3 The geology of Doncaster

3.1 Introduction – bedrock

The oldest rocks that are found at the surface in Doncaster belong to the Pennine Middle Coal Measures Group of the Carboniferous System (Figure 2); (Figure 3); (Figure 4) and whilst older rocks have been proven by colliery shafts and boreholes and were once highly significant to the coal mining industry, these are underground and not considered relevant to this report.

The configuration of landmasses across the earth during Carboniferous times was very different from today. By the beginning of the Carboniferous Period, roughly 360 million years ago (Ma), the area destined to become South Yorkshire was part of a continent known as Laurasia that had moved to a position almost astride the equator. At this time much of what is today northern England began to be progressively submerged beneath a wide, shallow tropical sea, in the clear, warm waters in which beds of limestone accumulated. Periodic influxes of sand and mud, deposited by deltas building from a landmass to the north or north east, periodically established swamp or delta top environments, occasionally with the development of lush tropical forests. The evidence for these conditions is preserved today as the layers of sandstone and mudstone of the Carboniferous rocks. As Carboniferous times progressed, tropical forest cover became much more frequent, the remains of which are preserved today as the coal seams of the Coal Measures.

Towards the end of Carboniferous times, about 290 million years ago, that part of the earth's crust on which the Carboniferous sediments had been deposited continued to drift northwards. Major Variscan earth movements associated with the formation of the supercontinent, Pangaea, once more created mountains across what became northern England. By about 280 million years ago, during the early Permian Period, northern Europe was one of the world's great deserts and the area that is today the Pennines probably consisted of mountains, with valleys choked with rock debris broken from these rapidly eroding barren uplands. Up to 500 m of Carboniferous rocks were eroded by this desert erosion, forming huge wind-blown sand dunes that covered much of a comparatively low gently rolling plain that sloped gently eastwards into the subsiding North Sea Basin. These are the 'Yellow Sands Formation' that is very occasionally seen at the base of the limestone escarpment in the western part of Doncaster today.

This Permian desert was soon inundated by the rapidly advancing waters of a sea, known to geologists as the Zechstein Sea. This occupied an area within a subsiding basin, flanked by uplands to the south and west, which included that of the modern North Sea and stretched into Eastern Europe. Sediments deposited in the Zechstein Sea record five major and numerous minor cycles of sea level change, with periods of high salinity, in part due to periods of evaporation of substantial parts of the sea, resulting in the deposition of repeated sequences of carbonate, evaporite and clastic sediments.

The earliest Zechstein sediments in Doncaster, associated with the first phase of inundation by the sea, comprise a muddy dolostone (formerly termed limestone) sequence (formerly called the Lower Permian Marl, but now included as the lower part of the Cadeby Formation), which was deposited at the south-western edge of the North Sea Basin in a large river estuary or a lagoon. With the sea level continuing to rise, a succession of dolostones was deposited, which, from the common occurrence of the magnesium carbonate mineral dolomite, was previous known as the Lower Magnesian Limestone (now Cadeby formation). A well-known feature of the Cadeby Formation is the presence of very well preserved fossilized reefs composed of bryozoans, algae, bivalves and brachiopods. These were formed in shallow water, very near to an ancient shoreline to the west.

With the next major change in sea level and the regression of the Zechstein Sea into the centre of the marine basin to the north-west, the land reverted to a low lying, wide coastal plain containing transient lagoons and playa lakes into which sediments derived from an arid hinterland to the west and south were deposited. This Edlington Formation (formerly The Middle Permian Marl) comprises calcareous mudstones, with occasional layers of gypsum that indicates the periodic incursion and evaporation of an increasingly saline Zechstein Sea.

Another substantial rise in sea level during the middle of the Permian Period saw the land once again inundated, with a return to shallow shelf conditions and the deposition of the dolomitic limestones of the Brotherton Formation (formerly the Upper Magnesian Limestone) near to the ancient sea shore.

Once again, the Zechstein sea level dropped with a return to a palaeoenvironment dominated by lagoons and playa lakes, where layers of anhydrite and rock salt were formed; especially to the north and east of the region and extending into north-east England, where thick deposits were laid down in the centre of the still subsiding basin. At the end of the Permian, 250 million years ago, when this Roxby Formation was formed, the Zechstein Sea finally dried up and the region remained arid and was covered in thick spreads of sandy fluvial deposits, commonly with pebbles and laid down as flash floods, that were derived from the erosion of upland areas to the south. Although in England there are no obvious boundaries visible in the rocks, the deposition of the Sherwood Sandstone Group (formerly Bunter and Lower Mottled Sandstones) marks the transition from the Permian to the Triassic Period, which ended 205 million years ago.

Successively younger rocks to the east of the region record geological events up to modern times, in Doncaster these are absent and there is no tangible evidence of the geological history until the deposits left by ice sheets during the glacial period of the Quaternary which began here about two million years ago. However, based on the geological record found in the surrounding regions, some general assumptions can be made. The latest Triassic saw the continuation of desert conditions, dominated by dust storms.

For much of the Jurassic Period the district was covered by shallow open seas, with mudstone and at times limestone deposition, but it is possible that in the middle part of the period, northern and western areas experienced brackish and freshwater depositional conditions, with transient emergence and erosion. Similar mainly nonmarine and periodically emergent conditions probably continued during much of the early Cretaceous. In the late Cretaceous, however, the sea in which the Chalk was deposited covered the entire district. During the Tertiary, differential uplift and the imposition of an overall easterly dip resulted in prolonged erosion, which removed all the post-Triassic rocks from the district and exposed Permian rocks in the extreme west. The westerly and northerly flowing drainage pattern evolved during this time.

3.2 Introduction — Quaternary

At the start of the Quaternary, which commenced approximately 2.5 Ma and is commonly referred to as the 'Ice Age', an episode of global cooling caused polar ice sheets to extend southwards to cover much of Great Britain and Northern Europe. During the Quaternary the climate oscillated between colder (glacial) and warmer (interglacial) stages. Study of sediments, landforms and fauna onshore and offshore have identified 14 to 17 stages of alternating cold glacial and warm interglacial conditions in Great Britain. The extensive ice sheets, which in places were over 1 km thick, resulted in erosion and modification of the existing landscape. The effects of persistent freeze-thaw action in ground, which was often very deeply frozen, and the deposition of a variety of glacial sediments further modified this pre-existing landscape.

The most recent glaciation, the Devensian, ended around 11,500 years ago, marking the beginning of the Holocene or recent period and deposits reflect erosion and deposition in a varied succession of environments during much milder climatic conditions. Fluvial deposits occur in almost all valleys or river courses and are still forming. These include a wide range of deposits including clays, silts, sands and gravels. Landslides occur in many areas and are not necessarily limited to steep slopes or hillsides. Peat deposits also developed during the Holocene after the glaciers retreated and occur both in local topographic lows in the deglaciated landscape and as extensive expanses of blanket bog over areas of high ground.

In Doncaster, Quaternary deposits cover 60 per cent of the land (Figures 5 and 6), generally being most extensive and thickest in the low-lying areas. Much of the form of the present day physical landscape derives from the effects of this prolonged period of ice cover and its subsequent melting. This has strongly influenced settlement patterns agriculture and, in historical times, man has diverted some of the rivers during high tides to produce extensive spreads of artificially induced alluvium, or warp to raise and fertilise the land.

The interpretation of the Quaternary deposits provides a wealth of information on the environments of the recent geological past. Information from glacial landforms and the nature and morphology of glacial deposits is essential to the understanding of these climatic conditions and may provide valuable insights into likely future environmental changes related to global warming. The study of Holocene fluvial sediments allows interpretation of the evolution of rivers or streams, including extreme events such as flooding.

BGS has subdivided Britain into a number of Quaternary domains, based on the occurrence of distinctive Quaternary landform-sediment associations and structural characteristics. Doncaster is covered by three Quaternary domains (Figure 7):

1. Plateau and Valley Domain
2. Dissected Till Domain
3. Lowland Basin Domain

Within the district there are deposits attributable to the last three British Quaternary stages (the Ipswichian, Devensian and Flandrian), and also to an older, pre-Ipswichian, glacial stage. Consequently, the long, early part of the Quaternary appears to represent a continuation of the denudational regime that had persisted during Tertiary times. The oldest deposits, of pre- Ipswichian glacial origin, indicate the existence of a thick cover of ice derived from the north and north-west, beneath which deep subglacial incision and deposition took place; fluvioglacial meltwater deposits entered the district from the south and west during deglaciation. Subsequent fluvial incision occurred just prior to the temperate Ipswichian Stage as a result of the sea level being at or more than 13 m below OD, which suggests retarded glacioeustatic effects. As sea level rose to about, or just above, OD during this interglacial, estuarine deposits formed in the incised drainage courses.

Somewhat later, the rivers Don and Idle deposited extensive spreads of river terrace deposits (Older River Gravel on some maps). In the cold Devensian Stage, which apparently began about 120 000 years ago, sea level fell to more than 20 m below OD, again reflecting glacioeustatic effects, and rivers crossing the district incised wide valleys directed towards the Humber Gap to the east. Periglacial conditions, indicated mainly by cryoturbation structures and ventifacts, prevailed during at least part of this long incision phase. However, except possibly for some fluvial sand and gravel now deeply concealed beneath the Hemingbrough Formation, and also possibly some head, there is no evidence of deposition until late in the Devensian.

Then, probably about 18 000 years ago, glacial blockage of the Humber Gap impounded a large lake (Lake Humber) across much of the district and adjacent areas. The lake rose initially to about 30 m above OD, sand and gravel being deposited around its margins. During this high- level lacustrine phase a tongue of ice surged southwards down the Vale of York and into northern and eastern parts of the district, depositing sand and gravel into the lake. The ice soon melted and the lake level fell, apparently transiently to as low as 4 m below OD, before establishing a longer lasting level at about 9 m above OD. Lake Humber finally disappeared, apparently by filling up with sediments, which are known as the Hemingbrough Formation.

Rivers then deposited sandy levees as they initiated courses across the emergent lacustrine plain. In the last millennium of the Devensian (which by definition terminated 10 000 radiocarbon years ago), blown sand accumulated in places, and some ventifacts and cryoturbation structures at the top of the Devensian glacial and lacustrine deposits may have formed at this time.

At the beginning of the Flandrian or slightly earlier, breaching of the glacial deposits in the Humber Gap allowed the rivers crossing the district to incise their courses down almost to 20 m below OD, again in response to the continuing eustatically low sea level. As the sea rose to its present level later in the Flandrian, alluvium eventually filled these incised courses and spread thinly but widely beyond them, locally covering peat that had developed in the prevailing wetter climate and more waterlogged conditions.

3.3 Geology and landscape — natural areas

There is a fundamental relationship between the bedrock geology and the topography and landscape of the Doncaster area. Natural England has subdivided England into areas each with a unique identity resulting from the interaction of wildlife, landforms, geology, land use and human impact. Doncaster is covered by three Natural Areas (Figure 8) which closely match the bedrock geology (Figure 3):

1. Coal Measures
2. Southern Magnesian Limestone
3. Humberhead Levels

The Coal Measures Natural Area, in the west of the borough, coincides with distinctive scarp and dip slope topography resulting from the folding of the Carboniferous rocks, the differential erosion of the sandstones and intervening shales and the drainage patterns of the rivers Don and Dearne.

The Southern Magnesian Limestone Natural Area coincides with the Permian rocks that occupy the west-central part of the region. It is generally characterised by well drained rolling countryside, with minor landforms controlled by local faulting and folding, and a western boundary sharply defined by the very distinctive limestone escarpment.

The Humberhead Levels Natural Area concides with the Triassic rocks and unconsolidated Quaternary sediments that are found in the central and eastern part of the region. East of a line that runs approximately from Arksey, Doncaster to Tickhill, the Sherwood Sandstone that comprises the Doncaster and Rossington Ridges passes into the relatively flat, lowland areas of eastern Doncaster, where the solid bedrock is covered by sand and gravel, silt, clay and peat.

These Natural Areas are also readily distinguishable on the NEXTMap Britain Digital Surface Model (Figure 9).

3.4 Carboniferous

The bulk of the Carboniferous rocks in Doncaster lie deeply buried beneath a thick sequence of younger rocks to the east of the limestone escarpment, which essentially defines its western geographical boundary. Historically, their position was marked by numerous pit heads and collieries that, until recently, contributed greatly to the economic wealth and growth of settlements in the borough. Details of the geology, as seen in numerous colliery shafts and boreholes, are available in BGS Memoir 88; The Geology of the country around Goole, Doncaster and the Isle of Axholme and other mine records but other than to note that landscaped coal waste tips now add to the natural topography of the area, these are considered beyond the scope of this report.

The upper part of the Pennine Coal Measures Group of Carboniferous age exposed at the surface in Doncaster form an insignificant part of the geology of the borough and occur west of the limestone escarpment around Denaby, Mexborough, Barnburgh and the areas west of Hickleton, Hooton Pagnell and Clifton.

The Coal Measures rocks comprise a succession of largely mudstones and siltstones with subsidiary sandstones, seatearths (fireclays) and coals, which occur in a cyclical sequence throughout and reflect changes in sea level and repeated transitions between a marine and freshwater environment. Sedimentological characteristics of the Coal Measures indicate mainly lacustrine, fluvial and swamp deposition on an extensive and flat coastal plain, with sediments being derived from the ancient and long eroded Caledonian mountains to the north.

Medium grained sandstones form the most distinctive topographic features and in places stand out as bold escarpments but, in the district, these vary considerably in thickness and quickly die away laterally. The mudstones and siltstones occupy the intervening, lower lying areas.

Although the exposed carboniferous rocks in Doncaster are of limited geographical extent, they coincide with important structural and topographic features in the region. The Don Monocline and the North and South Don faults have controlled the river courses of the Dearne and the Don and have strongly influenced the distribution of younger strata and the development of distinctive landforms that can be seen around Mexborough, Conisbrough, along the Don Gorge to Doncaster and at Cusworth Hall. Significant Carboniferous formations are as follows (representative geodiversity sites are listed in square brackets):

3.4.1 Pennine Middle Coal Measures Formation

3.4.1.1 Mexborough Rock [D6-Denaby Lane; D166-Doncaster Road]

A medium grained sandstone that forms a north-west trending ridge from Mexborough to Adwick-upon-Dearne and a north-east trending escarpment at Denaby Wood, plus a small but very distinctive feature to the immediate west of Old Denaby. Together, these provide good evidence of the position and influence of the Don Monocline. Mexborough Rock has been locally exploited as a building stone and contributes to the character of the local historic built environment and has been a good source of water supply.

3.4.1.2 Shafton Coal

With a maximum thickness of 1.5 m, this was once the highest of the important productive coal seams. Whilst once important underground, it was also once mined extensively at outcrop and in shallow workings at Denaby Wood (Figure 4).

3.4.2 Pennine Upper Coal Measures Formation

3.4.2.1 Ackworth Rock [DR2-Harlington Railway Cutting]

A medium grained buff coloured sandstone that forms a topographic feature to the west of Barnburgh but rapidly thins out at Harlington and appears again south of the Don at Denaby Wood (Figure 4).

3.4.2.2 Dalton Rock [DR3-Cadeby Waste Water Works; DR6-Barnburgh Cliff]

A medium grained buff coloured sandstone that appears between High Melton and Cadeby and also forms small topographic features in the area to the west of the limestone ridge to Hickleton .

3.4.2.3 Wickersley Rock

A medium grained buff coloured sandstone that forms a prominent feature at Stotfold and at the edge of the borough at Howell Wood, north-west of Clayton.

3.4.2.4 Ravenfield Rock

A medium grained buff coloured sandstone that forms small features to the south-west and north-west of Hooton Pagnell.

The highest Coal Measures in the area are mudstones and subordinate sandstones with thin coals, the topmost beds of which are usually stained red, the result of weathering of the Upper Carboniferous strata during the period of uplift and erosion in an arid climate that was a feature of the Permian period. Exposures are very rare and are usually only evident from boreholes, colliery shafts, clay and brick pits, cuttings, trenches and miscellaneous excavations.

3.5 Permian

3.5.1 Yellow Sands Formation (formerly Basal Permian Sands) [D4-Watchley Crags; D15-Melton Park]

In much of South Yorkshire the denuded and weathered top of the Carboniferous sequence is covered unconformably by a friable and locally incohesive sandstone which varies from 0–30 m in thickness. Evidence from boreholes within the district indicates that the Yellow Sands Formation form a nearly continuous spread, but some boreholes failed to prove the deposit and it is uncertain whether the thickness variations mainly reflect irregularities in the surface on which the sandstone was deposited or an undulating top to the sandstone. The isolation of some of the thicker sequences suggests that deposition may have been in localised dune fields.

In boreholes, the sandstone is predominantly pale to medium grey and, more commonly in its upper part, bluish grey. It is mainly fine to medium grained, fairly well sorted and dominantly composed of quartz. The constituent sand grains are rounded or sub-angular and their surface is frosted in a manner suggestive of wind-abrasion and implies an aeolian origin. However, current bedding appears to be due to water action, so that it seems likely that the products of wind erosion were finally deposited under water, further evidenced by the occasional presence of argillaceous layers.

At outcrop, the Yellow Sands Formation is found only occasionally in the west of Doncaster, immediately beneath the limestone that forms the escarpment that essentially defines the western boundary of the borough. Where the sandstone is weathered the ferruginous component of it weathers from the bluish grey seen in boreholes to a yellow or orange-yellow colour.

Near Hampole, between Hooton Pagnell and Hickleton, at High Melton and at Conisbrough there are exposures of yellow, current-bedded sand that were formerly worked as building and moulding sand but, in no exposure are these beds more than 20 ft. thick. Elsewhere, the Yellow Sands Formation is not exposed.

3.5.2 Cadeby Formation (formerly Lower Magnesian Limestone) [DR4-Nearcliff Wood Quarries; D300-Conisbrough Caves East; D302-Conisbrough Caves South]

The Cadeby Formation comprises a white to grey, calcitic and dolomitic carbonate sequence, generally up to 80 m, and locally more than 100 m thick. It forms the main topographical feature, a major escarpment, along the west of the Permian outcrop that extends the length of its 300 km outcrop. Locally there is also a fault bounded outlier at Conisbrough and the escarpment is transected by the Don Gorge.

It comprises a thick sequence of limestones laid down in a shallow shelf marine environment at the edge of the Zechstein Sea and generally thickens to the east. During its formation, the calcium carbonate sediments of the Cadeby Formation were dolomitised, the result of chemical reaction with the increasingly hypersaline sea.

The lower calcareous mudstone (marl) facies of the Cadeby Formation (formerly Lower Permian Marl) appears to be absent from Permian strata that outcrop in the west of the borough and is known only from its occurrence in boreholes, in thicknesses of up to 4 m. It consists of pale or, more rarely, dark grey, flaggy to massive, calcareous and/or dolomitic mudstone and siltstone, with thin beds and lenses of argillaceous dolomitic limestone in places. It contains a restricted fossil assemblage consisting mainly of carbonaceous plant debris, fish debris, foraminifera and a locally abundant calcareous macrofauna, notably of bryozoans and brachiopods.

The Lower Marl Facies was deposited in shallow coastal lagoons, which passed laterally into a shallow marine shelf, on which were deposited the limestones of the Cadeby Formation.

The Cadeby Formation may be divided into two major stratigraphical subdivisions, the lower being the Wetherby Member and the upper the Sprotbrough Member separated by the Hampole Beds. These in turn are divided into several rock-types.

3.5.2.1 Wetherby Member [DR6-Barnburgh Cliff; D11-Hazel Lane Quarry; D4-Watchley Crags; D15-Melton Park; D133-Hooton Pagnell; D13-North Cliff Quarry; D5-Hooton Pagnell Village Pound; D20–22-Cadeby Cliff–Constitution Hill; D112-Parknook Quarry; D28-Pot Ridings Wood Railway Cutting]

The Wetherby Member consists mainly of well-bedded fine grained to coarsely granular limestone and ooid-limestone, appreciably dolomitised and generally forming thick parallel beds, although small-scale cross-bedding and ripple-bedding are present locally. In places the beds are fossiliferous, but the fauna is rich in individuals rather than in species. Associated with these beds are masses of unbedded limestones, commonly referred to as reef-limestone, which are frequently crowded with fossils. Brachiopods occur in the reefs, though they are rarely found in the bedded limestones.

At the base a few feet of sandy limestone have been observed in places. Above this, ooidal limestones are the most important constituent, forming thick beds that are frequently fossiliferous. The ooids are small, well-formed and comparatively little altered. Many of the beds clearly show that they originally contained normal ooidal grains plus shell fragments and that both these constituents became completely crystalline during dolomitisation. With the ooid-limestones are pisoid-limestones (pisolites), a rock-type that is more common in the southern portion of the area. Some beds contain rhombs of dolomite that are clearly visible.

Near the base there are lenticular or irregular masses of hard, fine-grained, unbedded reef- limestone, which is white or cream in colour and locally brecciated. They consist largely of unbroken shells and fragments of lamellibranchs, brachiopods and bryozoa, accompanied in places by gastropods and foraminifera. Later alteration appears in some cases to have resulted in the obliteration of the fossils and the production of hard, compact, fine-grained limestone.

3.5.2.2 Sprotbrough Member [D28-Pot Ridings Wood Railway Cutting; DR5 Levitt Hagg Wood; D94- Warmsworth Quarry; D78- Warmsworth Park]

The Sprotbrough Member consists mainly of finely or, less commonly, coarsely crystalline dolostone, some of it minutely cellular due to the recrystallisation of ooids; locally there is also some less altered ooid-limestone. The subdivision is practically unfossiliferous.

It commonly exhibits large-scale cross-bedding and wedge bedding that is one of the most striking features of the Sprotbrough Formation. Individual beds thicken and thin rapidly; thus in a few metres beds may thicken to as much as one metre and just as rapidly thin out.

Two main types of dolostone are found. The more abundant is a grey, white, cream or buff, crystalline, often saccharoidal dolostone that is largely composed of dolomite rhombs. Differences in cementation account for the variation in hardness between hard, compact, crystalline varieties and others, which are so friable as to break down readily to ‘dolostone sand.’ Stylolites are common. Small black specks, possibly consisting of a salt of manganese, are sometimes present.

The second type of dolostone is light in weight, cellular and therefore very porous. The rock is seen to be composed of numerous minute cells occasionally accompanied by larger examples. These minute cells make up a high proportion of the volume of the rock, the remainder of which is composed of finely granular crystalline material. Microscopical examination demonstrates that these rocks were originally ooidal. The ooids appear to have been dissolved away thus giving a cellular structure, modified by recrystallisation of the matrix during dolomitisation.

The Wetherby and Sprotbrough Members are separated by the Hampole Discontinuity, recognised locally at outcrop as a minor erosional surface with alteration of the dolostone below it. It is particularly seen around Hampole, Cadeby and Sprotborough where it is well exposed in quarries and railway cuttings. The Hampole Beds lie mainly above the discontinuity and comprise a sequence up to 1.5 m thick, composed of three thin, greenish, fissile mudstones separated by two cream, finely ooidal and partly laminated calcitic dolostones.

3.5.3 The Edlington Formation (formerly the Middle Permian Marl) [D61-New Edlington Brick Pit; D31-Leys Hill Bridge]

The Edlington Formation is infrequently exposed to the east of the outcrop of the Cadeby Formation. It usually occupies a belt of low lying, wet ground rising up to the escarpment of the Brotherton Formation and, as seen at Skelbrooke, Skellow, Edlington, Wadworth and Tickhill, it yields heavy, typically reddened soils.

It comprises a sequence of red and subordinate greyish green, locally dolomitic, calcareous and gypsiferous mudstones and siltstones. Where it is exposed in railway cuttings, drainage ditches and water logged and overgrown brick pits (D61), fibrous gypsum layers can occasionally be seen. This and the interbedded gypsum was once used to make plaster of Paris.

The Edlington Formation shows thickness variations of up to 6 m, with the most marked thinning frequently corresponding with a thickening of the Cadeby Formation below and vice versa, thus suggesting that the Edlington Formation fills hollows in the surface of the Cadeby Formation, where it was deposited in transient lagoons on a wide coastal plain.

From the evidence of boreholes and colliery shafts, the formation is seen to contain increasing amounts of nodular and layered anhydrite to the north and east of its outcrop, where these are concentrated at certain stratigraphical levels and are considered to be distinct formations in their own right. Although they make no contribution to the landscape, they provide good evidence of the geological history of the region, especially the changes in sea level, increasing salinity, aridity and evaporation that took place in the ancient Zechstein Sea. These are briefly summarised below:

'Marl' between Cadeby Formation and ?Hayton Anhydrite

Comprises an argillaceous reddish, marl, with some gypsum or anhydrite as seen in Thorne Colliery No.1 Shaft.

?Hayton Anhydrite

This formation is recorded as being 13 m thick in the Thorne Colliery Centre Borehole and comprises reddish to grey anhydrite with various amounts of gypsum, dolostone, calcareous mudstones, siltstone and mudstone.

Kirkham Abbey Formation

A thin limestone, the feather edge of which may occur in the district, based on evidence from the east of Doncaster but has not been fully proven in recent boreholes.

'Marl' Between ?Hayton Anhydrite and ?Fordon Evaporites

Grey and blueish mudstones and siltstones containing lenses of anhydrite have been proven in Thorne Colliery No. 1 Shaft.

3.5.4 Brotherton Formation (formerly Upper Magnesian Limestone) [D51-Hexthorpe Flatts – The Dell]

The Brotherton Formation is a relatively uniform sequence of white to grey, mainly dolomitic limestones 13 – 16 m thick, producing a minor feature along much of the outcrop which stretches from Burghwallis in the north to Tickhill in the south and coincides approximately with the line of the A1.

The limestone is always thin-bedded and flaggy, with individual beds varying somewhat in thickness but seldom exceeding 100 mm. Such thicker beds as are present never approach the size of those in the Cadeby Formation and this is a distinguishing feature. Much of the sequence is finely crystalline and small-scale cross-bedding, ripple-bedding and channel cut and fill structures testify to shallow water deposition. Ooid-limestones are present in some western locations and are considered to be near-shore sediments. In more eastern areas the highest strata are locally algal-laminated, suggesting an epitidal environment.

Especially in the upper beds, the bedding-planes may be coated with thin films of red or grey calcareous mudstone or form distinct red mudstone partings. A local development at the base of the Brotherton Formation is a sandy dolostone resembling that found in a similar position beneath the Cadeby Formation.

Fossils are rare and are concentrated in certain beds and include algae, bivalves and some gastropods that are tolerant to saline conditions, however, the formation does contain abundant filaments of the alga Calcinema permiana, which allow it to be easily identified. These filaments look like thin matchsticks and are commonly present as concentrations in the cross-bedded units.

3.5.5 The Roxby Formation (formerly Upper Permian Marl)

Despite being 28 m thick at outcrop near Askern, 18 – 20 m at Bentley and 14 m in Doncaster, the Roxby Formation is very poorly exposed and thins considerably to the south, where it eventually passes laterally into the Lenton Formation, in Nottinghamshire. It is seen in sections exposed by limestone quarrying or old brick pits, at Skelbrooke and Balby respectively, where the sequence comprises reddish and greenish grey mudstone and siltstone, containing thin lenses of anhydrite and/or gypsum in places. Like the Edlington Formation it is evidenced by heavy, reddened soils.

Also like the Edlington Formation it originated mainly as fluvial and lagoonal sediment, deposited on a wide coastal plain and possesses very similar characteristics, including the development of distinct deposits, indicating hypersaline conditions and intense evaporation; these are proven in boreholes and colliery shafts showing that the units thickens away from the district to the north east. Like those of the Edlington Formation, the deposits seen deeper in the basin provide good evidence of the geological history of the area and are summarised below:

'Marl' between Brotherton Formation and Billingham Main Anhydrite

Comprises grey-green and red-brown silty marls as proved in the Thorne Colliery Centre

Borehole, with gypsum veins and layers up to 30mm thick in places.

Billingham Main Anhydrite

This formation is laterally impersistent and in many places is not recorded in boreholes and has a maximum thickness of 4.6 m where found near Askern. It comprises grey anhydrite, with grey and white gypsum and is commonly associated with grey and red marl, particularly in the west.

Carnallitic Marl

The Carnallitic Marl is a sequence of red and subsidiary greyish green mudstones and siltstones, less than 5 m thick where recorded in the Austerfield area and at Rossington Colliery it may be less than 2.5 m thick.

Upper or Sherburn Anhydrite

Where found in the Hatfield Moors No.1 and No.2 boreholes, it is described as white, clear, translucent and finely crystalline in the Thorne Colliery Centre Borehole, it is 5.4 m thick and pearly white with red marl layers up to 80mm thick.

3.6 Triassic

3.6.1 Sherwood Sandstone Group (formerly Lower Mottled and Bunter Sandstone) [D101— Dunsville Quarry; D102- Common Lane Quarry; S190-92- Blaxton Common]

The Sherwood Sandstone Group occurs at or very near to the surface to the east of the A1 where landforms such as the Rossington and Doncaster ridges provide the largest outcrops. Here the sandstone weathers to form pale brown, light, sandy soil. Except for these and small areas north and east of Tickhill (Lenton Formation), where there is a pronounced scarp slope, the Sherwood Sandstone is overlain by loosely consolidated Quaternary sediments but is frequently exposed in sand and gravel pits, notably around Balby, Dunsville and Austerfield.

The Sherwood Sandstone Group in the south of the Doncaster area is subdivided into two formations, the lower unit is the Lenton Formation of probable Permian age and it is overlain by the Nottingham Castle Sandstone Formation of Triassic age. In the north of the area the Sherwood Sandstone Group is mainly covered by thick Quaternary deposits and is undivided. A borehole at Bentley towards the west of the outcrop proves 35 m of sandstone, but at Hatfield Moors and Misson, this increases to 260- 280 m. In the east where the Sherwood Sandstone is overlain by younger Triassic sediments, just east of the borough at Misterton, it has a full thickness of over 400 m.

The Sherwood Sandstone consists mainly of red, brown, fine to medium grained cross-bedded sandstone. Green-grey varieties are occasionally found and thin layers and lenses of brownish red and greenish grey mudstone and siltstone are common. It is moderately hard to friable, well to poorly sorted, and contains scattered, but locally numerous, rolled fragments of reddish and greyish mudstone and siltstone rip-up clasts. Although subangular to subrounded grain shapes predominate in the sandstone, the localised occurrences of rounded grains, and also of ventifacts and desiccation cracks, testify to some degree of aridity, with some wind blown deposits formed on dry land.

The Sherwood Sandstone is unfossiliferous. The Lenton Sandstone is interpreted as aeolian with minor fluvial interludes. The Nottingham Castle Sandstone represents a fluvial sequence deposited along the western margin of the Southern North Sea Basin as a major braided river system sourced from northern France The deposits suggest continuing, but spasmodic, uplift of the London–Brabant Massif, a large landmass that lay to the south in Permo-Triassic times.

3.6.1.1 Lenton Sandstone Formation

The Lenton Sandstone Formation crops out to the north and south of Tickhill. It consists mainly of red-brown and buff mottled, very fine- to medium-grained, argillaceous, cross-stratified sandstone with subordinate beds of red-brown mudstone and conglomerate.

3.6.1.2 Nottingham Castle Sandstone Formation [D44-Cedar Road Adventure Playground]

The Nottingham Castle Sandstone Formation Sandstone overlies the Lenton formation and consists of, pinkish red or buff-grey, medium- to coarse-grained, pebbly, cross-bedded, friable sandstone with subordinate lenticular beds of reddish brown mudstone. The pebbles die out north of Doncaster and hence the formation is not recognised.

3.6.2 Mercia Mudstone Group (formerly Keuper Marl)

This thick sequence of mainly reddish mudstones and siltstones, with occasional gypsum dolostone, succeeds the Sherwood Sandstone Group. The earliest deposits represent depposituion on abroad alluvial plain, with a complex association of channel sandstones, overbank deposits, lacustine and lagoonal environments. Later, the Mercia Mudstone became a desert-sabkha association, dominated by wind blown dust deposition with periodic flash floods deposited on a coastal plain around the western margin of the Southern North Sea Basin.

In Doncaster, they occupy a very small area on the eastern boundary and, being covered in Quaternary sediments, are exposed only in excavations.

3.7 Neogene (Quaternary)

The superficial deposits in the area mainly represent the deposits from at least the last two ice- ages and the intervening interglacial deposits (Figure 6). The landscape has been subjected to several episodes of erosion and several episodes of deposition. The lateral extent and thickness of the Quaternary is extremely variable and many of the sedimentary deposits possess very similar lithologies that are not easily distinguished.

The soft and unconsolidated nature of the sediments mean that they do not form easily recognisable outcrops and details of much of the geology is known from boreholes, excavations, cuttings and particularly from the temporary exposures seen in the numerous sand and gravel pits found in the area. Much of the natural landscape and topography is obscured by sand and gravel workings, but detailed field surveys reveal a wide variety of low lying landforms and structures associated with these recent geological events. The superficial geological sequence is shown in Table 1.

Table 1 The sequence of superficial deposits in the Doncaster area. Numbers in the name column are used in the sections below and on (Figure 2).

3.7.1 Pre-Anglian or Anglian Glacial Deposits

3.7.1.1 Channel Deposits (14)

The bedrock of the area is traversed by eleven deeply buried channels that are only proved in boreholes and which are mainly orientated approximately north-west to south-east, with the only exception being the most southerly, with an orientation of west to east. These are named as the Moss, Barnby Dun Station, Arksey, Armthorpe, Wheatley Park, Bessacar, Rossington, Blackwood, Loversall, Hunster Grange and Lim Pool Channels.

The deposits filling the channels consist largely of virtually stoneless and commonly laminated greyish clay. Sand, with or without gravel and commonly containing coal particles, occurs in several channels, mainly in their lower parts and towards their eastern ends. Where pebbles are present they are mainly of Carboniferous sandstone, limestone and associated rocks, and of Permian limestone; they are commonly grooved and scratched.

The channels are unrelated to the present or any known pre-existing valleys and are believed to have been cut by powerful subglacial drainage, produced from the action of meltwater beneath advancing glaciers. The easterly or south-easterly trend of the channels, and the obviously Pennine derivation of some of the contained deposits, suggest that they probably flowed from sources high in the Pennines. Most of the channels in the district are aligned with gaps through the Permian scarp to the west and also point eastwards to the Haxey Gap south of the Isle of Axholme, so that a genetic relationship between the channels and these gaps is possible.

These are all interpreted as being pre-Ipswichian and most probably related to the Anglian glacial event.

3.7.1.2 Till (13) [D61-New Edlington Brick Pit; D51-Hexthorpe Flatts – The Dell; D44-Cedar Road Adventure Playground]

Patchy glacial till has been mapped throughout the western part of the area where it mainly forms relics sitting on slightly elevated bedrock so that it caps hills and ridges. These include isolated occurrences at Adwick upon Dearne, Skelbrooke, Braithwell and on the Rossington ridge. Around Balby and Warmsworth, much thicker and more extensive deposits are preserved in an ancient valley. On the flanks of the hills they are commonly much thinner and in the low ground they have not been recognised having presumably been eroded away.

Till (shown as boulder clay on older geological maps) consists of bluish grey to reddish brown silty and locally sandy diamicton with scattered erratics up to boulder size; it is more reddish or yellowish where weathered. The erratics are mainly of Carboniferous sandstone, siltstone and coal, and Permian limestone, with smaller numbers of Carboniferous limestone and chert, derived from the Pennines. A few erratics of igneous rocks, some recognisably from the Lake District, are also present.

On the evidence of these erratics, the ice which deposited the clay till in the district had traversed the eastern Pennine slopes, and some of it had originated or passed close to the Lake District. The stone orientations and analysis of coal erratics at Balby, and distribution of Permian erratics west of the Permian outcrops beyond the district show that most of the ice which entered the district from the north and north-west had flowed south down the Vale of York after crossing the Pennines. The sparsity of clay till, its isolation either on elevated locations or in sheltered low-lying areas, and the absence of associated glacial landforms, suggests a glaciation of considerable antiquity. The presence, locally above the clay till, of older river gravel, for which there is fossil evidence of an Ipswichian interglacial age, confirms the glaciation as Anglian.

3.7.1.3 Pre-Ipswichian, possibly Anglian Fluvioglacial Deposits (12) [D44-Cedar Road Adventure Playground; D102 Common Lane Quarry; D109-Hurst Plantation Quarry]

The fluvioglacial deposits occur in two main concentrations within the area, capping the Doncaster and Rossington ridges where they rest on bedrock and, occasionally, the underlying till. The deposits comprise beds, lenses and layers of both pebble-free sand, and gravel with a sand matrix. They are well bedded, with cross-bedding and cut-and-fill channel structures in places, and fairly well sorted, although cobbles and a few small boulders are also present.

However, the deposits vary considerably in composition across the district and imply an origin from different source rocks.

The sediments on the Rossington Ridge contain abundant ‘Bunter ’quartzite pebbles whose only possible source is the Sherwood Sandstone of Nottinghamshire and the northern Midlands. In the absence of accompanying durable Jurassic rocks, flint pebbles are unlikely to have come directly from the east, and the only other source is the ‘chalky’ glacial deposits in the middle Trent Valley to the south.

Although the sand and gravel on the Doncaster ridge is superficially similar in composition to the clay till and glacial deposits, Carboniferous limestone, chert, Permian limestone and igneous rocks are virtually absent. Instead their constituents imply derivation from Coal Measures to the west instead of the glacial trans-Pennine origin to the north-west,.

The sedimentary features and compositions of these deposits, together with their ridge top location, which implies transport over a watershed, indicates a fluvioglacial origin with meltwater flowing from ice sheets in the south and west.

3.7.2 Ipswichian Deposits

3.7.2.1 Older River Gravel (11) [D101 — Dunsville Quarry]

Large spreads of Older River Gravel are present in the north and east of the district where they form a terrace-like area with an elevation of up to 12 m above OD. They contain sedimentary structures indicative of deposition from a fluvial environment.

These deposits consist of beds, lenses and layers of well sorted fine to medium gravel with a sand matrix, without pebbles, which include level bedding and gentle cross-bedding, and also shallow cut-and-fill channel structures. They rest mainly on Sherwood Sandstone but transgress locally over clay till and glacial channel deposits. Their top, whether at outcrop or concealed beneath younger deposits, is commonly severely cryoturbated and strewn with ventifacts.

There is a wide variation in the composition of the sand and gravel and this, in addition to variations in palaeocurrent directions, indicates different geographical origins. To the north–west of Doncaster at Edenthorpe, Armthorpe and Dunsville and along the Don Valley, the pebbles mainly comprise Carboniferous sandstone and suggest deposition by fluvial activity of the river Don.

To the south-east of Doncaster at Blaxton, Finningley and Austerfield, the pebbles mainly comprise ‘Bunter’ quartzite, deposited by the rivers Idle and Thorne which flowed from the south.

Fossiliferous deposits within the Older River Gravel near Austerfield and Armthorpe have provided good evidence of the palaeoenvironment. Wood fragments, fruits, pollen and seeds indicate oak, pine, hazel, birch and alder in a temperate environment. Other non-tree pollen suggest freshwater and saltmarsh habitats, with dinoflagellate cysts and forams also implying an estuarine tidal reach.

3.7.3 Devensian Deposits

The Devensian cold Stage started approximately 120 000 years ago and, using modern radiocarbon dating techniques, is considered to have ended about 10 000 years ago.

During this time, the region was subjected to severe periglacial conditions when the land was generally deeply frozen. At the start and end of the Devensian Stage, there are distinctive sedimentary and topographical structures that are termed the Lower and Upper Periglacial Surfaces.

Four types of non depositional evidence reflect these conditions. They are cryoturbation structures, alases, ventifacts and desert pavements and all are important features that have enabled geologists to interpret climatic conditions throughout the northern hemisphere.

Cryoturbation structures are subsurface disruptions resulting from freezing and thawing of groundwater in what is called the active layer. Alases are wide, shallow, steep-sided, flat- bottomed depressions, commonly circular or oval in shape, as seen in the West Moor depression. Ventifacts are stones, generally of large pebble size or bigger, that have been shaped by prolonged impact of wind-blown sand grains and possess flat facets with sharp edges. Desert pavements are the remnants of rock debris after lighter particles have been blown away by wind.

Position of Lower Periglacial Surface

3.7.3.1 Glacial Sand and Gravel (10)

Small outcrops of glacial sand and gravel run in a line from Thorne to Wroot. The deposits contain pebbles consisting mainly of Carboniferous sandstone and Permian limestone, with a few of other Carboniferous rocks including limestone and chert, and rare Lake District rocks, indicating a provenance from the north-west.

The deposits share their stratigraphical position between the two periglacial surfaces with the lacustrine sand and gravel which, as described below, were formed in and around Lake Humber when at its maximum level of about 30 m above OD in the late Devensian. It is highly probable that the ice surged transiently into the lake and deposited sand and gravel, mainly along its western and southern edges, as it melted.

3.7.3.2 Lacustrine Sand and Gravel Deposits (9)

Sand and gravel deposits with compositions similar to older sediments described above occur throughout the area, but are not detailed on the current geological map.

Around Burghwallis, Cusworth and Askern, these comprise angular to subrounded pebbles of Permian limestone in a grey silt matrix and at Bentley, there are also Carboniferous rocks. Further south, at Rossington, Bawtry and Austerfield, as seen in sand and gravel pits, there is a predominance of ‘Bunter’ quartzite pebbles.

These deposits indicate an origin by reworking of pre-existing deposits in situ, with no input of sediment from outside the immediate locality and imply deposition as beach deposits at the edge of Lake Humber. Throughout the district, these deposits occur at 27 m OD and it is a striking fact that dry valleys, which are frequent in the Permian limestone, all terminate at about this level.

3.7.3.3 Glaciolacustrine Deposits (Silt and Clay) (8)

Known previously as the 25 Foot Drift but now termed the Hemingbrough Formation, this vast expanse of loose, unconsolidated sediment forms most of the flat plain of the southern part of the Vale of York that, in Doncaster, covers most of the low lying areas or flat land east of the A1.

It essentially comprises a sequence of silt and clay with some fine grained sand deposited in and at the edges of Lake Humber, which was formed as the result of a blockage of the established river drainage system by an ice sheet that had encroached from the north-east. The details of this important period in Doncaster’s recent geological history need to be the subject of extensive field survey work and research but a brief summary of knowledge acquired to date is as follows:

Silt and Clay: These beds comprise fine grained grey to red sediment with low-angle cross- bedding and ripple structures that contain virtually no stones. The sporadic stones that do occur are ‘drop stones’ that have been deposited from melting ice.

Marginal Sand: The sand is fine and rarely medium grained, often with silt, clay, abundant coal particles and, in some areas, a few small pebbles.

It is often not easy to distinguish either of these, as they pass laterally into one another but they were both formed in a relatively placid environment, undisturbed by the influx of high energy, rapidly flowing rivers.

3.7.3.4 Glaciolacustrine Deposits (Sand) (7)

Resting on the deposits described above, sand forms discontinuous, low ridges and mounds around Hampole Beck, Braithwaite and Fishlake, with silt, clay and coal particles at their margins. Many of these landforms are adjacent to present rivers and suggest that these are levees which indicate that Lake Humber had partly filled with sediments and drained so that rivers, now recognisable in modern times, had begun to make their mark on a flood plain. An increasing abundance of sand dunes indicates the action of wind upon an increasingly dry land surface and many of the deposits can be interpreted as fluvio-aeolian.

3.7.3.5 Head (6) [D20–22-Cadeby Cliff/Constitution Hill; Dr4-Nearcliff Wood

Quarries]

Head deposits are mainly associated with the older Quaternary deposits or with exposed bedrock within the area. They are generally unsorted gravels and clays that are the product of reworked local glacial and fluvioglacial sediments. They are found in valley bottoms and generally represent re-deposition of material, by freeze and thaw conditions (solifluction) and hillwash in a periglacial environment.

3.7.3.6 River Terrace Deposits (5)

River terrace deposits are present in the north-west of the area near Bentley and around the river Don, where the clast component is predominantly of Carboniferous rocks. Further to the south- east, especially at Austerfield, quartzites derived from the Sherwood Sandstone Group are the main constituent. Together, these sediments are intimately linked with events that were taking place in the Vale of York and terrace river valleys.

Position of Upper Periglacial Surface

3.7.4 Flandrian Post-Glacial Deposits

3.7.4.1 Blown Sand (4)

Blown sand is extensive in the north-east of the district, where it forms thin spreads of fine- grained silty sand, but much is largely concealed beneath and alluvium. It is characterised by its fine-grained, well-sorted nature and forms linear and crescentic dunes, often with horns that provide evidence of the wind direction. The sand is often associated with the formation of river levees and these are seen along the River Torne from Auckey Common to Wroot.

The sand overlies both Sherwood Sandstone and glaciofluvial sediments and was formed after Lake Humber drained and dried up.

3.7.4.2 Alluvium (3)

Extensive areas of alluvial deposits are present in the area associated with all the main drainage courses. In the Doncaster area it is associated with the River Don, but also spreads out into low- lying area of Potter Carr to the south of Doncaster. Along the River Don, the alluvium is up to around 6 m thick. By comparison, the large ponded areas of alluvium are only 3 or 4 m thick and are mainly concentrated in a belt along the junction of the Sherwood Sandstone Group and the Roxby Formation. In the north-east of the area the alluvium associated with the east of Hatfield Moors is much thicker than the other rivers of the area and reaches around 6-8 m.

In the deeper parts of the former alluvial channels much of the deposit consists of sand and silt, commonly with a gravelly base. The alluvium becomes increasingly clayey upwards; the surface deposits of the major rivers consist of silt, but this grades away from the rivers into stiff, heavy and commonly peaty clay. The upward-decreasing coarseness of the alluvium reflects decreasingly energetic fluvial deposition in the incised river courses as sea level rose rapidly in the Humber region during the Flandrian. After the incised courses were filled with alluvium, deposition culminated in thin but extensive spreads of appreciably peaty clay and peat on adjacent low-lying areas.

3.7.4.3 Incision and denudation

Contours at and below OD on the base of the Flandrian deposits reveal a landscape in which rivers crossing the district, including minor ones, have deeply incised their courses, reaching depths of nearly 20 m below OD as they approach the Humber Gap. This vigorous fluvial incision was accompanied by little or no interfluvial erosion. It resulted from a rapid drop of regional drainage base level, when the ‘nickpoint’ of the ‘River Humber’ finally eroded through the glacial deposits in the Humber Gap to reach the soft, waterlogged sediments of the Hemingbrough Formation to the west.

3.7.4.4 Peat (2)

Peat is extensive in the east of the area, where it forms spreads resting on the flat Glaciolacustrine deposits. The peat is rarely more than a few metres thick, but on Hatfield Moors and Thorne Moors, where it has been extensively worked, it is in excess of 3 m thick. It is also commonly associated with present and past drainage courses in the centre and west of the area, notably along the length of the River Torne. A significant deposit also occurs in the West Moor depression.

The peat growth may be attributed mainly to two factors. One is the wetter climate which ensued from Atlantic times onwards, and which, particularly from the onset of Sub-Atlantic times, was conducive to raised bog development in suitable areas. The other is the waterlogged ground and poor drainage in low-lying areas produced in late Flandrian times in the Humber region by the change of sea level, which rose sharply from about 9 m below OD to between 3 m and 5 m below OD between 7000 and 6000 radiocarbon years ago, but which has oscillated within a metre or two of OD within the last 3500 radiocarbon years.

3.7.4.5 Warp (1)

Warp or “floodwarp” develops by building flood banks around field areas and artificially flooding the ground so that layers of clay and silt are built up. Over time the land can be raised by a metre or so. This can be seen around Thorne Moors. In several places on Hatfield Moors “cartwarp” has been deposited. This term refers to the process of raising the level of the land manually by transporting material into the fields and spreading it out.

3.7.4.6 River diversions

Several man-made river diversions are recognisable in the district, partly by comparing the early Flandrian courses with the present courses.

A side branch of the River Don, formerly known as Turnbrigg Dike, was constructed northwards from Thorne to the River Aire near East Cowick, at some time before 1410 beheading the lower course of the River Went at a locality which is now their confluence, south of New Bridge. The drainage alterations accomplished by Cornelius Vermuyden in 1625-27 consisted essentially of diverting two rivers. The River Torne, having previously joined the Idle near Tunnel Pits Farm, was channelled into an artificial course, the New River Torne, which joins the Trent outside the district at Althorpe.

3.8 Structure

Towards the end of the Carboniferous period, during the hiatus between Coal Measures deposition and the renewal of sedimentation in the late Permian Zechstein Sea, the Hercynian Orogeny produced gentle folding, extensive faulting, uplift and consequent erosion in the region.

In general, the pattern of folding is aligned north-west to south-east with Carboniferous strata dipping gently to the north-east, reflected in the dip and scarp topography that can be seen in exposed Coal Measures in western Doncaster to the north of the River Don. Geophysical evidence and detailed mapping of the concealed Carboniferous strata during exploration of the coal fields reveals similar trends, with the major structures being principally the Finningley syncline, the Askern-Spital anticline, with smaller similarly aligned structures to the north.

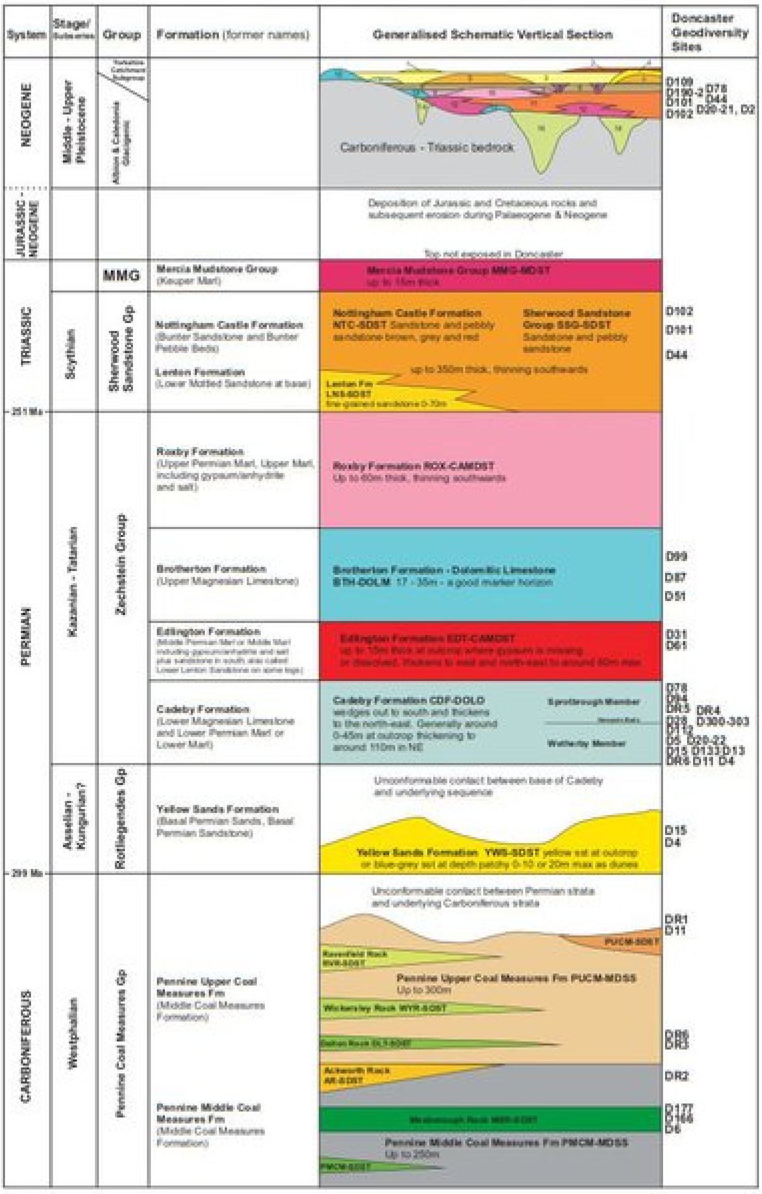
The exception is a narrow belt that extends from Rotherham to Mexborough and Cadeby, associated with the Don Monocline, which runs from the south-west to north-east and where, locally, the strata dip as much as 30 degrees to the south-east. At Denaby, this is evidenced by small but very distinctive landforms with steep dip and scarp topography.

The pattern of faulting follows the general plan common in the coalfield, in which two sets of faults at right angles and trending respectively north-west and north-east may be recognized. In the area as a whole there is nothing to choose in importance between the two groups.

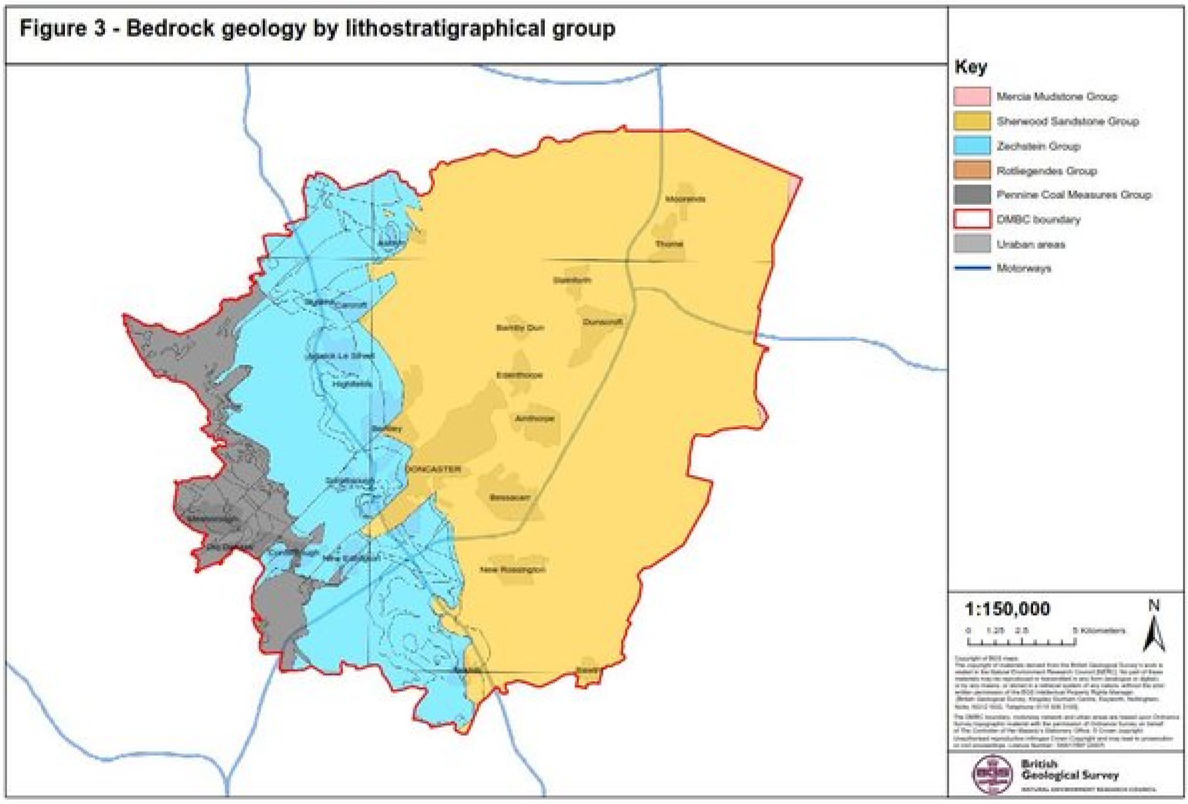
However, a belt of parallel faults trending north-eastwards, associated with the Don Monocline, have had a considerable influence on the geology and topography of the region. The most persistent of these is the South Don fault (Figure 4) which is evident at Conisbrough, Cadeby and Cusworth and has been located at several places in Thorne Colliery; it can also be traced on the NEXTMap image (Figure 9). South-east trending faults are notable along the Askern-Spital structure but whilst once important to the collieries do not greatly affect the topography of the area.

Along the limestone escarpment, particularly at Hampole, Bilham and Conisbrough, overlying Permian strata have been displaced by these faults. These along with rift, or graben, structures around Warmsworth, Balby and Loversall, in which Triassic sediments were laid down, show that movement often continued into Permian and Triassic times. The rift structures around Loversall are also associated with movement along south-east trending faults along the axis of the Finningley Syncline, where there is evidence that this area was also subjected to crustal tension and subsidence.

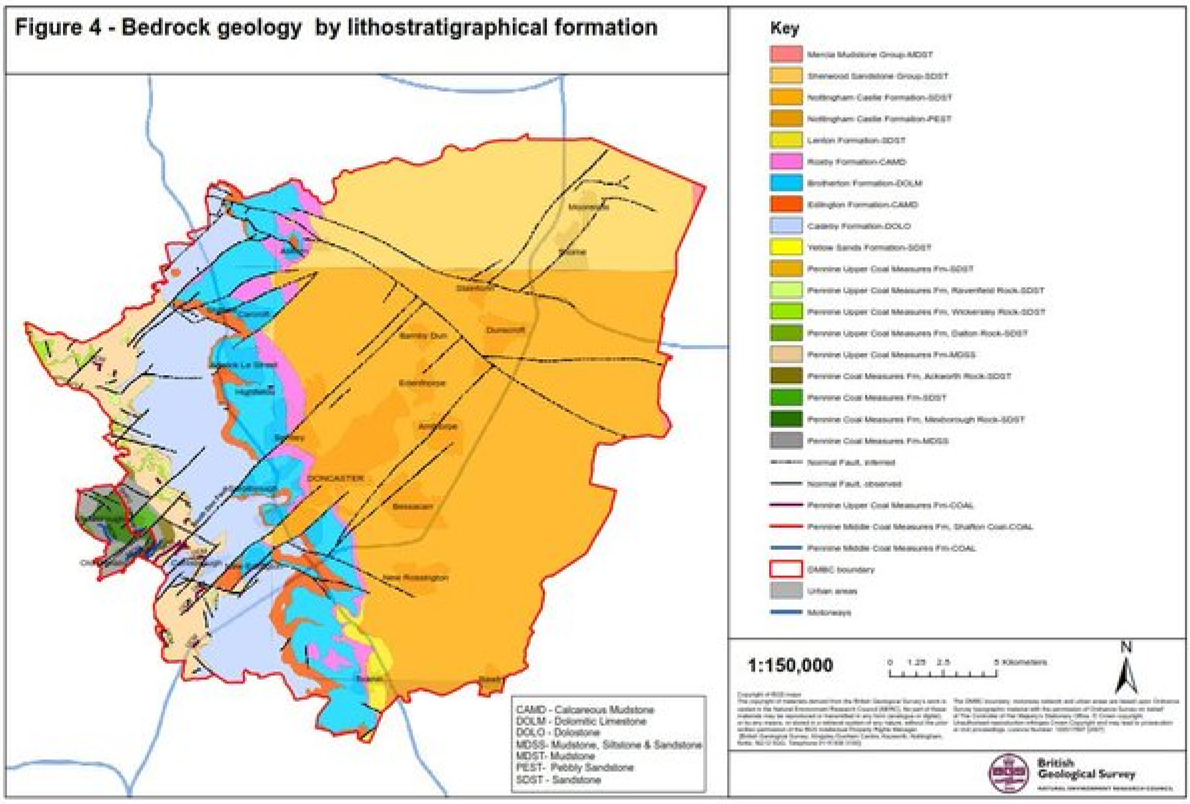
The Permian rocks rest with marked unconformity on the underlying Coal Measures and although local variations relate to earth movements that affected Carboniferous rocks, they generally have a very shallow dip to the east or north-east. Along with the overlying Triassic rocks that possess a similar dip this may partly be attributable to the continuing tilting and subsidence of the Southern North Sea Basin in which the Zechstein Sea was formed. However, evidence from younger strata to the east of the district shows that there were unrelated earth movements during the Jurassic period and post-Cretaceous times and that the dip of the Permo- Triassic rocks is probably best considered as a composite structural feature.



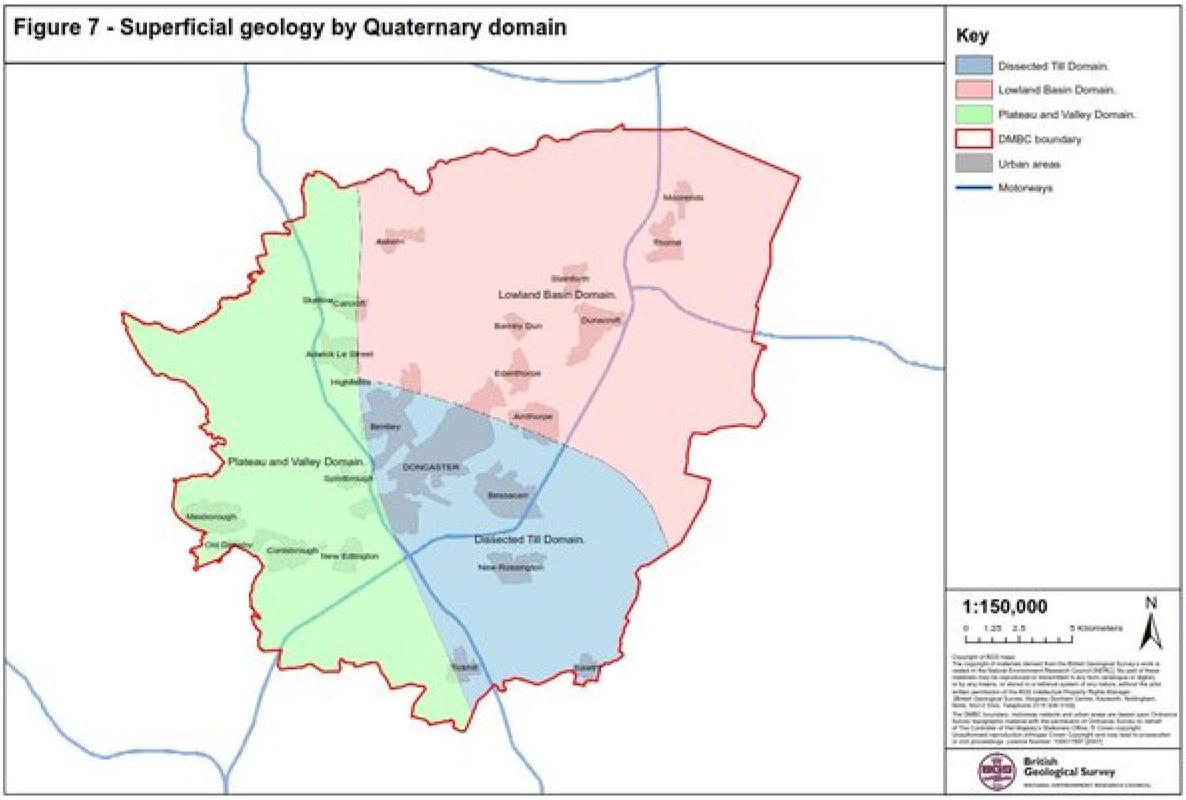
(Figure 2) Generalised vertical section of the strata exposed in Doncaster.



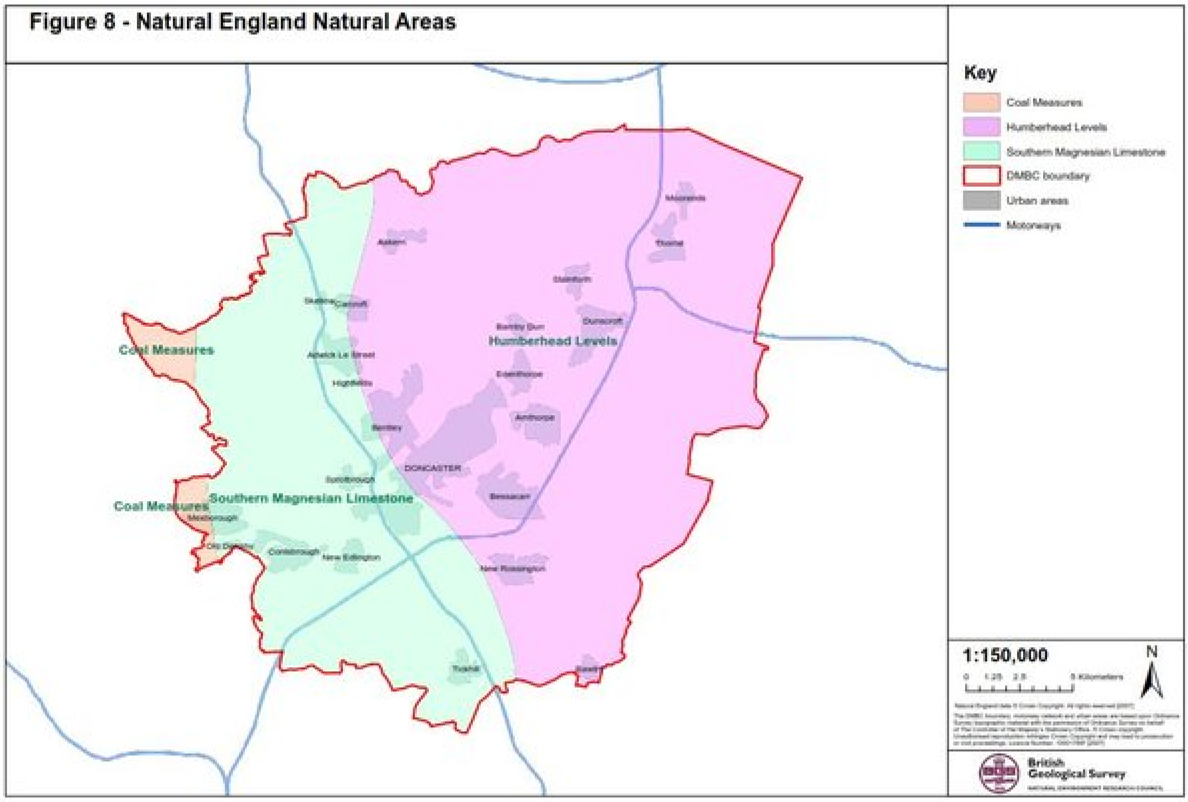
(Figure 3) Bedrock geology by lithostratigraphical group (Figure 4) Bedrock geology by lithostratigraphical formation (Figure 5) Superficial geology by lithostratigraphical group (Figure 6) Superficial deposits by lithogenetic class.



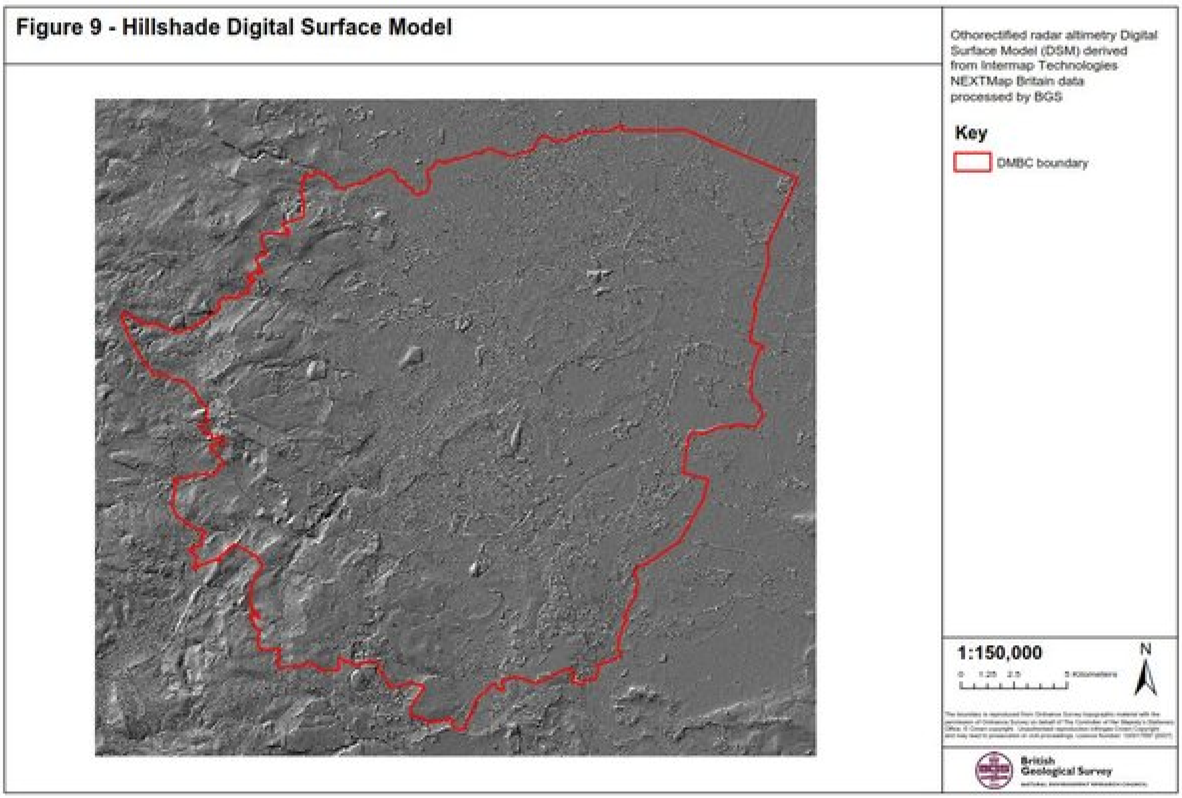
(Figure 4) Bedrock geology by lithostratigraphical formation



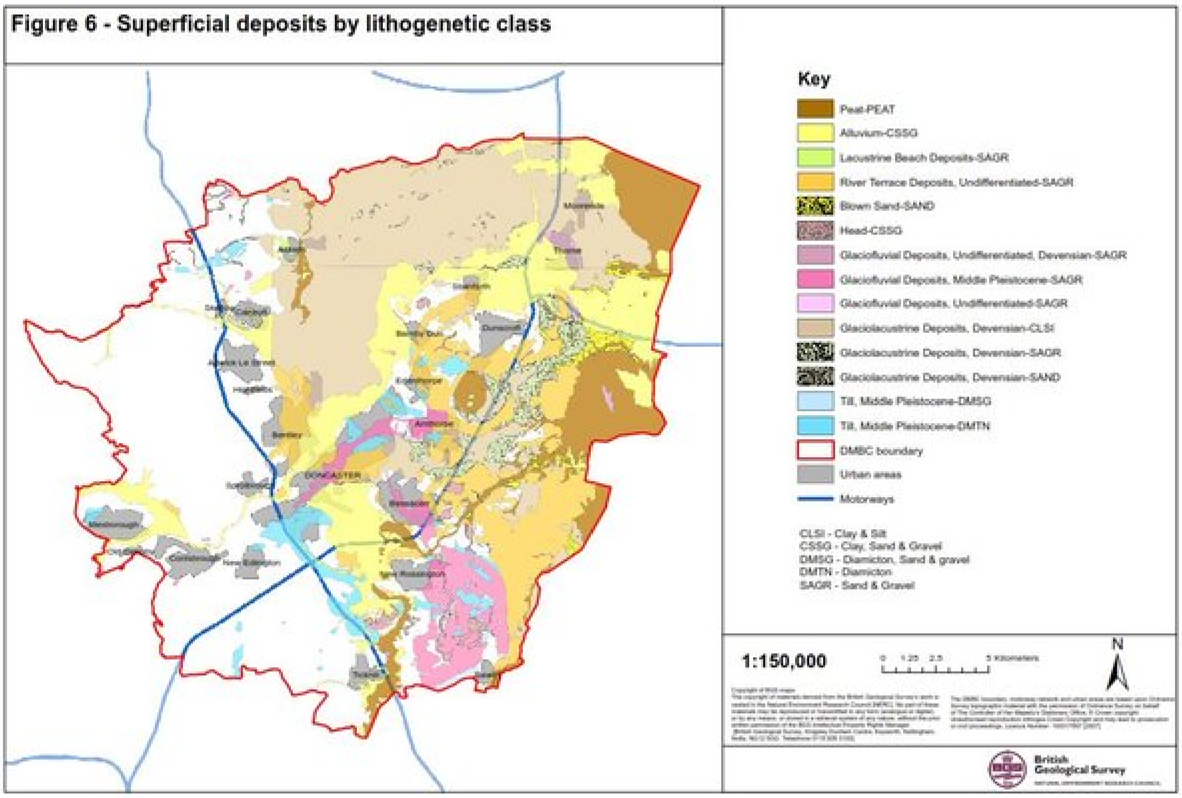
(Figure 7) Superficial geology by Quaternary domain.



(Figure 8) Natural England Natural Areas.



(Figure 9) Hillshade Digital Surface Model.



(Figure 6) Superficial deposits by lithogenetic class