Geological Evolution of Central England with reference to the Trent Basin and its Landscapes

John Carney

Abstract A fundamental geological control over development of the Trent catchment system is indicated by the preference for its trunk streams to follow the Triassic outcrop, with the older rocks mainly restricted to the interfluves. This relationship between geology and drainage is partly due to differences in the relative erodibility of the rock sequences, but also to a more subtle role played by tectonics. The most important structural elements were established during the early Palaeozoic (end-Caledonian) earth movements, but their influence persisted long afterwards.

The landscapes and drainage systems of southern Britain are widely considered to have developed during the Cenozoic Period, following the destruction of the shelf sea in which Jurassic and, ultimately, Cretaceous strata were deposited (see review in Gibbard & Lewin, 2003). When this region is studied in greater detail, however, it can be argued that its modern physiography is the culmination of a more fundamental geological inheritance, over hundreds of millions of years. The trunk streams of the Trent catchment system (Fig. 1) demonstrate this, in that they are spatially related to outcrops of Triassic strata (Fig. 2). What are not so obvious are the tectonic factors that have exerted an underlying control over drainage and landscape development. This article briefly assesses the structural framework of the Trent Basin, emphasizing the role that plate tectonics has played in controlling geological and geomorphological evolution through time.

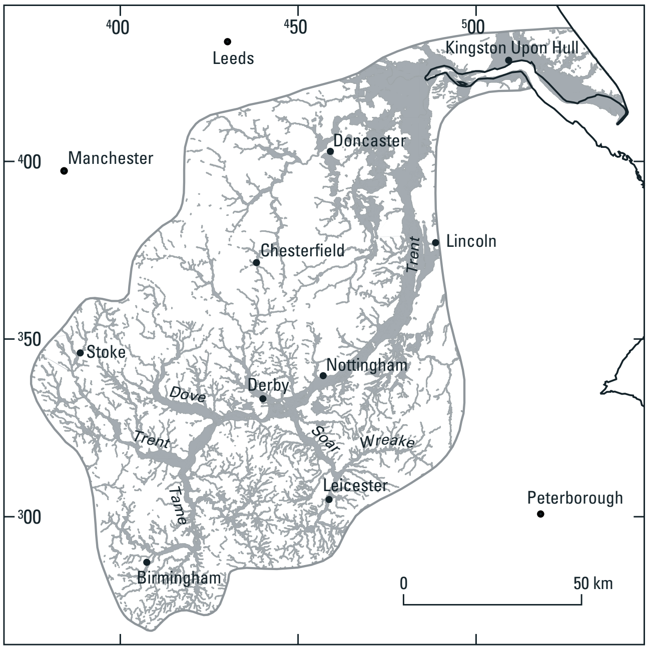

Figure 1. Distribution of Trent floodplains defined by their deposits (alluvium and 'floodplain terrace'). Extracted from BGS digital databases (DiGMapGB)

The rocks that frame the Trent Basin (Fig. 2) and its varied landscapes are the products of a complex geological history spanning at least 600 million years. They record periods of volcanic activity, igneous intrusion and sedimentation separated by episodes of deformation, metamorphism, uplift and erosion. The structural events are of particular importance because they have determined patterns of major faults that have been periodically reactivated, thereby controlling sedimentation and uplift within the region and, ultimately, in Cenozoic times, the emergence of the modern Trent catchment system. Such structures are the response of the Midlands' crust to fundamental changes in prevailing plate tectonic regimes, as England 'drifted' progressively northwards across the Equator and into the present temperate latitudes where, in the Quaternary, combinations of fluvial erosion, periglaciation and ice action have completed the Trent landscape evolution.

Precambrian to early Devonian: establishing the basement

The basement (i.e. pre-Carboniferous) rocks are the fundamental crustal 'building blocks' of England. In the Trent Basin, clues to their composition are to be found only in deep boreholes and in the series of small, structurally controlled inliers at Charnwood Forest, Nuneaton and around Birmingham (Fig. 2). The former two areas reveal Precambrian rocks, which mainly consist of volcaniclastic sedimentary strata together with massive andesites and dacites of probable subvolcanic origin, and intrusions. Chemical analyses of the more primary igneous components show that the parental magmas were similar to those of modern volcanic arcs generated above a subduction zone (Pharaoh *et al*., 1987a). They further indicate that the Nuneaton and Charnwood Precambrian sequences belong to a single, geochemically uniform basement entity, known as the Charnwood Terrane. This formed one segment of the complex Avalonian volcanic arc system situated in the southern hemisphere, off the margin of the Gondwana supercontinent, between about 700 and 560 Ma (Pharaoh & Carney, 2000).

Structural considerations suggest that by end-Precambrian times the Charnwood Terrane had become tectonically merged with chemically different volcanic arc rocks (Wrekin Terrane) seen at the Wrekin and Long Mynd. This juxtaposition occurred along a major northerly trending structure, named as the ‘Malvern lineament’ by Lee *et al*. (1991), which in this region broadly coincides with the faults defining the Knowle and Needwood Triassic basins (Fig. 4). This ‘Malvernian’ tectonic influence persisted long afterwards, and will be discussed later.

In Charnwood Forest, the Precambrian rocks form a distinctive landscape of rolling hills crowned by craggy knolls, with intervening valleys excavated in the much softer, unconformable Triassic strata. They are divided (Moseley & Ford, 1985) into two lower groups of volcaniclastic rocks, of which the younger Maplewell Group contains primary volcanic components in the form of tuffs and extremely coarse, bouldery fragmental rocks (Fig. 3). The latter are interpreted as the products of pyroclastic block flows, similar to the recent eruptions on Montserrat in the Caribbean island arc (Carney, 1999; 2000). Their presence is due to the close proximity of local Precambrian volcanic centres, which were situated in the Bardon Hill and Whitwick-Sharpley areas (Carney, 2000). The Caldecote Volcanic Formation of Nuneaton differs in containing tuffaceous beds, up to 60 m thick, characterised by abundant whole or fragmentary quartz and plagioclase crystals (Bridge *et al*., 1998). As in Charnwood Forest, these rocks are cut by two sets of quartz diorite intrusions. The youngest of these has a distinctive granophyric texture and at Nuneaton it has yielded zircons giving a Late Neoproterozoic U/Pb age of 603 ± 2 Ma (Tucker & Pharaoh, 1991). The stratigraphically higher volcaniclastic strata of the Maplewell Group in Charnwood Forest have, however, given younger U/Pb zircon ages of around 566-560 Ma (Compston *et al*., 2002). That part of the succession is famous for its fossil fauna (Boynton & Ford, 1995), which includes *Charnia*, a major index fossil of the newly-established Ediacaran Stage – the final division of Precambrian time, which is considered to have ended at c 543 Ma.

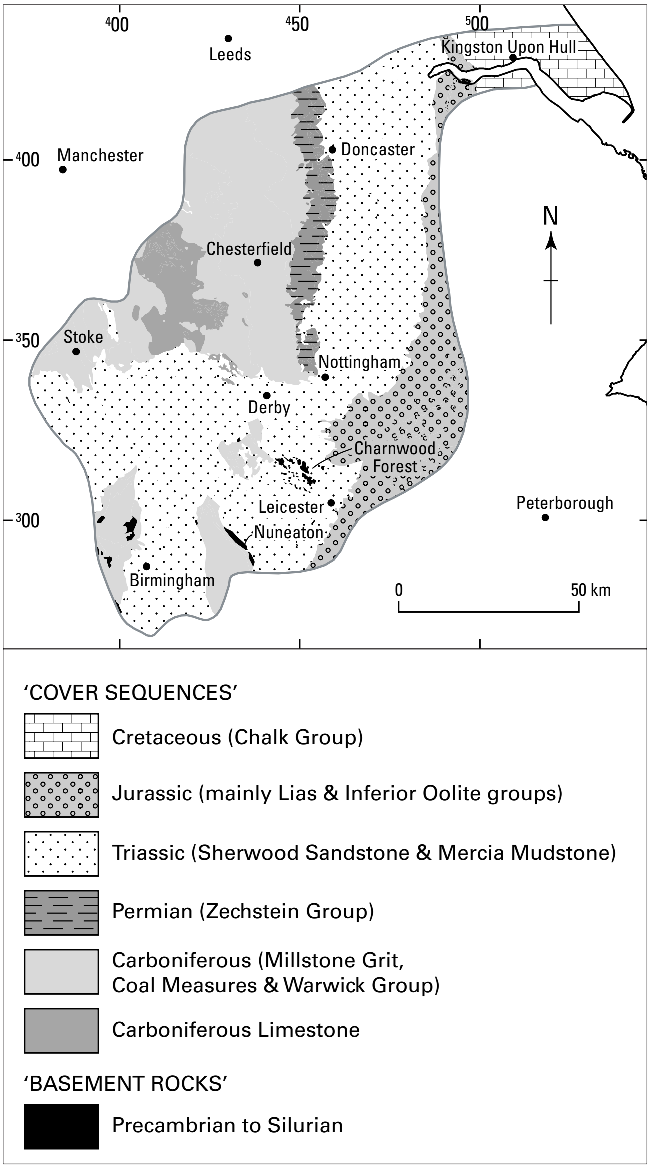

Figure 2. *Simplified geology of the Trent catchment basin*

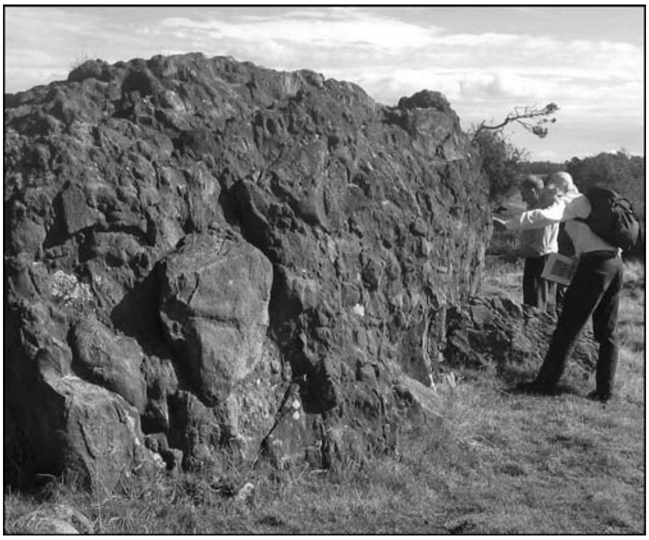

Figure 3. *Precambrian volcanic breccia at the ‘Bomb Rocks’, in the Charnwood Lodge Nature Reserve.*

By the close of the Precambrian, the various volcanic arc terranes had been tectonically amalgamated to form the elongate microcontinent of Eastern Avalonia (Gibbons & Horák, 1996; Pharaoh & Carney, 2000). The sea then invaded this eroded landmass, depositing a transgressive sedimentary sequence, the fullest development of which is exposed within the Nuneaton inlier (Fig. 2). It commences with the Hartshill Sandstone Formation, deposited in nearshore, tidally influenced environments (Brasier *et al*., 1978; Bridge *et al*., 1998), which rests with erosional unconformity on deeply weathered Precambrian rocks (Carney, 1995). Near the top, this formation contains a minor depositional hiatus represented by the Home Farm Member (‘*Hyolithes* Limestone’), a condensed sequence of Lower Cambrian age (Tommotian-Atdabanian) hosting the earliest shelly fossils to be found in Britain (Brasier, 1984). Trilobite-bearing mudrocks of the overlying Stockingford Shale Group are at least 700 m thick at Nuneaton where the topmost unit, the Merevale Shale Formation, has fossils indicative of a lowermost Ordovician (Tremadoc) age (Taylor & Rushton, 1971). Remarkably, Tremadocian mudrocks are also encountered in deep boreholes beneath Leicester (Molyneux, 1991), 33 km farther east. As borehole cores indicate that these rocks commonly dip steeply, the most likely explanation for their regional extent, without invoking extraordinary thicknesses, is that the Stockingford Shale Group has been tectonically repeated across faults and folds in a structurally complex basement.

In Charnwood Forest the suggestion of a Lower Cambrian age for the youngest, Brand Group rocks is a recent major development that has followed from the discovery of *Teichichnus*, a Phanerozoic trace fossil, on local headstones carved from quarries in the Swithland Formation (Bland & Goldring, 1995). The Brand Group may thus be a close contemporary of the Stockingford Shale Group, although there is no other faunal evidence to corroborate this.

Further rock sequences of probable early Ordovician (Tremadoc) age to the west and north of the Birmingham conurbation (Fig. 2) are represented by the Barnt Green Volcanic Formation, which includes water-laid tuffs, and the overlying Lickey Quartzite Formation, the latter probably deposited in nearshore, tidally influenced environments (Molyneux in Old *et al*., 1991; Powell *et al*., 2000). There are possible links between these isolated exposures and the more complete successions of the Welsh Basin, which includes igneous rocks generated by the subduction of Iapetus oceanic crust beneath Avalonia.

Silurian rocks are preserved only in the far west of the region, their most extensive outcrop being the inlier centred on Walsall, north of Birmingham (Fig. 2). They locally rest unconformably on the Lickey Quartzite Formation and their deposition is attributed to a marine transgression that occurred in Llandovery (Telychian) times (Powell *et al*., 2000). Silurian strata mainly consist of mudstones interbedded with limestone-dominant units, the most famous of which is the Much Wenlock Formation, exposed at the Wren's Nest Nature Reserve. The overlying mudstones of the Lower Ludlow Shales and Ledbury Formation (Pridoli age) are the youngest preserved elements of this transgressive sequence, the deposition of which would have been terminated, in earliest Devonian times, by the onset of the late Caledonian earth movements.

East of Birmingham, no strata between Tremadoc and late Devonian age have been found. However, igneous intrusions emplaced within the Precambrian, Cambrian and Tremadoc rock sequences have been radiometrically dated to Ordovician age (Caradoc to Ashgill), by Noble *et al*. (1993). Their calc-alkaline chemistry is compatible with magma generation during subduction of the Iapetus/Tornquist plate system beneath the Midlands, which then formed part of the northwards-migrating Avalonia microcontinent (Pharaoh, 1999). In the Trent region, these igneous intrusions are major sources of hard-rock aggregate and are well known from their exposures in large quarries, such as those currently operating at Croft and Mountsorrel (see article by A. McGrath, this issue). They fall into two chemically and mineralogically distinct 'clans': the Midlands Minor Intrusive Suite, of olivine-bearing lamprophyres and hornblende diorites, is exposed in quarries around Nuneaton (Bridge *et al*., 1998). Farther east are the granodiorites and quartz-diorites of the Mountsorrel Complex and South Leicestershire Diorites (Le Bas, 1972). The Mountsorrel and South Leicestershire plutonic rocks are chemically comparable with the contemporary Caradocian intrusions of Snowdonia and the Lake District, confirming the extension of the Caledonian magmatic system - the 'concealed Caledonides' of Pharaoh *et al*. (1987b) – down the eastern side of England.

Forming the structural template: late Caledonian orogenesis

This important tectonic episode is here divided into two parts a) movements that accompanied the late Silurian docking of Avalonia with the Laurentian plate along the Iapetus and Tornquist suture zones, and b) the Acadian orogeny (*sensu* McKerrow *et al.,* 2000) , which occurred some 20 Ma later, in Devonian (Emsian) times (Soper & Woodcock, 2003). The deformation created a structural template for much of the basement of southern Britain. In the Trent region, however, its effects have mainly been deciphered by considering the movement histories of the late Caledonian, and in some cases Precambrian, faults that have been rejuvenated through an extensive cover of younger (Upper Palaeozoic to Mesozoic) rocks. The orientations of these fundamental basement structures show significant variation across the Trent catchment, outining the three tectonic domains shown in the inset of Figure 4 (Smith *et al*., 2005). The least deformed domain is represented by the Midlands Microcraton, where northerly fault systems were ultimately inherited from the latest Precambrian phase of volcanic arc amalgamation along the 'Malvern lineament', discussed above. Those fault systems are truncated to the west by north-easterly structures of the Iapetus domain, representing Acadian deformation within the Welsh Basin. In the east, they are beheaded by the structures of the Tornquist domain, reflecting displacements within the concealed Caledonides basement of eastern England.

Charnwood Forest provides an important window on local Tornquist deformation, which here was particularly intense and accompanied by upper

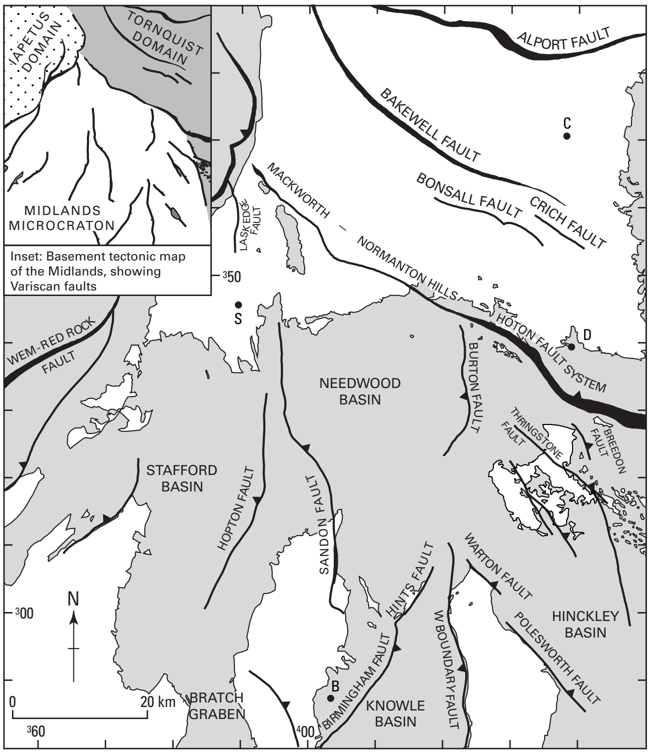

Figure 4. *Triassic outcrop (shaded) and named extensional basins, overlaid with major Variscan faults. For explanation of pre-Triassic rocks (blank areas) see Fig. 2. Inset shows the Precambrian to Palaeozoic tectonic domains that influence the underlying structure of the Trent region. Data from Smith et al. (2005). Urban conurbations shown are: B, Birmingham; C, Chesterfield; D, Derby; S, Stoke.*

greenschist metamorphism (Merriman & Kemp, 1997). The structures that resulted included north-west trending displacements, such as the Thringstone Fault and the adjacent Charnwood anticline, as well as a west-north-westerly trending, penetrative cleavage fabric (Carney *et al*., 2001). Argon isotope dating of mica cleavage fabrics suggest that in this part of Britain the cleavage, and associated folding and faulting, was actually a pre-Acadian event, which occurred in late Silurian times, about 425-416 Ma (Unpublished BGS data). The importance of these structures to the subsequent geological evolution of the region cannot be overstated; they exerted a tectonic control that persisted 'posthumously' long afterwards, and the Charnwood cleavage direction had a particular influence. It is seen in the orientation of Variscan structures such as the Mackworth-Hoton Fault System and other parallel Tornquist domain faults (Fig. 4), some of which remained periodically active into post-Jurassic times.

Late Devonian to end-Carboniferous: sedimentary and structural events

The sheer variety of sedimentary rocks produced during this period is a major feature of Trent Basin geology, and an important landscape agency. It also reflects the underlying influence of the Variscan tectonic cycle that was developing throughout the Carboniferous Period in response to stresses generated by movements within the Variscan suture and associated fold belt, which lay across southern Britain. This orogenic system marked the final stage in the tectonic amalgamation of the Pangaea supercontinent.

Following the fifty million years or so of erosion after the end-Silurian and Acadian uplifts, a change to at least localised subsidence in this region is detected in latest Devonian (Frasnian-Famennian) times, with the accumulation of mainly continental, fluvial deposits. These are only preserved along the western margin of the Nuneaton inlier, as the Oldbury Farm Sandstone Formation (Bridge *et al*., 1998). Progressive crustal extension subsequently affected the north-east of the region, where Eastern Caledonide, 'Tornquist' structures predominate (inset, Fig. 4). Deep, sediment-filled, asymmetric grabens were formed, controlling the syn-rift phase of Carboniferous deposition (Fraser & Gawthorpe, 1990; 2003). Their bounding faults have west-north-westerly orientations suggesting an underlying 'basement' structural control that is related to the tectonic 'grain' produced by the Charnwood Forest cleavage direction. In the Trent area the deepest of these troughs was the Widmerpool half-graben (or 'Gulf'), in which about 5.5 km of turbiditic, mud-dominated sediment accumulated during the Early Carboniferous (Dinantian) Period (Carney *et al*., 2001) along the northern, hangingwall side of the Mackworth-Hoton Fault System (Fig. 4). Coral reefs and carbonate shelves were established in the shallower marine environments created in parts of this tilted block and graben topography (Miller & Grayson, 1982). They belong to the fossiliferous Peak Limestone Group (formerly the Carboniferous Limestone Series or Supergroup), a major landscape-forming sequence exposed within the core of the Pennine Anticline (Fig. 2).

By Namurian times crustal extension had largely ceased, heralding the commencement of the 'post-rift' tectonic phase, characterised by regional thermal subsidence (Fraser & Gawthorpe, 1990). Sediments filled in the remaining basins, eventually expanding outwards across the bounding faults. Turbiditic mudstones, siltstones and sandstones of the Edale Shales (now the Bowland Shale Formation) were the initial products of this cycle. They were followed by the southwards encroachment of deltas that deposited the thick, feldspathic sandstones of the Millstone Grit Group. The resistance of these sandstones to erosion, compared with the intervening mudstone beds, produces the spectacular 'edges' that dominate the landscape of the Dark Peak (Fig. 5). Subsequently, during the Westphalian Carboniferous Epoch, a vast, featureless, equatorial delta plain occupied the gradually subsiding Pennine Basin (Fig. 8A). The strata deposited, belonging to the Pennine Coal Measures Group, mostly comprise repeated sedimentary cycles (Guion *et al*., 1995), commencing with dark grey to black, lacustrine or marine

Figure 5. *Burbage Edge, Derbyshire; typical upland Carboniferous scenery developed on tilted sandstone beds of the Millstone Grit Group. The slope below the sandstone exposure is veneered by a periglacial waste-mantle of Late Devensian age.*

mudstones passing upwards into sandy siltstones of overbank or lacustrine delta facies, then into channel sandstones that are commonly surmounted by a seatearth (palaeosol horizon) and coal seam (swamps and mires). This lithological diversity, when combined with later erosion, has produced a strongly featured terrain that is typical of all Coal Measures outcrops.

It is tempting to attribute this essentially quiescent geological interval to the absence of local tectonism; however, 'growth' faults have been recognized in Westphalian strata, and to the east of the region, in the Vale of Belvoir area, boreholes show that virtually the whole of the concealed Lower Coal Measures sequence was replaced by low-angled shield volcanoes. From these were erupted 'within-plate' -type alkali olivine basalt lavas and peperitic breccias (Kirton, 1984; Carney *et al*., 2004), a style of volcanism that is commonly associated with fissure activity, implying at least localized extension. Coal Measures deposition was terminated by tectonic movements that ushered in better-drained, alluvial environments in which were deposited the predominantly red-coloured mudstones and sandstones of the Warwickshire Group (formerly 'Barren Measures). These Bolsovian to Stephanian sequences are exemplified by the exposures in the South Staffordshire and Warwickshire coalfields, west of Birmingham and Nuneaton respectively (Fig. 2). The reddened, ferruginous palaeosol horizons distinctive to many parts of this group signify deep weathering associated with emergence. Uplift was probably in part fault-controlled, and was a prelude to widespread inversion of the Pennine Basin during the culmination of the Variscan Orogeny in latest Carboniferous to earliest Permian times (Besly, 1988).

The end-Variscan uplifts are most obviously manifested by the fold that formed the limestone-cored Pennine Anticline in the north (Fig. 2). Different structural styles prevailed farther south, however, in the area occupied by the Midlands Microcraton basement block. There, the Pennine Basin Coal Measures were inverted as a series of synclinal structures, the margins of which are both defined and controlled by faults which, with predominant northerly trends (Fig. 4), reflect the underlying but persistent influence of structures associated with the 'Malvern lineament' Precambrian terrane boundary. Intervening between the inverted 'coalfield synclines' were uplifted massifs composed of Precambrian and Lower Palaeozoic basement rocks (Fig. 8B). In the Tornquist structural domain the associated faults and fractures acted as conduits for the expulsion of hot, metal-rich basinal fluids that gave rise to the Derbyshire lead and fluorspar mineralisation (e.g. Ford, 2001), and many faults were bordered by inversion anticlines that favoured oil migration and accumulation, with important economic consequences for the East Midlands (Fraser & Gawthorpe, 2003).

Permian to end-Triassic: sedimentation and structural development

Throughout much of the Permian Period, of almost 40 million years duration, the land surface of eastern England was undergoing erosion within an arid, rock-desert located just to the north of the Equator, in the heart of the Pangaea supercontinent. Late in Permian times, however, marginal marine sedimentation occurred as the Southern North Sea Basin encroached across the northern parts of the Trent region. Strata of the Zechstein Group were deposited (Fig. 2), their main representative being the Cadeby Formation (Lower Magnesian Limestone), which forms the escarpment overlooking the Nottinghamshire-Derbyshire coalfield at places such as Bolsover.

By earliest Triassic times, crustal extension associated with the lead-up to Atlantic opening triggered widespread subsidence across the northern margin of Pangaea (Chadwick *et al*., 1989). In the west of the Trent region this subsidence was greatly accentuated by the development of deep, fault-bounded extensional basins (Fig. 8C). Figure 4 shows that the distribution of these basins was in large part controlled by the rejuvenation of pre-existing Variscan or earlier structures within the Midlands Microcraton, particularly those with inherited northerly, 'Malvernian' orientations; for example, the Hopton, Sandon, Burton and Western Boundary faults.

Three phases of sedimentation deposited the Triassic strata that dominate the Trent valley catchment geology (Fig. 6). Initially, major rivers flowed from the south (Warrington & Ivimey-Cook, 1992), exploiting the developing extensional basins and depositing sandstones and conglomerates of the Sherwood Sandstone Group. These strata, which are major aquifers, host the famous caves of Nottingham (Waltham, 1996), and form the many exposures around Nottingham University campus (Howard, 2003). The magnitude of differential subsidence during this earliest part of the Triassic is exemplified by the 760 m of sandstone present in the Knowle Basin (Powell *et al*., 2000), as opposed to the 50-150 m thickness range that is typical outside such basins.

Later in the Triassic Period, intensely arid climatic environments characterised deposition of the Mercia Mudstone Group. The widespread distribution and thickness of these strata is attributed to regional crustal downwarping that created a basin in which the Triassic sediments were confined and preserved, allowing them to thicken and eventually to completely cover remaining topographical elements, such as the Precambrian mountainland of Charnwood Forest. In the latter area, the basal Triassic unconformity is spectacularly displayed in Bardon Hill Quarry (Fig. 7), and at Buddon Wood Quarry, Mountsorrel (*this issue*). It is the locus of sporadic mineralization that includes base metals (Pb-Cu-V-Mo) and, more rarely, gold and silver (King, 1968). The red-coloured Mercia Mudstone strata that are so distinctive to the landscapes of the Trent catchment have been compared with loess-type deposits, and latterly (Jefferson *et al*., 2002) with the modern 'parna' of the south-eastern Australian desert. A complex of mainly continental environments is represented, albeit with occasional marine influences, in which were accumulated thick sequences of red-brown or rarely green-grey mudstone of aeolian to lacustrine origin, punctuated by fluvial episodes that deposited beds of green-grey dolomitic siltstone and sandstone, commonly referred to as 'skerries' because of their relative hardness and resistance to erosion. Higher in the group, evaporitic conditions are indicated by the incoming of gypsum, of local commercial importance.

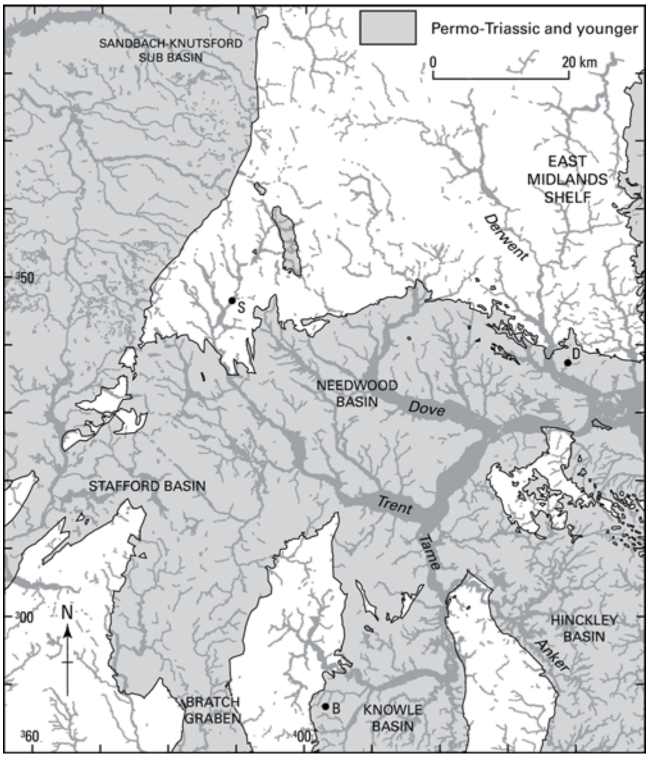

Figure 6. *Outcrop of mainly Permo-Triassic strata (shaded), with named Triassic basins (see Fig. 4), in relation to the distribution of Trent floodplain deposits.*

The Penarth Group, of Rhaetian (latest Triassic) age represents the final phase of sedimentation. These predominantly argillaceous strata are of marginal marine facies (Swift & Martill, 1999) and represent the initial deposits of a major transgression. They form a small but conspicuous escarpment feature throughout the Trent region.

Jurassic to Cretaceous: submergence of the Pangaea margin

Marine conditions persisted throughout the Trent region during this 140 million year interval. Jurassic strata of the Lias and Inferior Oolite groups are the main survivors of later Cenozoic erosion. They are disposed within a 'wolds'- type landscape of cuestas and dip-slopes on the eastern margin of the Trent catchment (Fig. 2). In part, their outcrop limit determines the course of the Trent as it approaches the Humber estuary (Fig. 1). The grey mudstones of the Lias Group accumulated in the warm, shallow, sub-tropical sea that was now established across the East Midlands Shelf. The waters deepened with time, leading to better oxygenation and a transition into hemipelagic shelf environments (Weedon, 1986) that supported a diverse fauna of ammonites and bivalves. The Marlstone Rock Formation gives rise to a particularly dramatic escarpment overlooking the Vale of Belvoir, and has been a major source of ironstone and building stone. With its locally prominent cross-bedding, the unit represents one of the shallow water, regressive episodes on the East Midlands Shelf. A later regression is recorded by the Northampton Sand Formation, which is basal to the Inferior Oolite Group (Hallam, 2001).

Cenozoic uplift and erosion: the modern landscape emerges

Cretaceous strata probably accumulated across the whole of the Trent region during the final stages of the Pangaea shelf sea; however, little is known of their final extent or age because they were largely removed during 60 million years of Cenozoic erosion (Green *et al*., 2001). The latter study suggested at least two episodes of uplift, which are usually attributed to a combination of tectonic events: the opening of the Atlantic Ocean and compression transmitted from the Alpine Orogeny, which developed from the middle Cenozoic onwards. Recent work suggests that the Cenozoic tectonic regime was asymmetric, involving a principal axis of uplift along the western seaboard of England (Bott & Bott, 2004). This produced eastward tilting, about one degree, or less, on average, that allowed erosion to etch out the scarp and dip-slope topography that characterises the 'wolds' landscape on the Jurassic and Cretaceous outcrops in the far east of

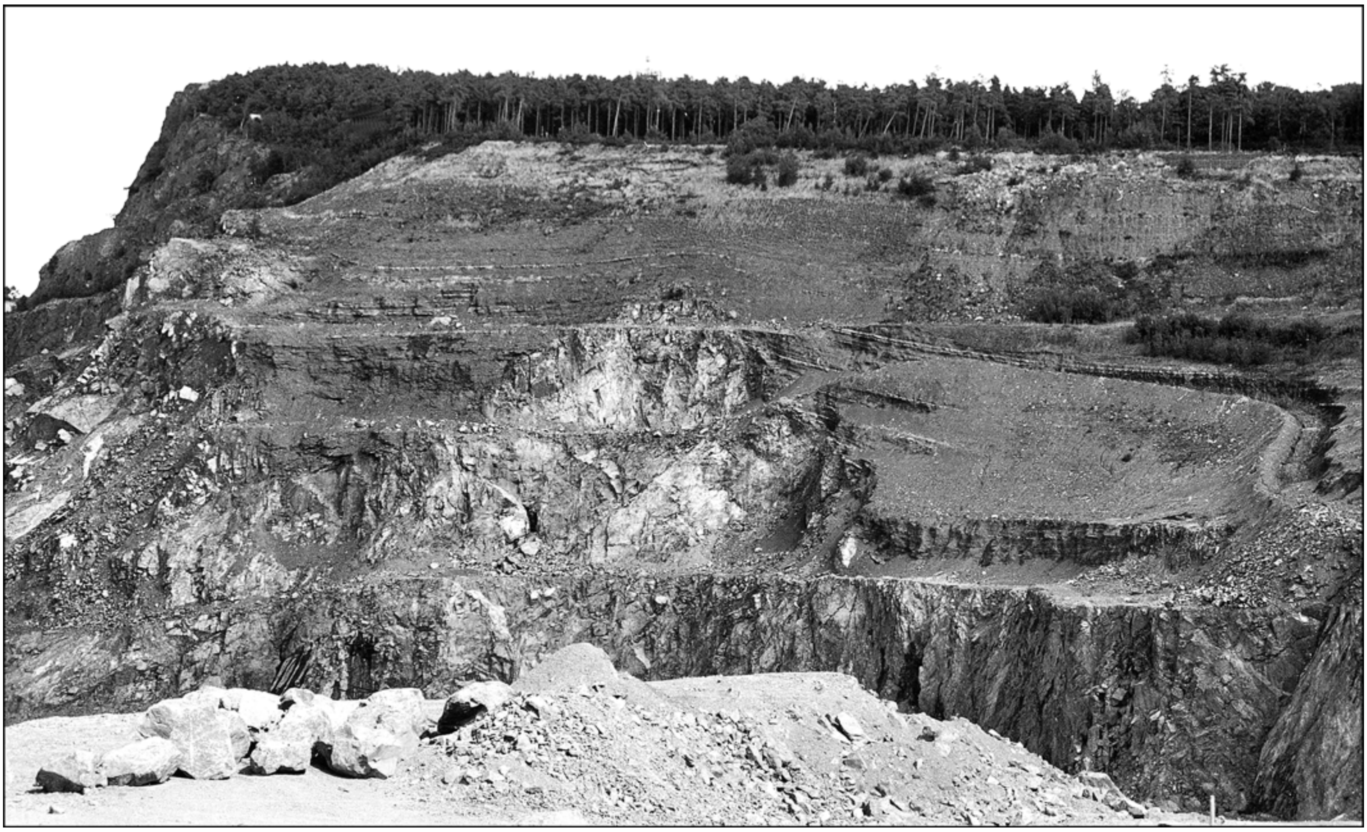

Figure 7. *Early Triassic palaeovalleys excavated on a mountainous Precambrian landsurface and filled with Mercia Mudstone strata, revealed on the east face of Bardon Hill Quarry, Charnwood Forest.*

the Trent region. The tilting initiated systems of east-flowing trunk streams, which were the main agencies for dissecting and removing the Jurassic and younger sequences (Gibbard & Lewin, 2003). One of these systems was the Bytham (or 'proto-Soar') River, the sandy deposits of which indicate that it originally flowed north-eastwards through Leicester (Fig. 1), along the present Soar valley and thence eastwards, along what is now the Wreake valley (Rice, 1991).

The geomorphological process of drainage superimposition, acting on uplifted and tilted Cretaceous strata, explains the eastward-draining river systems proposed by Gibbard and Lewin (2003), and elements of this direction are indeed represented in central England; for example the upper and middle Trent and Dove rivers. This pattern is, however, disrupted in parts where the trunk streams follow northerly courses, as shown in Figure 6. The most obvious control over this deflected drainage pattern is geological structure, with the northerly flowing streams favoured by the former sites of early Triassic rifting; for example, along the Knowle and Hinckley basins, Bratch Graben and parts of the Needwood Basin. This control was most probably facilitated by reactivation of the Triassic structures with Variscan inheritance that originally delineated these basins (Fig. 4). Thus as it was being uplifted and tilted, the Jurassic to Cretaceous cover strata were in places subsiding along fault-controlled troughs (Fig. 8D), the formation of which would have interfered with and locally deflected the easterly-flowing, superimposed river courses. There is abundant evidence in the Trent region for such post-Triassic fault reactivation (Smith *et al*., 2005; figure 44), including displacement of the youngest-preserved (Lower Jurassic) strata; for example by the Princethorpe and Whitnash faults north of Warwick (Old *et al*., 1987).

Quaternary drainage development

The progressive northwards drift of the Eurasian Plate throughout the Cenozoic Period, acting in combination with other factors, culminated in the onset of colder climatic conditions early in the Pleistocene Period. In terms of the deposits left behind in the Trent region, the most significant glaciation occurred during the Anglian Quaternary Stage, about 440 000 years ago, when ice sheets traversed the whole area, depositing locally thick 'superficial' sequences of glacigenic material dominated by till (boulder clay). BGS mapping has shown that the glacigenic deposits mantle a pre-existing topography, which includes pre-glacial valley systems such as that of the Bytham River (Rice, 1991). Thus the topography revealed following the partial erosional removal of the Anglian deposits is largely that of the Cenozoic landscape. Since ice withdrawal, however, there have been many minor, and some significant, drainage reorganisations to the pre-Anglian

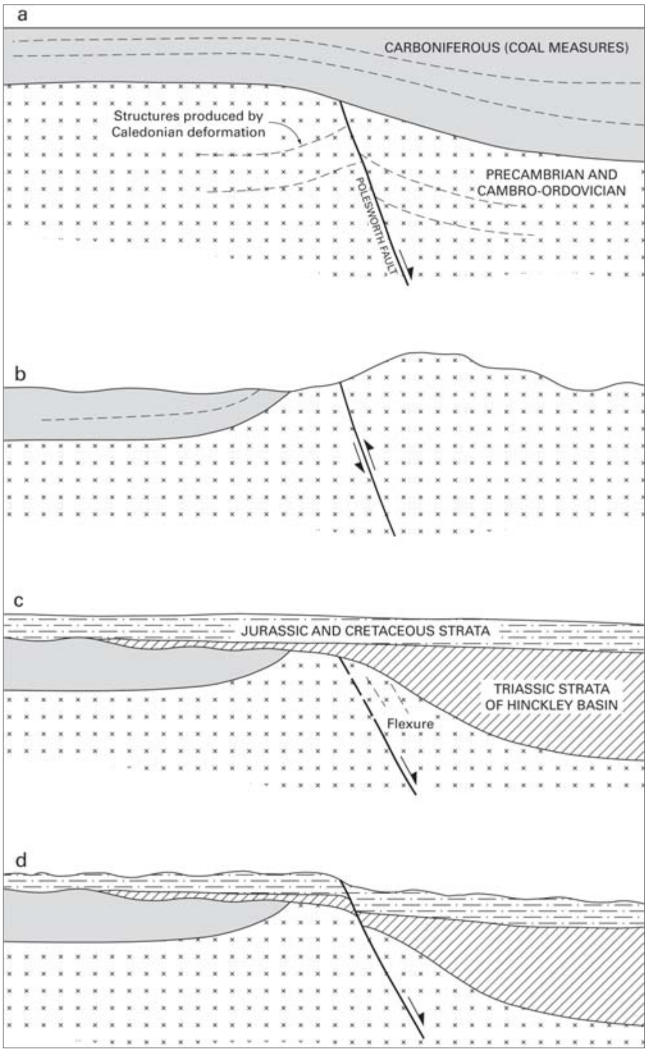

Figure 8. *Schematic rejuvenation history of a typical late Caledonian structure in Central England, using as an example the record of past movements documented for the Polesworth Fault (Bridge et al., 1998). A, possible role as a growth fault during Coal Measures sedimentation; B, end-Variscan fault rejuvenation and basin inversion; C, extensional relaxation and reversal of previous throw, with probable associated flexuring, to form early Triassic rift basins; D, further fault rejuvenation during Cenozoic regional uplift and initiation of the modern drainage pattern.*

systems. For example, the drainage in the Wreake valley (Fig. 1) was reversed to its modern westwards flowing direction.

Regional isostatic rebound and superimposed glacioeustatic fluctuations, dating from the Anglian ice withdrawal, have further influenced not only landscape development, but also the nature and distribution of fluvial deposits throughout the later part of the Pleistocene and into Holocene times. Successive aggradations and incisions over this period have resulted in a ‘flight’ of five Trent river terraces (e.g. Posnansky, 1960; Carney *et al*., 2001), each separated by a 4-7 m vertical interval. The highest and oldest terraces (Eagle Moor and Balderton terraces) have been radiometrically age-dated by Brandon & Sumbler (1991); their outcrops indicate that in pre-Ipswichian (‘Wolstonian’) times at least, the Trent must have flowed eastwards through the gap in the Jurassic escarpment at Lincoln (Fig. 1). Its subsequent diversion northwards to the Humber estuary may be a result of the younger, Late Devensian glaciation that occurred about 30 000 to 12 000 years ago, the ice front of which would have presented a barrier to drainage around the eastern, northern and western fringes of the Trent Basin. The youngest Trent terrace, the ‘floodplain terrace’ of Posnansky (1960), represents the valley-confined glacial outwash deposits of this latest cold stage; it is commonly thickly developed beneath the modern alluvium and is a major producer of sand and gravel. In Figures 1 and 6 its outcrops (named as either the Syston or Holme Pierrepont terraces) have been combined with those of the modern alluvium to provide a geology-based model of the Trent catchment in the form of its active floodplain network. This is perhaps a more realistic depiction of a river system than more conventional portrayals that are simply based on distribution of the main river channels and tributary streams. The mid-Pleistocene through to Holocene geomorphological and archaeological development of the Trent valley is summarised by Knight & Howard (2004).

Conclusions

The protracted geological history of the Trent region has played an important, albeit subtle role in determining its modern physiography. This article has documented the effects of major plate tectonic changes that have underpinned such a role, generating varied rock sequences and perpetuating structures controlling geological and geomorphological processes. The most obvious legacy of this structural evolution is a plethora of ‘weak’ crustal zones in the form of faults, folds and cleavage belts. Many of these were initiated hundreds of millions of years ago but they have persisted through time as a result of their repeated, ‘posthumous’ reactivations, a process recognised by Turner (1949). By extrapolation into Cenozoic time, it is likely that inherited structure continued to be an important geomorphological influence, imparting a differential component to uplift and tilting and contributing to the wide variety of rocks, landscapes and drainage patterns seen today in the Trent catchment.

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J. N. Carney
British Geological Survey
Keyworth, Nottingham NG12 5GG
jnca@bgs.ac.uk