrove Sandstone
232	3416 1846	163	M42	Bromsgrove Sandstone
233	3418 1862	157	M42	Bromsgrove Sandstone
234	3427 1895	154	M42	Bromsgrove Sandstone
235	3433 1923	168	M42	Bromsgrove Sandstone
237	3435 1940	164	M42	Bromsgrove Sandstone
238	3435 1954	169	M42	Head, Bromsgrove Sandstone
241	3439 1972	174	M42	Bromsgrove Sandstone
260	3458 1559	109	Rotherwood	Millst. Grit, Carb. Limestone, Stockingford Shale Group

SK21NE/	NGR	ELEV	NAME	SUMMARY
1	2759 1994	76.8	Bretby Colliery No.5	MCM, LCM
2	2594 1963	65	Stanton House Farm	Drift, Bromsgrove Sst., Polesworth Fm., ?Moira Fm., LCM
7	2608 1999	67.5	Bretby West No.3	Bromsgrove Sst., Polesworth Fm., LCM
5	2579 1848	66.5	Ashley Barn	Bromsgrove Sst., Polesworth Fm., MCM, LCM
8	2753 1843	~82	Cadley Hill Colliery No.1	Polesworth Fm., Moira Fm., MCM
11	2723 1899	~70	Cadley Hill Colliery No.4	Polesworth Fm., MCM
14	2775 1887	76.8	Cadley Hill	LCM, Millst. Grit
16	2779 1996	70.8	Bretby Colliery No.3	MCM, LCM
19	2882 1892	~94	Gresley Wood Colliery	MCM, LCM
21	2911 1940	~82	Swadlincote Colliery No.3	MCM, LCM
22	2842 1981	79	Stanton Colliery	MCM, LCM
23	2660 1757	101	Caldwell	Bromsgrove Sst., Polesworth Fm., MCM, LCM
24	2600 1734	~83	Caldwell No.1	Bromsgrove Sst., Polesworth Fm., Moira Fm., ?UCM, MCM
25	2568 1672	~87	Caldwell No.2	Radcliffe & Sneinton Fms., Bromsgrove Sst., Polesworth Fm., Moira Fm., Etruria Fm., ?UCM, MCM
26	2532 1721	80	Caldwell Hall	Radcliffe & Sneinton Fms., Bromsgrove Sst., Polesworth Fm., Moira Fm., UCM, MCM, LCM
27	2558 1587	87	Botany Bay	Gunthorpe Fm., Radcliffe &Sneinton Fms., Bromsgrove Sst., Polesworth Fm., Moira Fm., Etruria Fm., UCM, MCM, LCM
28	2652 1547	106	Grange Wood	Gunthorpe Fm., Radcliffe, Sneinton Fms., Bromsgrove Sst., Polesworth Fm., Meriden Fm., Halesowen Fm., Etruria Fm., UCM, MCM, LCM
29	2690 1775	90	Coton Park	Bromsgrove Fm., Polesworth Fm., MCM, LCM
33	2732 1792	76	Coton Park Colliery No.2	Bromsgrove Fm., Polesworth Fm., Moira Fm., MCM, LCM
34	2631 1780	~89	Coton Park No.3	Bromsgrove Fm., Polesworth Fm., ?Moira Fm., MCM
37	2624 1551	105	Netherseal No.3	Gunthorpe F., Radcliffe & Sneinton Fms., Bromsgrove Sst., Polesworth Fm.
38	2678 1521	122	Netherseal Rosliston	Edwalton Fm., Gunthorpe Fm., Radcliffe & Sneinton Fms., Bromsgrove Sst., Polesworth Fm., Moira Fm., Meriden Fm., Halesowen Fm., Etruria Fm., ?UCM
39	2764 1590	103	Netherseal Colliery No.1	Polesworth Fm., Moira Fm., MCM

SK21NE/ (cont.)	NGR	ELEV	NAME	SUMMARY
44	2921 1805	126	Church Gresley	MCM, LCM
49	2786 1806	81.5	Home Farm	Polesworth Fm., MCM
50	2784 1774	75	Castle Hill	Bromsgrove Sst., Polesworth Fm., MCM, LCM
58	2513 1811	85	Ashley House	Bromsgrove Sst., Polesworth Fm., MCM, LCM
59	2996 1514	102	Poplars Farm	Moira Fm., MCM
63	2811 1744	84	High Cross Bank	Polesworth Fm., Moira Fm., MCM, LCM
69	2732 1755	77	Coton Park Village	Bromsgrove Sst., Polesworth Fm., Moira Fm., ?MCM
70	2741 1737	77	Coton Park Grange Farm	Bromsgrove Sst., Polesworth Fm., Moira Fm., MCM, LCM
71	2706 1888	72	Cauldwell Lane	Bromsgrove Sst., Polesworth Fm., ?Moira Fm.
73	2771 1800	76	Castle Mount	Polesworth Fm., Moira Fm., MCM
79	2757 1543	115	Netherseal Colliery No.4	Bromsgrove Sst., Polesworth Fm., Moira Fm., MCM, LCM
107	2562 1514	91	Linton Lane	Drift, Edwalton Fm., Gunthorpe Fm., Radcliffe/Sneinton Fms., Bromsgrove Sst., Polesworth Fm., Moira Fm., Halesowen Fm., Etruria Fm., UCM, MCM, LCM
132	2628 1925	~58	-	Alluvium, Bromsgrove Sst.
136	2592 1929	~57	-	Alluvium, Bromsgrove Sst.
139	2552 1941	~57	-	Glaciofluvial Deposits
141	2526 1953	~56	-	Glaciofluvial Deposits
177	2943 1818	~130	-	MCM

11. OTHER UNPUBLISHED SOURCES OF INFORMATION

This section presents in tabular form the principal items of information used to compile this report and accompanying 1:10 000 scale maps. The information is available to public examination by application to the National Geological Records Centre of the BGS.

ITEM	DETAILS
SHEET SK31NW:	
Site investigation reports	Various
Field notebooks	Fox-Strangways
Field notebook	B C Worssam
Field notebook	G H Mitchell
Field notes, new-style filofax	J N Carney
Field slips, for DY60 NE, NW, SE, SW	Fox-Strangways
Field slips for same	G H Mitchell
Field slips for SK31NW (part of)	B C Worssam
Field slips for SK31NW	J N Carney
*Opencast completion plans	Various
*Underground mine plans	Various
SHEET SK21NE:	
Site investigation reports	Various
Field notebooks	Fox-Strangways
Field notebook	B C Worssam
Field notebook	G H Mitchell
Field notes, new-style filofax	J N Carney
Field slips for DY60 SE, SW	Fox-Strangways
Field slips for same	G H Mitchell
Field slips for SK21NE (part of)	B C Worssam
Field slips for SK21NE	J N Carney
*Opencast completion plans	Various
*Underground mine plans	Various

*A more extensive collection of these records is kept by the Coal Authority whose office is located at Bretby, near Swadlincote, South Derbyshire.

Acknowledgements

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