The Geological Evolution of Warwickshire

Jonathan D. Radley

Abstract: The geology of the central English county of Warwickshire demonstrates 600 million years of continental drift, tectonism and palaeoenvironmental change. Neoproterozoic and Lower Palaeozoic rocks demonstrate island arc accretion, Cambrian marine transgression, and Ordovician subduction-related intrusive igneous activity. Times from Upper Palaeozoic to Triassic witnessed mainly continental environments at equatorial and circum-equatorial latitudes, including deposition of coal measures and red-beds. Latest Triassic marine transgression ultimately led to deposition of richly fossiliferous Jurassic sediments. The solid geological succession and its structure indicate several episodes of folding, faulting and erosion, influenced by deep-seated structural lineaments within the central English Precambrian basement. The modern landscape is influenced by these ancient structures and reflects Palaeogene and Neogene uplift and erosion, as well as further changes by Quaternary erosion and weathering, and glacial and fluvial deposition.

Warwickshire demonstrates remarkable geodiversity, with a mainly sedimentary succession representing roughly 600 million years of Earth history. The county is characterised by a mainly agricultural landscape of low, rolling hills and vales. Covering an area of just under 2000 sq km, Warwickshire tells a story of continental drift across the face of the globe, tectonism, climate change, biological extinctions and sweeping evolutionary changes among the region's plant and animal inhabitants. Many aspects of Warwickshire's geology are of national and international importance and have attracted the attention of researchers and collectors since the earliest days of geological investigation in Great Britain. Locally collected palaeontological specimens can be found in many local, regional and national museums and other collections. Highlights include the Cambrian faunas of the Nuneaton Inlier (Illing, 1916; Rushton, 1966; Taylor & Rushton, 1971; Brasier, 1984), Permian-Triassic, continental-freshwater, vertebrate faunas and trace fossil assemblages of the Warwick-Kenilworth district (Walker, 1969; Paton, 1974, 1975; Benton & Spencer, 1995; Tresise & Serjeant, 1997), spectacular Early Jurassic marine reptiles from southern and eastern Warwickshire (Cruickshank, 1994; Benton & Spencer, 1995; Smith & Radley, 2007), and the Middle Pleistocene fluvial-glacial succession of eastern Warwickshire with its fossiliferous channel deposits and Lower Palaeolithic stone tools (Shotton, 1953; Shotton *et al*., 1993; Keen *et al*., 2006). The county's geological history was summarised most recently by Shotton (1990). Since then, new data and interpretations have been provided principally by the British Geological Survey (BGS), through a series of revised geological maps and associated sheet memoirs.

Warwickshire sits across the outcrop of generally shallow-dipping Triassic and Jurassic strata that reaches from Devon to the Yorkshire coast (Fig. 1). Constituting the county's backbone, the Warwickshire Coalfield diversifies this pattern, forming an elevated area between the Triassic lowlands of the Hinckley and Knowle basins in the east and west respectively (Bridge *et al*., 1998). Geologically, the coalfield and adjacent Nuneaton Inlier equate to the Coventry Horst, bounded partly by the Polesworth Fault in the northeast and by the Western Boundary Fault (Fig. 2). These faults and a number of other local structures appear to be underpinned by deep-seated lineaments within the largely concealed Precambrian basement of the Midlands Microcraton (Lee *et al*., 1990). In

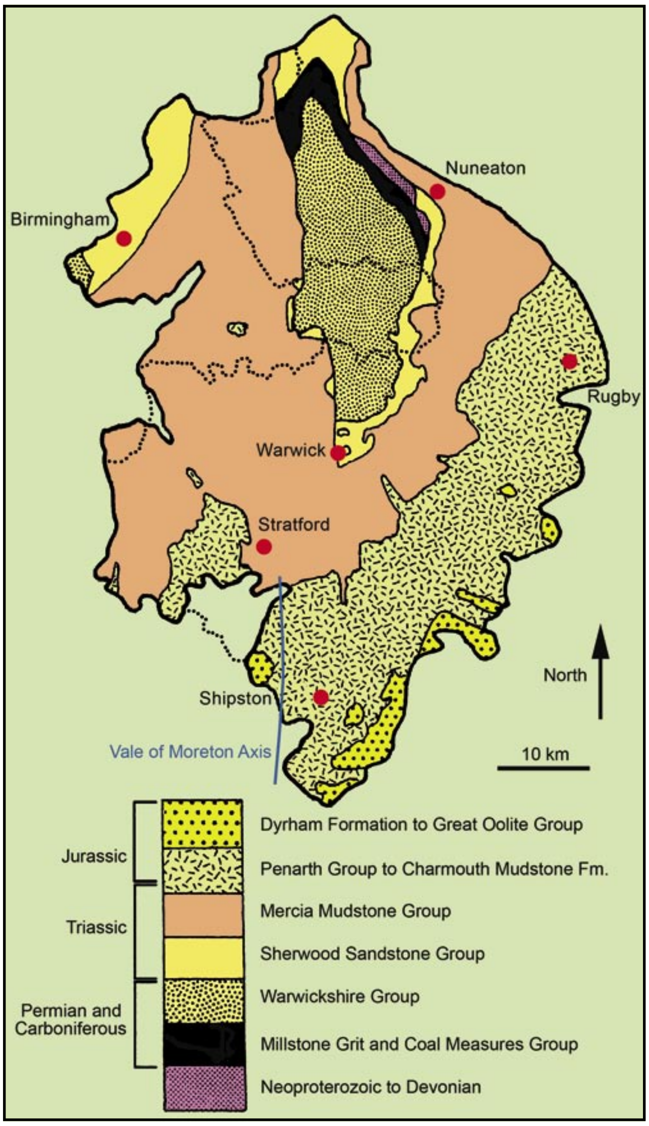

***Figure 1**. Outline solid geology of Warwickshire at its earlier extent; the new county boundary is shown by the dotted line.*

recent decades, surface and subsurface investigations, carried out principally by the BGS, have underlined the important role of such structures in regional tectonic evolution (Carney, 2007). The Western Boundary Fault (Fig. 2) has a typical, north-south 'Malvernoid' trend. This is a widespread structural grain in the West Midlands, possibly inherited from a Neoproterozoic suture zone (Pharaoh *et al*., 1987a; Pharaoh & Carney, 2000). Along the northeastern margin of the Nuneaton Inlier, the NW-SE trend of the Polesworth and Warton faults is of 'Charnoid' aspect, reflecting a proximity to the concealed Caledonides of the eastern Midlands, and also Warwickshire's position near the northern corner of the microcraton (Pharaoh *et al*., 1987b; BGS, 1996; Fig. 3).

The surface geology of the Coventry Horst is dominated by the Upper Carboniferous to Lower Permian Warwickshire Group (Fig. 1), largely comprising non-marine mudstones and sandstones developed partly as red-beds (Powell *et al*. 2000; Waters *et al*., 2007). The Warwickshire Group is flanked around the northern edge of the horst by the underlying Westphalian Coal Measures, traces of Namurian Millstone Grit and Devonian Old Red Sandstone, and steeply-dipping Neoproterozoic and Lower Palaeozoic rocks that have been extensively quarried in the Nuneaton Inlier (Taylor & Rushton, 1971; Bridge *et al*., 1998). Quaternary sands, gravels and clays are widespread throughout the county, including glacial deposits and river terrace gravels (Shotton, 1990).

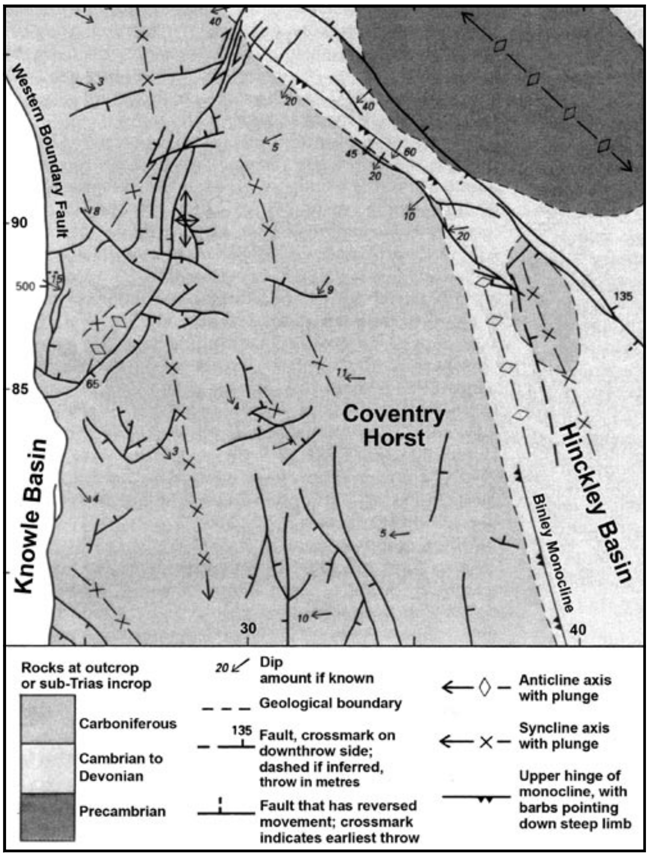

Figure 2. *Geological structure of the Warwickshire Coalfield (after Bridge et al., 1998).*

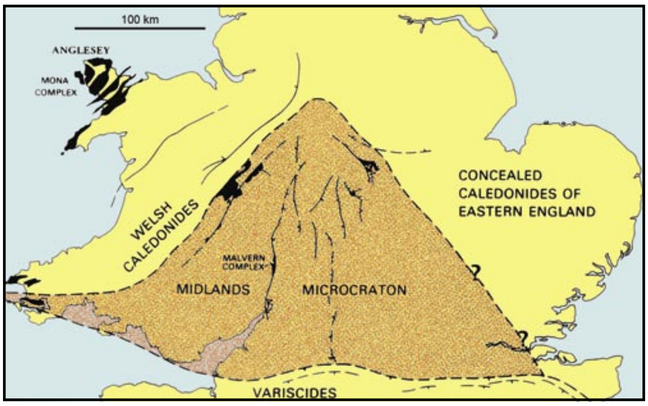

Figure 3. *Outline structural framework for the Midlands Microcraton (after Pharaoh et al., 1987b).*

Neoproterozoic

The geological story commences with the Neoproterozoic (Charnian) Caldecote Volcanic Formation that crops out within the Nuneaton Inlier along the northeastern margin of the Coventry Horst. Judkins' Quarry, north of Nuneaton, has historically provided the most extensive exposure (Fig. 4). A range of volcanic lithologies has been documented (Allen, 1968; Carney & Pharaoh, 1993). Coarser-grained, crystal-rich rocks are probably marine pyroclastic flow deposits derived from dacitic magmas; finer-grained tuffs were deposited subaqueously as ash and dust following andesitic eruptions. Radiometric dates from intrusions within the volcanic pile prove that magmatic activity terminated at about 600 Ma (Tucker & Pharaoh, 1991; Bridge *et al*., 1998). Geochemical studies show that these rocks formed part of the subduction-related Charnian arc along the western margin of the Gondwana continent; a component of the Avalonian arc complex (McIlroy *et al*., 1998; Pharaoh & Carney, 2000). Palaeomagnetism of the Caldecote Volcanic Formation indicate that it formed at a latitude of about 27.5ºS (Vizan *et al*., 2003).

Figure 4. *Northwestern end of Judkins' Quarry, Nuneaton, with tuffs and intrusive volcanic rocks of the Neoproterozoic Caldecote Volcanic Formation, overlain by well-bedded sandstones of the Lower Cambrian Hartshill Sandstone.*

Lower Palaeozoic

Some time prior to the Cambrian but postdating the local magmatic activity, the arc complex (Charnwood Terrane of Pharaoh *et al*., 1987b) had collided with others to form the microcontinent of Avalonia (Carney, 2007). This collage of island arc terranes now constitutes the crust of central England (Lee *et al*., 1990; Bluck *et al*., 1992; British Geological Survey, 1996;). Accordingly, the Lower Cambrian Hartshill Sandstone Formation rests unconformably on the slightly metamorphosed Caldecote Volcanic Formation throughout the Nuneaton Inlier, and indicates marine transgression around 520 Ma (Brasier, 1985; Carney *et al*., 1992; Rushton, 1999). At Judkins' Quarry, sandstones and conglomerates resembling beach and shoreface deposits rest on a fissured surface of volcanic rocks, tentatively interpreted as a wave-cut platform. Nearby, at Boon's Quarry, the oldest Cambrian rocks are relatively poorly-sorted sandstones resembling submarine debris flows, overlying spheroidal-weathered tuff (Bridge *et al*., 1998; Rushton, 1999; Fig. 5). The overlying strata of the Hartshill Sandstone Formation (Fig. 6) are dominated by grey, red and maroon sandstones, some glauconitic, deposited in shoreface to inner shelf environments. Continental reconstructions for the southern British Cambrian indicate a setting far south of the equator (McKerrow *et al*., 1992; Rushton, 1999; Holdsworth *et al*., 2000).

An Early Cambrian trace fossil assemblage dominated by simple trails occurs at several horizons within the Hartshill Sandstone Formation (Brasier & Hewitt, 1979), notably within the Tuttle Hill and Jee's members. The phosphatic and stromatolitic carbonates of the Home Farm Member possibly signify sediment starvation due to sea-level rise (Bridge *et al*., 1998; Rushton, 1999). Significantly they have yielded simple shelly fossils of Tommotian-Atdabanian age allowing comparison with contemporaneous assemblages in Newfoundland and Siberia (Brasier, 1984, 1985, 1992).

Figure 5. *Spheroidally weathered volcanic rocks of the Charnian Caldecote Volcanic Formation overlain unconformably by pebbly sandstones of the Lower Cambrian Hartshill Sandstone Formation in Boon's Quarry, Hartshill.*

Figure 6. *Lower Cambrian Hartshill Sandstone Formation at Midland Quarry, Nuneaton.*

Above the sandstones, the Cambrian and Early Ordovician Stockingford Shale Group was deposited in outer shelf settings following a major marine flooding episode (Bridge *et al*., 1998; Rushton, 1999). Dominant rock-types include dark-coloured blocky to fissile mudstones; some pyritic or bioturbated. Sandstone beds are conspicuous at some levels, for example within the Mancetter Shale and Moor Wood Sandstone formations. Fossils recovered from the Stockingford Shale include sponge spicules, brachiopods and trilobites; the latter proving the presence of many standard English-Welsh Cambrian biozones. At the top of the Stockingford Shale, the Merevale Shale Formation yields the graptolite *Rhabdinopora flabelliforme*, indicating the Lower Ordovician Tremadoc Series (Taylor & Rushton, 1971; Bridge *et al*., 1998). Early nineteenth century workers interpreted the Hartshill Sandstone and Stockingford Shale as Carboniferous, but the Cambrian age was proved in the 1880s by Professor Charles Lapworth of the University of Birmingham, on palaeontological grounds (Lapworth, 1882). Significantly, this work confirmed the great antiquity of the underlying Caldecote volcanic rocks.

The crust beneath southern Britain broke away from Gondwana probably during the Ordovician Period. This crustal fragment (Avalonia) drifted northwards to a latitude of around 20ºS throughout the Ordovician, a process that involved progressive closure of the Iapetus Ocean and opening of the Rheic Ocean (Woodcock, 2000a; Rushton, 1999; Cocks & Torsvik, 2002). Post-Tremadoc Ordovician sedimentary rocks are absent in Warwickshire, though Late Ordovician (early Ashgill) magmatism is seen in the lamprophyre and diorite sills of the Midlands Minor Intrusive Suite, which are widespread in the Nuneaton Inlier (Bridge *et al*., 1998; Carney & Pharaoh, 1999; Fig. 7). The intrusions locally cross-cut folds within the Cambrian-Tremadoc sedimentary succession, indicating an intra-Ordovician

Figure 7. Eastern end of Midland Quarry, Nuneaton, with intrusive rocks of the Midlands Minor Intrusive Suite, flanked by Lower Cambrian Hartshill Sandstone and overlain unconformably by bedded breccias and sandstones assigned to the Triassic Bromsgrove Sandstone Formation.

deformational phase (Bridge *et al*., 1998; Vizan *et al*., 2003; Fig. 8). The intrusions are probably a late-stage product of subduction that took place along the northern Avalonia margin, in the general area of northwest Britain (Bridge *et al*., 1998; Woodcock, 2000a). This accompanied the final stages of closure of the Iapetus Ocean which, by Late Devonian times, led to the joining of Avalonia with Laurentia and Armorica along a suture zone located within the Southern Uplands of Scotland. This resulted in the formation of Laurussia, the Old Red Sandstone Continent (Woodcock, 2000b).

Silurian strata are not seen in Warwickshire, though derived pebbles of Silurian sandstone are locally abundant in Late Carboniferous alluvial beds. This period marked a continuing drift of Eastern Avalonia towards the equator (Torsvik *et al*., 1996; Holdsworth *et al*., 2000). Thirty kilometres west of the Warwickshire coalfield, the Wenlock reefs of Dudley, West Midlands, confirm a climate of subtropical or tropical aspect. It seems likely that an unknown thickness of Lower Palaeozoic strata was eroded from the northern part of the Midlands Microcraton during mild Early to Middle Devonian (Acadian) deformation and uplift (Bridge *et al*., 1998; Woodcock *et al*., 2007).

Upper Palaeozoic

The Late Devonian Oldbury Farm Sandstone Formation of the Merevale area near Mancetter, rests unconformably upon Cambrian mudrocks (Taylor & Rushton, 1971). The Devonian age of the Oldbury Farm Sandstone (Bridge *et al*., 1998) was first confirmed on palaeontological grounds by the BGS during the early 1960s; prior to which it was thought to be Upper Carboniferous in age. The Oldbury Farm Sandstone comprises predominantly alluvial mudstones, sandstones and conglomerates featuring burrowing, mudcracked surfaces and calcrete developments. A marine interval marked by a shelly fauna indicates a late Devonian transgression from the south (Taylor & Rushton, 1971).

Carboniferous times witnessed convergence of the eastern margin of Laurussia with Gondwana, bringing central England northwards to roughly equatorial latitudes (Turner *et al*., 1985; Guion *et al*., 2000). North of the zone of major Variscan deformation, Late Devonian to Lower Carboniferous extension led to the development of an extensional basin (the Pennine Basin) bordered along its southern edge by the Wales–London-Brabant Massif (Cope *et al*., 1992; Guion *et al*., 2000; Fig. 10). In Upper Namurian times, thermal sag within the Pennine Basin (Fig. 8) was accompanied by deltaic progradation from the north, and deposition of sandstones and mudstones (Millstone Grit) unconformably on Cambrian-Ordovician rocks in an embayment along the northern edge of the massif (Taylor & Rushton, 1971; Fulton & Williams, 1988). Later, in Westphalian (Langsettian-Duckmantian) times, this area became the site of Coal Measures deposition, the strata ultimately becoming the Warwickshire Coalfield (Fulton & Williams, 1988; Guion, 1992).

The Pennine Coal Measures Group (Waters *et al*., 2007) thins to the southeast (Fulton & Williams, 1988)

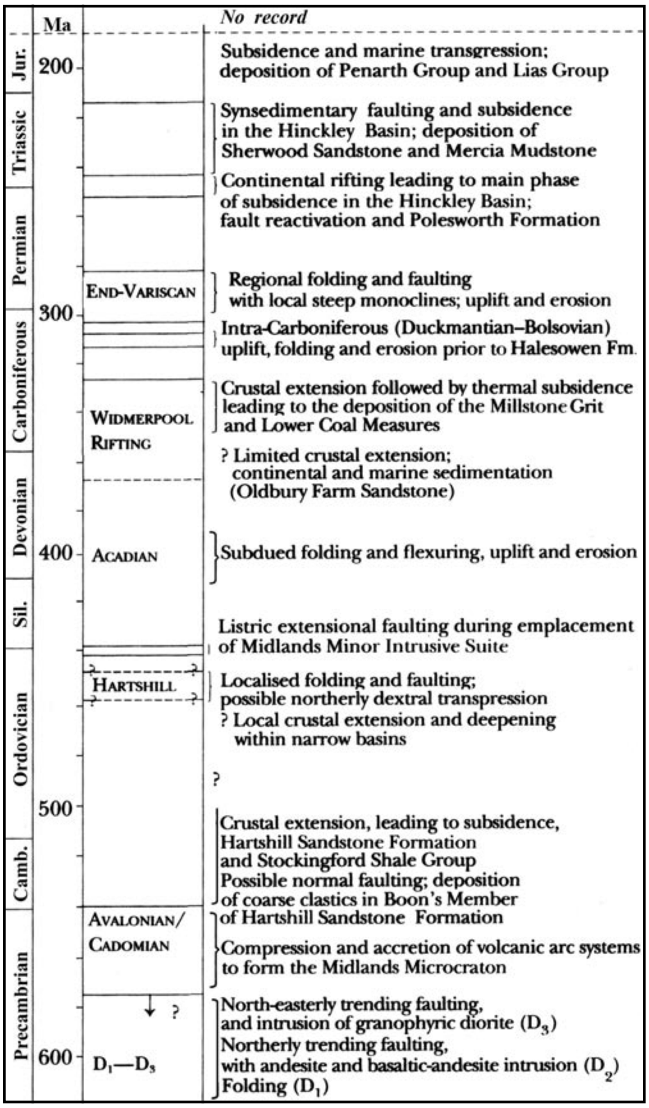

Figure 8. Chronology of main structural events in Warwickshire (after Bridge et al., 1998).

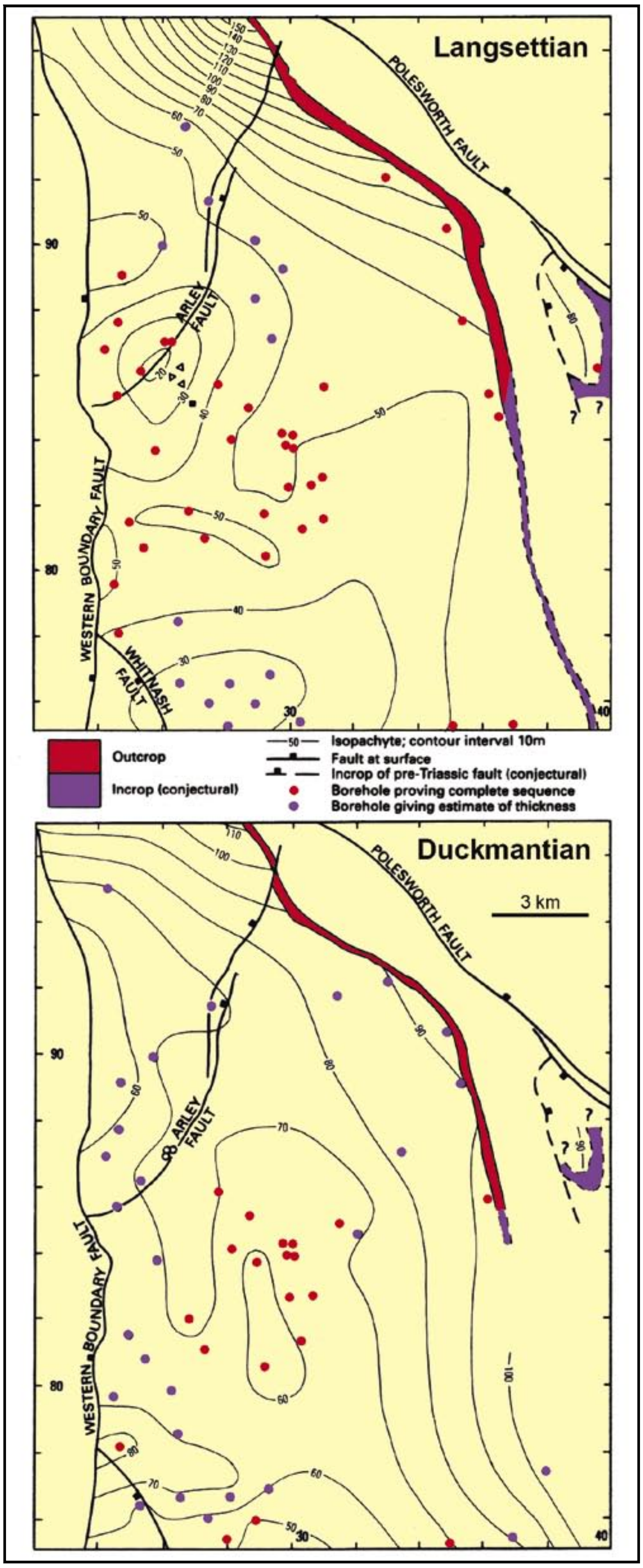

***Figure 9**. Isopach maps of Langsettian and Duckmantian (Westphalian) strata in the central part of the Warwickshire Coalfield (after Bridge et al., 1998).*

and onlaps the Millstone Grit to rest upon Cambrian mudrocks (BGS, 1994). Facies and thickness variations within coal seams, marine bands and sand bodies close to the Western Boundary Fault (Fig. 9), indicate that this structure was active in Upper Carboniferous times (Fulton & Williams, 1988; Bridge *et al*., 1998).

The Coal Measures are dominated by mudstones and siltstones with subordinate sandstones, conglomerates and coals. These sediments, their structures and enclosed plant fossils confirm a shifting mosaic of warm, humid, equatorial, lacustrine and alluvial environments (Fulton & Williams, 1988; Bridge *et al*., 1998). Laterally persistent mudstone beds were deposited in lakes, or as brackish-water 'marine bands' during episodes of eustatic sea-level rise. Peat development resulted in formation of coal seams. The Duckmantian Warwickshire Thick Coal, still worked at Daw Mill Colliery north-west of Coventry, formed by prolonged peat accumulation, sometimes as a raised mire (Fulton, 1987).

Late Duckmantian to Bolsovian times witnessed a diachronous shift from Coal Measures deposition to the varicoloured mudstones that dominate the Etruria Formation of the basal Warwickshire Group (Besly, 1988; Powell *et al*., 2000). Thereafter, the Warwickshire Group, ranging up into the Permian, is dominated by sandstones, mudstones and pebble beds of non-marine origin often developed as red-beds (Waters *et al*., 2007). This phase signifies further northward drift into a circum-equatorial arid belt (Besly, 1988).

The Etruria Formation represents well-drained alluvial plain environments (Besly, 1988; Besly & Fielding, 1989). The scarcity of coals and the occurrence of oxidised, colour-mottled and reddened mudstones confirms a shift to conditions of better drainage. The earliest of these rocks occur on the more southerly flanks of the coalfield. Adjacent to the Western Boundary Fault, oxidised mudstone and mud-chip breccia suggest development of a fault-scarp and redistribution of locally derived material into the coal basin by flash floods (Besly, 1988). Near the eastern boundary of the coalfield the Weston Farm Borehole has revealed volcaniclastic lithologies that are possibly contemporaneous with similar rocks in the South Staffordshire Coalfield to the west (Bridge *et al*., 1998).

The overlying Halesowen Formation (Westphalian D) rests on a slightly folded and eroded surface of the Etruria Formation and Coal Measures in the northern part of the coalfield (Fig. 8). It oversteps the Coal Measures to the south, resting on Lower Palaeozoic rocks in the southern part of the coalfield and west of the Western Boundary Fault (Bridge *et al*., 1998). These relationships suggest decreasing influence of the coalfield margin horsts and re-establishment of a regime characterised by gentle subsidence. The Halesowen Formation is believed to have been of southerly derivation, suggesting that the Wales-London-Brabant Massif had been reduced in relief, allowing sediment from the rising Variscan mountains to the south to be swept across it. The lower part of the Halesowen Formation is dominated by thick fluvial sandstones interbedded with coals and palaeosols including calcretes, indicative of a moderately dry climate. Mudstones predominate higher up and include the

Index Limestone. This is a laterally extensive marker bed, probably lacustrine in origin (Powell *et al*., 2000).

The Salop Formation (Westphalian D probably up to Stephanian) is marked by the widespread reappearance of red-beds, signifying a return to relatively well-drained alluvial plain environments. Three overall upward-coarsening members have been recognised, thought to represent prograding alluvial fans (Bridge *et al*., 1998). The lowest, Whitacre Member is dominated by mudstones and sandstones. Locally pebbly Arley and Exhall sandstones dominate the upper part of the member (Shotton, 1927). Red-brown mudstones and thin sandstones also dominate the Keresley Member. The highest part of the Allesley Member has yielded large pieces of silicified wood (Eastwood *et al*., 1923).

The Tile Hill Mudstone Formation crops out within the southern suburbs of Coventry and is probably wholly Late Carboniferous (Stephanian) in age. Above it, the Kenilworth Sandstone Formation crops out north of Kenilworth and is characterised by reddened alluvial sandstones. It has yielded sparse terrestrial-freshwater vertebrate remains indicative of an Early Permian (Autunian) age (Powell *et al*., 2000). Near the base, the Gibbet Hill Conglomerate includes pebbles of Precambrian tuff and Carboniferous sedimentary rocks. Breccia lenses occur towards the top of the formation (Shotton, 1929). Constituting the highest division of the Warwickshire Group, the overlying Lower Permian Ashow Formation is dominated by red-brown mudstones with thin siltstones and sandstones (Shotton, 1929; Old *et al*., 1987). The local succession appears to have been influenced by flash floods depositing sandstones, pebble beds and breccias (Old *et al*., 1987; Smith & Taylor, 1992; Benton *et al*., 2002).

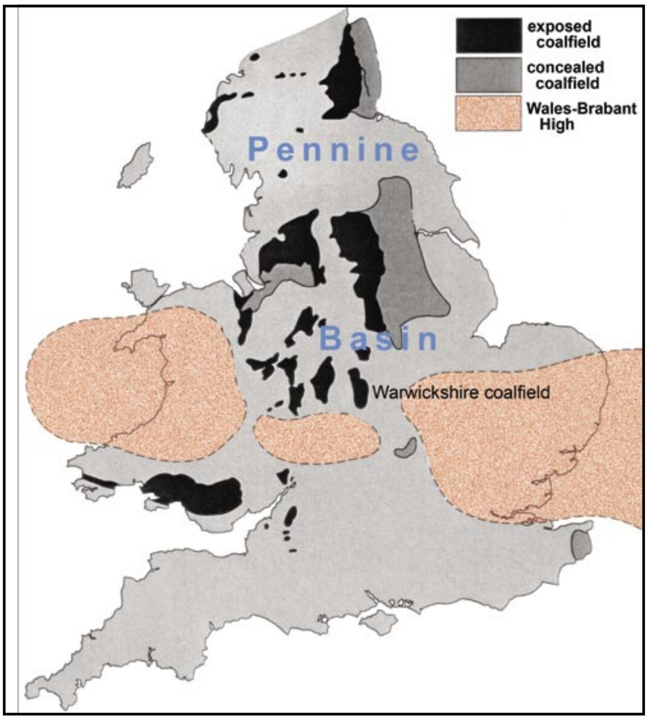

***Figure 10**. British coalfields in relation to the Pennine Basin and Wales-Brabant High (after Powell et al., 2000).*

End-Variscan deformation

The present-day synclinal structure of the Warwickshire Coalfield, involving strata ranging up to the Ashow Group, is largely due to early Permian (late Variscan) regional compression (Bridge *et al*., 1998; Fig. 8). It is likely that the N-S orientation of the coalfield is mainly a legacy of Malvernoid lineaments, notably the Western Boundary Fault (Fig. 2). On the broadest scale the tectonism was a response to deformation farther south involving the suturing of Laurussia and Gondwana along the Hercynian 'megastructure', consolidating the Pangaean supercontinent (Guion *et al*., 2000). Relatively small-scale folds and faults are superimposed upon the overall synclinal structure of the coalfield (Fig. 2). On its northeastern margin, structures with NW-SE orientations are evident. Among these, the Camp Hill Monocline represents a structure along which Carboniferous and older strata steepen progressively towards the Polesworth Fault, bringing the Precambrian and Lower Palaeozoic rocks to the surface within the Nuneaton Inlier. Along the southeastern margin of the Coalfield, the north-south trending Binley Monocline demonstrates a similar structural style (Bridge *et al*., 1998).

Triassic

Late Permian times in central England were marked by east-west crustal extension and rifting associated with early Atlantic opening, resulting in reactivation of favourably oriented basement faults. The succeeding Triassic strata were deposited mainly in the resulting fault-bound basins (Chadwick, 1985; Chadwick & Smith, 1988; Ruffell & Shelton, 2000; Radley, 2005; Fig. 8). These strata continue the trend of non-marine deposition in semi-arid to arid settings at 15-20°N (Ruffell & Shelton, 2000; Benton *et al*., 2002; Radley, 2005). The rocks largely occupy three structural units (Fig. 2). Northeast Warwickshire marks the southwestern part of the Hinckley Basin. To the west, the Coventry Horst was formed by partial tectonic inversion of the Late Carboniferous depocentre, and is characterised by an incomplete, patchy Triassic cover. Along the western edge of the horst, the Western Boundary and Warwick faults mark the eastern margin of the Knowle Basin (Bridge *et al*., 1998).

The Hopwas Breccia and overlying Polesworth Formation (Sherwood Sandstone Group) represent the oldest part of the Hinckley Basin fill. The breccia appears to be talus derived from the nearby horst margin and deposited in basin-margin fans. The Polesworth Formation includes typical 'Bunter' pebble beds, deposited by fast-flowing braided rivers. Among the pebbles, the abundant quartzite clasts appear to be derived mainly from the region of the Armorican massif (Brittany-Cornwall), by a large river system (the 'Budleighensis River' of Wills, 1956) draining north and northeast through the Worcester Basin (Warrington & Ivimey-Cook, 1992).

***Figure 11**. Southam Cement Works Quarry, Long Itchington, before it was flooded. Low faces in the foreground are of limestones of the latest Triassic (Rhaetian) Langport Member; the cliff in the background (about 30 m high) exposes part of the Early Jurassic Blue Lias Formation comprising mudstones of the Saltford Shale Member, overlain by alternating mudstones and paler limestones of the Rugby Limestone Member.*

The Bromsgrove Sandstone Formation is the oldest Triassic unit to overstep the major coalfield boundary faults onto the Coventry Horst (Fig. 7). On the southern end of the horst, in the Warwick district, the Bromsgrove Sandstone rests unconformably on Early Permian red-beds. There it is characterised by sandstones with subordinate red-brown mudstones of alluvial origin that have yielded an internationally important freshwater-terrestrial vertebrate fauna (Old *et al*., 1987; Benton & Spencer, 1995). The sandstones and immediately overlying strata are the principal source of the spa waters at Leamington.

The Bromsgrove Sandstone fines up into the Mercia Mudstone Group through a sequence of sandstones, siltstones and mudstones (Tarporley Siltstone Formation; formerly ‘Passage Beds’ and ‘Waterstones’), reflecting a broad alluvial plain and the regional breakdown of the river systems. The overlying Sidmouth Mudstone Formation (representing the lower part of the Mercia Mudstone Group; Howard *et al*., 2008) is dominated by unfossiliferous red-brown mudstones and siltstones, locally interbedded with siltstones and fine-grained sandstones. Nodular and vein gypsum has been encountered in boreholes. Most of the Mercia Mudstone is an accumulation of wind-blown dust (Arthurton, 1980; Jefferson *et al*., 2002), forming on a broad, low-lying sabkha. Laminated units possibly signify deposition in playa lakes, though much of the sediment probably accreted on extensive wind-swept flats that were damp due to a high, saline water table. This high water table resulted in the precipitation of gypsum close to the sediment surface; some may have formed within hypersaline lakes (Warrington & Ivimey-Cook, 1992). Thin siltstones and sandstones within the mudstones were formed by rapid runoff from flash floods (Powell *et al*., 2000).

Within the upper part of the Mercia Mudstone Group, the Late Triassic (Carnian) Arden Sandstone Formation is present as pale sandstones and siltstones with varicoloured mudstones. Unusually for the Mercia Mudstone Group, a number of fossils have been found, including land plants, molluscs, crustaceans, fish remains and amphibians, invertebrate burrows and reptile trackways (Old *et al*., 1991; Benton *et al*., 2002). The palaeontological and sedimentological evidence suggests an estuarine or deltaic setting, with the thicker sandstones representing distributary channels or a short-lived river system. The formation reflects a connection with southern, Tethyan marine sources (Radley, 2005). Ultimately, Warwickshire reverted to the essentially continental environment with flash-floods, playa-lakes and possible marine incursions, in which the red-brown mudstones of the Branscombe Mudstone Formation accumulated (Warrington & Ivimey-Cook, 1992; Howard *et al*., 2008). Forming the highest part of the Mercia Mudstone Group, the overlying Blue Anchor Formation comprises grey-green mudstones and siltstones. Scattered microplankton indicates increasing marine influence, prior to the Rhaetian transgression (Warrington & Ivimey-Cook, 1992).

In contrast to the Mercia Mudstone, the Rhaetian Penarth Group is characterised by fossiliferous mudstones, siltstones and limestones, some of fully marine aspect, that are subdivided into the Westbury and Lilstock formations. At the base, the Westbury Formation comprises laminated grey mudstone yielding molluscs, fish remains and other marine fossils. Slump structures attributed to seismic shock have been recorded at the top of the formation (Simms, 2003). Representing the lower part of the overlying Lilstock Formation, the Cotham Member is dominated by sparsely fossiliferous calcareous mudstones and siltstones (Old *et al*., 1987). East of southern Warwickshire’s Stour Valley, the Cotham Member is succeeded by the Langport Member, the highest division of the Penarth Group (Fig. 11), dominated by pale, fine-grained limestone that yields a shelly fauna (Swift, 1995). Both the Cotham and Langport members are ascribed to shallow-water, marine or quasi-marine environments (Old *et al*., 1987).

Jurassic

South of the coalfield, in Early and Middle Jurassic times the north-south trending (Malvernoid) Vale of Moreton Axis separated the London Platform and East Midlands Shelf in the east from the Worcester Basin in the west (Fig. 1). Southern Britain is thought to have laid roughly 10° south of its present latitude during the Jurassic, among a complex of seaways generated by crustal extension within the northwest European sector of Pangaea (Hesselbo, 2000). The presence of corals, thick-shelled mollusks, ooidal limestones and ironstones within the Warwickshire succession show that climates were warm and sometimes humid.

The Jurassic of Warwickshire was reviewed by Radley (2003). The strata range up to the Bathonian Stage of the Middle Jurassic. They comprise two overall upward-shallowing marine successions deposited under regional tectonic control, superimposed upon a picture of general sea-level rise following the latest Triassic - earliest Jurassic marine transgression. Each major shallowing succession is dominated by mudstones of offshore, relatively deep-water origin (Blue Lias, Charmouth Mudstone and Whitby Mudstone formations), passing up into shallow-water sandstones, limestones and ironstones (Dyrham and Marlstone formations; Inferior and Great Oolite groups). The picture is further complicated by a number of minor shallowing and deepening events of local to regional extent, evidenced for example by relatively localised erosion surfaces and facies changes (Radley, 2003).

The first upward-shallowing succession is represented by the Blue Lias (Fig. 11) and Charmouth Mudstone formations, passing up via the arenaceous Dyrham Formation into the ooidal ironstones of the Pliensbachian Marlstone Rock Formation (Radley, 2003). The second succession, commencing with the Whitby Mudstone Formation, concluded with deposition of Middle Jurassic limestones and sandstones (Radley, 2003). Above the Marlstone Rock Formation, the abrupt reappearance of ammonite-rich mudstones at the base of the Whitby Mudstone (Fig. 12) indicates Early Toarcian deepening, thought to have had a tectono-eustatic cause (Hallam, 2001).

***Figure 12**. Avonhill Quarry, near Avon Dassett, with Early Jurassic Toarcian basal Whitby Mudstone Formation overlying the Pliensbachian possibly up to Toarcian Marlstone Rock Formation, in a face 5 m high.*

Much of the Jurassic succession is richly fossiliferous. Mudstone-dominated formations, in particular, contain many biostratigraphically-important ammonites and historically have also yielded abundant marine reptile remains. Among these, the Blue Lias Formation, exposed in cement quarries (Fig. 11), provides evidence for subtle variations in water-depth and benthic oxygenation. The shallower-water facies developments of sandstones, shelly and/or ooidal limestones and ironstones commonly yield rich benthic faunas including many brachiopods, molluscs and echinoderms. Bioturbation is common throughout much of the Warwickshire Jurassic; notable exceptions are the finely laminated limestone and mudstone developments within the Blue Lias Formation (Ambrose, 2001; Radley, 2003).

The Vale of Moreton Axis clearly affected Jurassic deposition, coinciding with a number of lateral lithological and thickness changes within the local succession. Notable amongst these are the development of sands at the top of the Whitby Mudstone Formation west of the axis region. The London Platform also exerted a strong influence on deposition, evidenced for example by the development of Aalenian arenaceous strata (Northampton Sand and Grantham formations) in the south and east of the county (Radley, 2003).

Cenozoic

Younger Mesozoic rocks are absent in Warwickshire. Upper Jurassic and Cretaceous strata not far to the south (Oxfordshire) provide evidence for a further 100 million years of periodic marine inundation, minor tectonism and a drift towards 42°N (Warwickshire). It seems likely that the area was subject to uplift, tilting and erosion during the Palaeogene and Neogene (Green *et al*., 2001; Carney, 2007; Lane *et al*., 2008), shaping a precursor to the modern landscape.

The Pleistocene and Holocene are marked less by deposition and more by weathering and subaerial erosion in alternating cold and warmer spells which have further altered the precursor landscape. The oldest sediments constitute the Middle Pleistocene 'Wolston Series'; elucidated stratigraphically by Shotton (1953). These are well-known from sites between Stratford-upon-Avon and Rugby where they trace the line of Shotton's broad, shallow 'proto-Soar' valley. The earliest, fluvial deposits (Baginton Formation) are dominated by sand and gravel (Fig. 13) and record the northeasterly flow of a low-sinuosity braided river ('Bytham River' of Rose, 1994) through the region to Leicester and beyond, which reached the sea near present-day Lowestoft (Rose, 1989).

Near Bubbenhall, south-east of Coventry, the lower part of the fluvial Cromerian Baginton Formation has yielded a number of Palaeolithic stone tools and is locally underlain by temperate fossiliferous channel-fills cut into Mercia Mudstone bedrock (Shotton *et al*., 1993; Keen *et al*., 2006). The fluvial deposits are

***Figure 13**. Middle Pleistocene sediments at Wood Farm Quarry, near Bubbenhall. Gravels and sands in the lower part of the section represent the Thurmaston and Brandon members of the Baginton Formation, and are overlain by clayey till, the Thrussington Member of the Wolston Formation, in a face 6 m high.*

overlain by Thrussington Till rich in Mercia Mudstone (Fig. 13). This is now interpreted as signifying the onset of the Anglian glaciation (Maddy, 1999), involving ice advance up the 'proto-Soar' valley from the north (Sumbler, 1983).

Above, the laminated Wolston Clay and associated fluvial deposits suggest glacio-lacustrine deposition following glacial retreat. Shotton's (1953) concept of a glacial 'Lake Harrison', covering extensive areas of the Midlands, has been weakened in recent decades. Firstly, the presence of till layers within the Wolston Clay suggests the proximity of an ice sheet that would have exerted a strong influence on lacustrine deposition. Secondly, it seems likely that the Wolston Clay lacustrine deposits are at least partly diachronous. Thirdly, a putative lake shoreline bench, identified by Dury (1951) in southern and eastern Warwickshire, is now attributed to a resistant marker bed within the Early Jurassic Charmouth Mudstone Formation (Ambrose & Brewster, 1982). Accordingly, Shotton's concept of a single widespread lake has been superseded by a new model involving diachronous development of transient lakes and ponds, associated with ice sheets advancing from the north and east (Sumbler, 1983; Old *et al*., 1987).

A second ice advance later in the Anglian saw deposition of the Oadby Till, a dark grey till formed from Jurassic and Cretaceous rocks and noted for the abundance of flint and chalk erratics. This was formed by ice advancing from the north-east. The flint-rich Dunsmore Gravel of eastern Warwickshire, capping the glacial succession, was deposited possibly from meltwater derived from the decaying Oadby Till ice sheet (Shotton, 1953; Old *et al*., 1987; Keen, 1999). This glacio-fluvial depositional phase has been linked to the early establishment of the Avon Valley drainage system (Sumbler, 1983; Keen, 1999). Elsewhere, Anglian glacigenic deposits form a thinner, patchy cover on the Coventry Horst (Old *et al*., 1987; Bridge *et al*., 1998) while south of the Avon Valley, tills are largely restricted to the interfluves and scarp tops. In the west of the county, west of the Kingswood Gap, the glacial deposits are of western origin. Welsh igneous rocks occur (Tomlinson, 1935) with a greater variety of rocks found further west including Welsh and Uriconian igneous and Carboniferous lithologies (Old *et al*., 1991).

River terrace deposits dominated by pebbly sand are widespread in the Avon Valley. They post-date the earlier glacial and fluvial-glacial deposits (Keen, 1999), and indicate further uplift. The Middle Avon flows southwest, roughly parallel to, but incised below the course of the old north-easterly flowing proto-Soar. Below Stratford-upon-Avon it formed a broad belt of palaeomeanders now represented as the 3rd Terrace and dated to MIS 5 (Maddy *et al*. 1999). Alluvium is widespread along the modern valleys.

Acknowledgements

Brian Ellis and Ian Fenwick (Warwickshire Geological Conservation Group) are thanked for providing expertise on Quaternary geology and geomorphology. John Carney and Keith Ambrose (BGS), and Paul Guion (East Midlands Geological Society) contributed useful comments on an early draft of this paper.

References

Allen, J.R.L. 1968. The Nuneaton district. 15-19 in *The Geology of the East Midlands*. Sylvester-Bradley, P.C. & Ford, T.D. (editors). (Leicester University Press).

Ambrose, K. 2001. The lithostratigraphy of the Blue Lias Formation (Late Rhaetian-Early Sinemurian) in the southern part of the English Midlands. *Proceedings of the Geologists' Association*, **112**, 97-110.

Ambrose, K. & Brewster, J. 1982. A re-interpretation of parts of the 400 ft bench of south-east Warwickshire. *Quaternary Newsletter*, **36**, 21-24.

Arthurton, R.S. 1980. Rhythmic sedimentary sequences in the Triassic Keuper Marl (Mercia Mudstone Group) of Cheshire, northwest England. *Geological Journal*, **15**, 43-58.

Benton, M.J. & Spencer, P.S. 1995. *Geological Conservation Review Series: Fossil Reptiles of Great Britain.* (Chapman and Hall, London).

Benton, M.J., Cook, E. & Turner, P. 2002. *Geological Conservation Review Series: Permian and Triassic Red Beds and the Penarth Group of Great Britain*. (Joint Nature Conservation Committee, Peterborough).

Besly, B.M. 1988. Palaeogeographic implications of late Westphalian to early Permian red-beds, Central England. 200-221 in *Sedimentation in a Synorogenic basin complex: the Upper Carboniferous of Northwest Europe*. Besly, B.M. & Kelling, G. (editors). (Blackie, Glasgow and London).

Besly, B.M. & Fielding, C.R. 1989. Palaeosols in Westphalian coal-bearing and red-bed sequences, central and northern England. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **70**, 303-330.

Bluck, B.J., Gibbons, W & Ingham, J.K. 1992. Terranes. 1-3 in *Atlas of Palaeogeography and Lithofacies*. Cope, J.C.W., Ingham, J.K. & Rawson, P.F. (editors). Geological Society, Memoir 13.

Brasier, M.D. 1984. Microfossils and small shelly fossils from the Lower Cambrian Hyolithes Limestone at Nuneaton, English Midlands. *Geological Magazine*, **121**, 229-253.
Brasier, M.D. 1985. Evolutionary and geological events across the Precambrian-Cambrian boundary. *Geology Today*, **1**, 141-146.
Brasier, M.D. 1992. Background to the Cambrian Explosion. *Journal of the Geological Society,* **149**, 585-587.
Brasier, M.D. & Hewitt, R.A. 1979. Environmental setting of fossiliferous rocks from the uppermost Proterozoic-Lower Cambrian of central England. *Palaeogeography, Palaleoclimatology, Palaeoecology*, **27**, 35-57.
Bridge, D.McC., Carney, J.N., Lawley, R.S. & Rushton, A.W.A. 1998. Geology of the country around Coventry and Nuneaton. *Memoir of the British Geological Survey*.
British Geological Survey 1994. *Coventry. England and Wales sheet 169. Solid and Drift geology. 1:50 000*. (British Geological Survey, Keyworth, Nottingham).
British Geological Survey 1996. *Tectonic map of Britain, Ireland and adjacent areas*. *1:1 500 000*. (British Geological Survey, Keyworth, Nottingham).
Carney, J. 2007. Geological Evolution of Central England with reference to the Trent Basin and its landscapes. *Mercian Geologist*, **16**, 231-240.
Carney, J.N. & Pharaoh, T.C. 1993. Geology, chemistry and structure of Precambrian rocks in quarries north-west of Nuneaton. *British Geological Survey Technical Report WA/93/94*, 69 pp.
Carney, J.N. & Pharaoh, T.C. 1999. Griff Hollow. 227-230 in *Geological Conservation Review Series: Caledonian Igneous Rocks of Great Britain.* Stephenson, D. *et al*. (Joint Nature Conservation Committee, Peterborough).
Carney, J.N., Glover, B.W. & Pharaoh, T.C. 1992. Pre-conference field excursion: Precambrian and Lower Palaeozoic rocks of the English Midlands. *British Geological Survey Technical report WA/92/72*, 17 pp.
Chadwick, R.A. 1985. Permian, Mesozoic and Cenozoic structural evolution of England and Wales in relation to the principles of extension and inversion tectonics. 9-25 in *Atlas of Onshore Sedimentary Basins in England and Wales: Post-Carboniferous Tectonics and Stratigraphy.* Whittaker, A. (editor). (Blackie, Glasgow).
Chadwick, R.A. & Smith, N.J.P. 1988. Evidence of negative structural inversion beneath central England from new seismic reflection data. *Journal of the Geological Society,* **145**, 519-522.
Cocks, L.R.M. & Torsvik, T.H. 2002. Earth geography from 500 to 400 million years ago: a faunal and palaeomagnetic review. *Journal of the Geological Society*, **159**, 631-644.
Cope, J.C.W., Guion, P.D., Sevastopulo, G.D. & Swan, A.R.H. 1992. Carboniferous. 67-86 in *Atlas of Palaeogeography and Lithofacies.* Cope, J.C.W., Ingham, J.K. & Rawson, P.F. (editors). Geological Society Memoir 13.
Cruickshank, A.R.I. 1994. Cranial anatomy of the Lower Jurassic pliosaur *Rhomaleosaurus megacephalus* (Stutchbury) (Reptilia: Plesiosauria). *Philosophical Transactions of the Royal Society of London, Series B*, **343**, 247-260.
Dury, G.H. 1951. A 400-foot bench in south-eastern Warwickshire. *Proceedings of the Geologists' Association*, **62**, 167-173.
Eastwood, T., Gibson, W., Cantrill, T.C. & Whitehead, T.H. 1923. The geology of the country around Coventry, including an account of the Carboniferous rocks of the Warwickshire Coalfield. *Memoir of the Geological Survey of Great Britain*.
Fulton, I.M. 1987. Genesis of the Warwickshire Thick Coal: a group of long-residence histosols. 201-218 in *Coal and Coal-bearing Strata: Recent Advances.* Scott, A.C. (editor). Geological Society Special Publication 32.
Fulton, I.M. & Williams, H. 1988. Palaeogeographical change and controls on Namurian and Westphalian A/B sedimentation at the southern margin of the Pennine Basin, Central England. 178-199 in *Sedimentation in a Synorogenic basin complex: the Upper Carboniferous of Northwest Europe*. Besly, B.M. & Kelling, G. (editors). (Blackie, Glasgow and London).
Guion, P.D. 1992. Westphalian. 78-84 in *Atlas of Palaeogeography and lithofacies*. Cope, J.C.W., Ingham, J.K. & Rawson, P.F. (editors). Geological Society Memoir 13.
Guion, P.D., Gutteridge, P. & Davies, S.J. 2000. Carboniferous sedimentation and volcanism on the Laurussian margin. 227-270 in *Geological History of Britain and Ireland*. Woodcock, N.H. & Strachan, R.A. (editors). (Blackwell Science, Oxford).
Green, P.F., Thomson, K. & Hudson, J.D. 2001. Recognition of tectonic events in undeformed regions: contrasting results from the Midland Platform and East Midlands Shelf, Central England. *Journal of the Geological Society*, **158**, 59-73.
Hallam, A. 2001. A review of the broad pattern of Jurassic sea-level changes and their possible causes in the light of current knowledge. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **167**, 23-37.
Hesselbo, S.P. 2000. Late Triassic and Jurassic: disintegrating Pangaea. 314-338 in *Geological History of Britain and Ireland*. Woodcock, N.H. & Strachan, R.A. (editors). (Blackwell Science, Oxford).
Holdsworth, R.E., Woodcock, N.H. & Strachan, R.A. 2000. Geological framework of Britain and Ireland. 19-37 in *Geological History of Britain and Ireland*. Woodcock, N.H. & Strachan, R.A. (editors). (Blackwell Science, Oxford).
Howard, A.S., Warrington, G., Ambrose, K. & Rees, J.G. 2008. A formational framework for the Mercia Mudstone Group (Triassic) of England and Wales. *British Geological Survey Research Report, RR/08/04*, 33 pp.
Illing, V.C. 1916. The Paradoxidian fauna of the Stockingford Shales. *Quarterly Journal of the Geological Society of London*, **71**, 386-450.
Jefferson. I., Rosenbaum, M. & Smalley, I. 2002. Mercia Mudstone as a Triassic aeolian desert sediment. *Mercian Geologist*, **15**, 157-162.
Keen, D.H. 1999. The chronology of Middle Pleistocene ('Wolstonian') events in the English Midlands. 159-168 in *Late Cenozoic Environments and Hominid Evolution: a tribute to Bill Bishop.* Andrews, P. & Banham, P (editors). Geological Society Special Publication, London.
Keen, D.H., Hardaker, T & Lang, A.T.O. 2006. A Lower Palaeolithic industry from the Cromerian (MIS 13) Baginton Formation of Waverley Wood and Wood Farm Pits, Bubbenhall, Warwickshire, UK. *Journal of Quaternary Science*, **21**, 457-470.
Lapworth, C. 1882. On the discovery of Cambrian rocks in the neighbourhood of Birmingham. *Geological Magazine*, **9**, 563-568.
Lane, N.F., Watts, A.B. & Farrant, A.R. 2008. An analysis of Cotswold topography: insights into the landscape response to denudational isostasy. *Journal of the Geological Society*, **165**, 85-103.
Lee, M.K., Pharaoh, T.C. & Soper, N.J. 1990. Structural trends in central Britain from images of gravity and aeromagnetic fields. *Journal of the Geological Society*, **147**, 241-258.
Maddy, D. 1999. English Midlands. 28-44 in *A revised correlation of Quaternary deposits in the British Isles*. Bowen, D.Q. (editor). Geological Society Special Report 23.
Maddy, D. Lewis, S.G. & Keen, D.H. 1999. Pleistocene palaeomeanders of the River Avon, Warwickshire. *Proceedings of the Geologists' Association*, **110**, 163-172.
McIlroy, D., Brasier, M.D. & Moseley, J.B. 1998. The Proterozoic-Cambrian transition within the Charnian Supergroup of central England and the antiquity of the Ediacara fauna. *Journal of the Geological Society*, **155**, 401-411.
McKerrow, W.S., Scotese, C.R. & Brasier, M.D. 1992. Early Cambrian continental reconstructions. *Journal of the Geological Society*, **149**, 599-606.
Old, R.A., Sumbler, M.G., & Ambrose, K. 1987. Geology of the country around Warwick. *Memoir of the British Geological Survey*.
Old, R.A., Hamblin, R.J.O., Ambrose, K. & Warrington, G. 1991. Geology of the country around Redditch. *Memoir of the British Geological Survey.*

Paton, R.L. 1974. Lower Permian pelycosaurs from the English Midlands. *Palaeontology*, **17**, 541-552.
Paton, R.L. 1975. A Lower Permian temnospondylous amphibian from the English Midlands. *Palaeontology*, **18**, 831-845.
Pharaoh, T.C. & Carney, J.N. 2000. Introduction to the Precambrian rocks of England and Wales. 3-17 in *Geological Conservation Review Series: Precambrian Rocks of England and Wales*. Carney, J.N. *et al*. (Joint Nature Conservation Committee, Peterborough).
Pharaoh, T.C., Webb, P.C., Thorpe, R.S. & Beckinsale, R.D. 1987a. Geochemical evidence for the tectonic setting of late Proterozoic volcanic activity in central England. 541-552 in *Geochemistry and Mineralization of Proterozoic volcanic suites*. Pharaoh, T.C., Beckinsale, R.D. & Rickard, D. (editors). Geological Society Special Publication.
Pharaoh, T.C., Merriman, R.J., Webb, P.C. & Beckinsale, R.D. 1987b. The concealed Caledonides of eastern England: preliminary results of a multidisciplinary study. *Proceedings of the Yorkshire Geological Society*, **46**, 355-369.
Powell, J.H., Chisholm J.I., Bridge, D McC., Rees, J.G., Glover, B.W. & Besly, B.M. 2000. Stratigraphical framework for Westphalian to Early Permian red-bed successions of the Pennine Basin. *British Geological Survey Research Report, RR/00/01*, 28 pp.
Radley, J.D. 2003. Warwickshire's Jurassic geology: past, present and future. *Mercian Geologist*, **15**, 209-218.
Radley, J.D. 2005. The Triassic System in Warwickshire. *Mercian Geologist*, **16**, 89-98.
Rose, J. 1989. Tracing the Baginton-Lillington Sands and Gravels from the West Midlands to East Anglia. 102-114 in *The Pleistocene of the East Midlands: Field Guide*. Keen, D.H. (editor). (Quaternary Research Association, Cambridge).
Rose, J. 1994. Major river systems of central and southern Britain during the Early and Middle Pleistocene. *Terra Nova*, **6**, 435-443.
Ruffell, A.H. & Shelton, R.G. 2000. Permian to Late Triassic post-orogenic collapse, early Atlantic rifting, deserts, evaporating seas and mass extinctions. 297-313 in *Geological History of Britain and Ireland*. Woodcock, N. & Strachan, R. (editors) (Blackwell, Oxford).
Rushton, A.W.A. 1966. The Cambrian trilobites from the Purley Shales of Warwickshire. *Monograph of the Palaeontographical Society, Publication No. 511*. (The Palaeontographical Society, London).
Rushton, A.W.A. 1999. Cambrian rocks of England. 71-87 in *Geological Conservation Review Series: British Cambrian to Ordovician Stratigraphy.* Rushton, A.W.A. *et al*. (Joint Nature Conservation Committee, Peterborough).
Shotton, F.W. 1927. The conglomerates of the Warwickshire Coalfield. *Quarterly Journal of the Geological Society of London*, **83**, 604-621.
Shotton, F.W. 1929. The geology of the country around Kenilworth (Warwickshire). *Quarterly Journal of the Geological Society of London*, **85**, 167-222.
Shotton, F.W. 1953. The Pleistocene deposits of the area between Coventry, Rugby and Leamington and their bearing upon the topographic development of the Midlands. *Philosophical Transactions of the Royal Society of London, B***237**, 209-260.
Shotton, F.W. 1990. On the Rocks. 15-26 in *The Nature of Warwickshire.* Tasker, A. (editor). (Barracuda, Buckingham).
Shotton, F.W., Keen, D.H., Coope, G.R., Currant, A.P., Gibbard, P.L., Aalto, M., Peglar, S.M. & Robinson, J.E. 1993. Pleistocene deposits of Waverley Wood Farm Pit; Warwickshire. *Journal of Quaternary Science*, **8**, 293-325.
Simms, M.J. 2003. Uniquely extensive seismite from the latest Triassic of the United Kingdom: Evidence for bolide impact? *Geology*, **31**, 557-560.
Smith, A.S. & Radley, J.D. 2007. A marine reptile fauna from the Early Jurassic Saltford Shale (Blue Lias Formation) of central England. *Proceedings of the Yorkshire Geological Society*, **56**, 253-260.
Smith, D.B. & Taylor, J.C.M. 1992. Permian. 87-96 in *Atlas of Palaeogeography and lithofacies.* Cope, J.C.W., Ingham, J.K. & Rawson, P.F. (editors). Geological Society Memoir 13.
Sumbler, M.G. 1983. A new look at the type Wolstonian glacial deposits of Central England. *Proceedings of the Geologists' Association*, **94**, 23-31.
Swift, A. 1995. A review of the nature and outcrop of the 'White Lias' facies of the Langport Member (Penarth Group: Upper Triassic) in Britain. *Proceedings of the Geologists' Association,* **106**, 247-258.
Taylor, K. & Rushton, A.W.A. 1971. The pre-Westphalian geology of the Warwickshire Coalfield. *Bulletin of the Geological Survey of Great Britain*, **35**, 1-69.
Tomlinson, M.E. 1935. The superficial deposits of the country north of Stratford on Avon. *Quarterly Journal of the Geological Society of London*, **91**, 423-462.
Torsvik, T.H. *et al*. 1996. Continental break-up and collision in the Neoproterozoic and Palaeozoic – a tale of Baltica and Laurentia. *Earth Science Reviews*, **40**, 229-258.
Tresise, G. & Sarjeant, W.A.S. 1997. *The Tracks of Triassic Vertebrates: Fossil Evidence from North-West England*. (The Stationery Office, London).
Tucker, R.D. & Pharaoh, T.C. 1991. U-Pb zircon ages for Late Precambrian igneous rocks in southern Britain. *Journal of the Geological Society*, **148**, 435-443.
Turner, P., Vaughan, D.J. & Besly, B. 1985. Remanence acquisition in red beds from the Coal Measures of Central England. *Journal of the Geological Society*, **142**, 1015-1028.
Vizan, H. *et al*. 2003. Late Neoproterozoic to Early Palaeozoic palaeogeography of Avalonia: some palaeomagnetic constraints from Nuneaton, central England. *Geological Magazine*, **140**, 685-705.
Walker, A.D. 1969. The reptile fauna of the 'Lower Keuper' Sandstone. *Geological Magazine*, **106**, 470-476.
Warrington, G. & Ivimey-Cook, H.C., 1992. Triassic. 97-106 in *Atlas of Palaeogeography and Lithofacies*. Cope, J.C.W., Ingham, J.K. & Rawson, P.F. (editors). Geological Society Memoir 13.
Waters, C.N. *et al*. 2007. Lithostratigraphical framework for Carboniferous successions of Great Britain (onshore). *British Geological Survey Research Report RR/07/01*, 60 pp.
Wills, L.J. 1956. *Concealed Coalfields*. (Blackie, London).
Woodcock, N.H. 2000a. Ordovician volcanism and sedimentation on Eastern Avalonia.153-167 in *Geological History of Britain and Ireland*. Woodcock, N.H. & Strachan, R.A. (editors). (Blackwell Science, Oxford).
Woodcock, N.H. 2000b. Devonian sedimentation and volcanism of the Old Red Sandstone Continent. 207-223 in *Geological History of Britain and Ireland*. Woodcock, N.H. & Strachan, R.A. (editors). (Blackwell Science, Oxford).
Woodcock, N.H., Soper, N.J. & Strachan, R.A. 2007. A Rheic cause for the Acadian deformation in Europe. *Journal of the Geological Society*, **164**, 1023-1036.

Jonathan D. Radley
Warwickshire Museum, Market Place, Warwick CV34 4SA;
School of Geography, Earth and Environmental Sciences,
University of Birmingham, B15 2TT
J.D.Radley@bham.ac.uk