

Warwickshire's Jurassic geology: past, present and future

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Abstract. Jurassic strata were extensively quarried in Warwickshire, during the 19th and early to mid 20th centuries, but much of the succession is now poorly exposed. Selected sites are afforded statutory and non-statutory protection as Sites of Special Scientific Interest and Regionally Important Geological and Geomorphological Sites. Warwickshire's Jurassic history is outlined, demonstrating the value and purpose of the currently protected sites as repositories of stratigraphic, palaeontological and palaeoenvironmental data.

The fields, hills and villages of southern and eastern Warwickshire, central England, conceal a marine sedimentary succession of Lower and Middle Jurassic age (Figs 1 and 2). This is at least 400 metres thick (Williams & Whittaker, 1974) and spans about 40 million years of Earth history. The beds demonstrate a gentle regional dip towards the south-east and are affected by numerous normal faults (Institute of Geological Sciences, 1983), as well as cambering, landslipping and periglacial cryoturbation (Fig. 3). Unconsolidated Quaternary deposits locally cover the Jurassic sediments, notably in the Dunsmore area of eastern Warwickshire (British Geological Survey, 1984).

The latest Triassic-early Jurassic Wilmcote Limestone Member (Blue Lias Formation, Fig. 2) locally forms a well-marked dip slope in the south-west of the county. The widespread early Jurassic Salford Shale Member, Rugby Limestone Member and Charmouth Mudstone Formation give rise to the clay lowland agricultural region of the Warwickshire Feldon. Siltstones and sandstones of the Dyrham Formation form the gorse-clad slopes of prominent hills and escarpments, principally within the so-called Cotswold and ironstone fringes, south and east of the clay lowlands (Warwickshire County Council, 1993). Many of these are capped by the Marlstone Rock Formation - an ironstone still quarried at Edge Hill (Fig. 1) as 'Hornton Stone'. Edge Hill reaches a height of around 200 metres above sea level. In the south, a number of hills are capped by Middle Jurassic sandstones and limestones and reach around 250 metres above sea level (Fig. 4). These fringe the northern Oxfordshire uplands to the south and south-east, and the Gloucestershire Cotswolds to the south-west. The most picturesque villages in southern Warwickshire owe much of their character to the use of locally quarried Jurassic building stone, notably the rusty brown ironstone of the Marlstone Rock Formation.

The Vale of Moreton Axis is mapped as a north-south line running through the south-western part of the county (Sumbler, 1996; Fig. 1) and coincides with well-marked lateral facies and thickness changes in the Jurassic succession. The Axis is thought to be underlain at depth by a zone of steeply dipping basement faults that must have formed a

structural hinge throughout much of Lower and Middle Jurassic time (Horton *et al.*, 1987). This separated the London Platform and East Midlands Shelf in the east from the Severn (or 'Worcester') Basin in the west (Sumbler, 1996). West of the Axis, in south-western Warwickshire, the Lower Jurassic succession features a laminated, calcilutite-dominated Hettangian development (Wilmcote Limestone Member), a more arenaceous facies development of the Pliensbachian Marlstone Rock

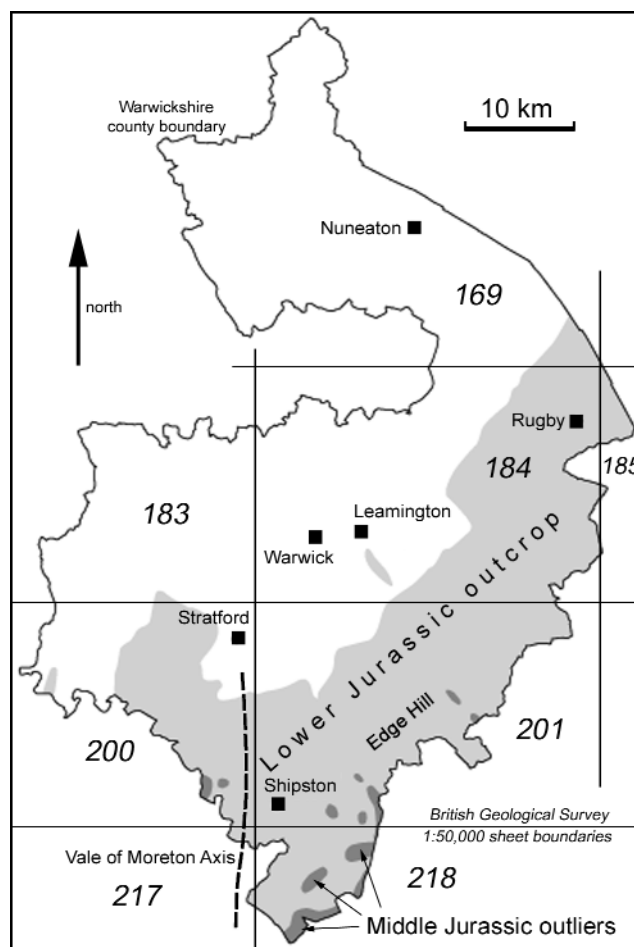


Figure 1. Outline map of Warwickshire, central England, showing Jurassic outcrop.

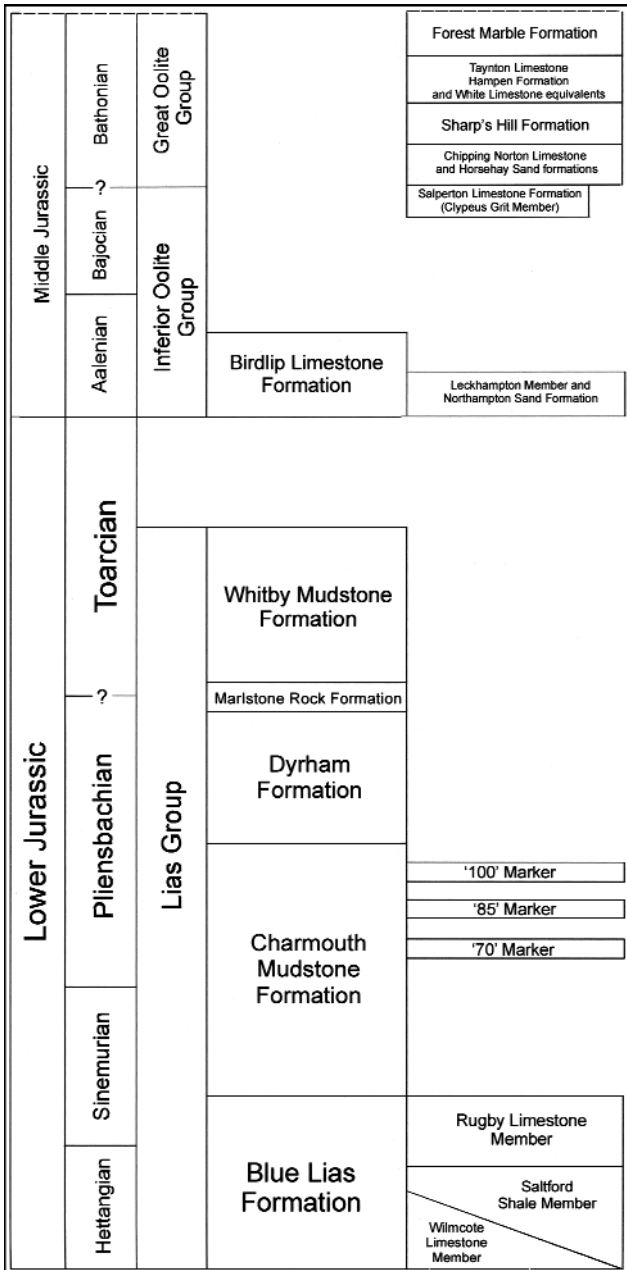


Figure 2. Outline of the Lower and Middle Jurassic succession in Warwickshire, central England (adapted from Sumbler, 1996; Barron *et al.*, 1997; Cox *et al.*, 1999; Ambrose, 2001 and Cox & Sumbler, 2002).

Formation, and sandstones forming the highest part of the Toarcian Whitby Mudstone Formation (Williams & Whittaker, 1974).

The Wilmcote Limestone is absent to the east of the Axis in southernmost and south-eastern Warwickshire (Ambrose, 2001). Here, a minor chronostratigraphic hiatus commonly separates latest Triassic from earliest Jurassic rocks that overstep onto the London Platform to the south-east (Donovan *et al.*, 1979; Old *et al.*, 1987). Where preserved in south-eastern Warwickshire, time equivalents of the Hettangian upper Wilmcote Limestone are developed largely as mudstones. Ambrose (2001) raised the possibility of localized fault control on their deposition (Princethorpe Fault north-east of Royal Leamington Spa). Higher in the succession, the Marlstone Rock Formation is developed here as a calcitic sideritic chamosite oolite (up to around 7.5 m thick), weathering to limonite. This was formerly quarried as iron ore within the Banbury ironstone field to the south-east (Whitehead *et al.*, 1952; Edmonds *et al.*, 1965). Nowadays it is quarried for ornamental and building purposes (as Hornton Stone), and as a source of aggregate.

The Middle Jurassic is represented to the west of the Axis by oolitic and bioclastic limestones of Aalenian age (Birdlip Limestone Formation; Barron *et al.*, 1997, 2002; Fig. 2). East of the Axis, the Aalenian strata are overstepped by the Clypeus Grit Member of the Upper Bajocian Salperton Limestone Formation (Cox & Sumbler, 2002) that ultimately rests on the Whitby Mudstone. There, the basal, arenaceous, Leckhampton Member of the Birdlip Limestone Formation is preserved, replaced further east by the Northampton Sand Formation (Horton *et al.*, 1987; Barron *et al.*, 1997). The Clypeus Grit is overlain by Warwickshire's youngest 'solid' geology - a Bathonian (Great Oolite Group) carbonate-dominated succession ranging from the Chipping Norton Limestone Formation possibly up into the Forest Marble Formation (Edmonds *et al.*, 1965; Horton *et al.*, 1987; Fig. 2). Warwickshire's Jurassic outcrop lies immediately north-west of Arkell's (1947) Oxfordshire Shallows that flank the

Figure 3. Rugby Limestone (Blue Lias Formation), periglacially cryoturbated in the Spiers's Farm excavation, Southam Cement Works (SP425635).



Figure 4. Aerial view of the Burton Dassett Hills RIGS (SP3952-3951). The hills are capped by the Pliensbachian up to Aalenian Marlstone, Whitby Mudstone and Northampton Sand formations. The old quarry workings are within Marlstone Rock Formation ironstones (photo: John Ball of Middlemarch Environmental).



London Platform to the south-east (also see Sylvester-Bradley, 1968).

At the broadest scale, the Lower and Middle Jurassic of Warwickshire comprises two overall upward-shallowing marine successions (Hallam & Sellwood, 1976; Holloway, 1985). These are superimposed upon a picture of general sea-level rise, following the earliest Jurassic eustatically driven marine transgression (Hallam, 2001). The succession comprises ammonite-rich mudstone facies (Blue Lias, Charmouth Mudstone and Whitby Mudstone formations), passing up into shallow-water sandstones, limestones and ironstones (Fig. 2). The earliest shallowing episode culminated in the Marlstone Rock Formation and is thought to be due to regional hinterland and/or sea-bed uplift. The second concluded with deposition of Middle Jurassic limestones in the Severn Basin, and the nearshore marine Northampton Sand and succeeding carbonate-rich strata on the adjacent shelf (Fig. 2). This has been attributed to upwarping of the central North Sea region (Hallam & Sellwood, 1976).

Southern Britain is thought to have lain about 10° south of its present latitude during the Jurassic (Hallam, 1993). Thick-shelled molluscs, corals, chamositic ironstones and oolitic limestones within the shallowest water facies show that prevailing climates were both warm and humid (Hallam, 1975). The diverse benthic faunas, shallow-water ichnofossils and tempestites that occur throughout much of the succession (Edmonds *et al.*, 1965; Clements, 1975; Horton *et al.*, 1987; Radley, 2002 and unpublished observations), suggest that central England's Jurassic seas were not much more than a few tens of metres in depth (Hallam, 1975, 1997).

The past

During the nineteenth and early twentieth centuries Warwickshire's Jurassic outcrop was riddled with quarries and pits, extracting rock as raw material for bricks, aggregate, building stone and ornamental stone. Additionally, freshly excavated railway cuttings provided some important sections (Woodward, 1893). This was the heyday of local Jurassic investigation. Many of the exposures and their palaeontology were documented by geologists such as the Rev. Peter Bellinger Brodie (*e.g.* 1868, 1874), Thomas Beesley (1877), John Judd (1875), Horace Woodward (1893), Edwin Walford (1899), Beeby Thompson (1898) and Linsdall Richardson (1922). Comprehensive bibliographies of the older works are provided by Arkell (1933), Edmonds *et al.* (1965), Williams & Whittaker (1974), Horton *et al.* (1987), Old *et al.* (1987, 1991).

Over the last fifty years, the larger quarries have attracted the attention of further workers who have continued to document and interpret their stratigraphy, palaeontology and palaeoenvironments (Howarth, 1958; Hallam, 1968; Clements, 1975, 1977; Weedon, 1986; Old *et al.*, 1987 and Wignall & Hallam, 1991). The lithostratigraphic scheme in current use (Fig. 2) has been developed by the British Geological Survey (Old *et al.*, 1991; Barron *et al.*, 1997; Cox *et al.*, 1999; Ambrose, 2001). Ammonite biostratigraphy was established for the Lower Jurassic by Dean *et al.* (1961), Getty & Ivimey-Cook (1980) and Howarth (1980a,b) and for the Middle Jurassic by Parsons (1980) and Torrens (1980).

The present

Only a handful of quarries remain in work at the present day. Lower Jurassic (Blue Lias Formation) mudstone and limestone is still exploited for the Rugby Cement industry and the Marlstone is currently quarried at Edge Hill for aggregate, building and ornamental purposes (see above). Many disused quarries occur, but their rock exposures are frequently obscured by talus and vegetation, or are flooded. Exposure is otherwise poor and largely limited to shallow, partly overgrown road, lane and railway cuttings, stream and ditch sections, and shallow, weathered landslip scars. Temporary exposures and field brash remain an important source of new data.

Interest in Warwickshire's geology remains high, notably among amateur geologists, students, engineers and geoconservation specialists. Protection of the field evidence for Warwickshire's Jurassic succession lies partly with English Nature through their geological SSSI (Sites of Special Scientific Interest) network and the county's RIGS (Regionally Important Geological and Geomorphological Sites) Group. The SSSI list has been developed nationally to identify, document and conserve sites that demonstrate the key scientific elements of Britain's geodiversity (Ellis, 1996). Warwickshire currently (2003) has three sites that are afforded statutory protection for their Jurassic interest through SSSI status - Wilmcote Quarry, NGR SP151594; Napton Hill Quarry, SP457613; Cross Hands Quarry, SP269290 (Cox & Sumbler, 2002; Simms *et al.*, in press).

Warwickshire's RIGS Group was established in the early 1990's to enable county-wide, non-statutory, geological and geomorphological site conservation (Harley, 1994). Up to March 2003, 80 RIGS have been documented, roughly a quarter of them for their Jurassic interest. RIGS selection is a dynamic process; new sites are constantly being appraised for their educational, scientific, historic and aesthetic importance, and it is likely that further Jurassic RIGS will be identified. This paper demonstrates the value and purpose of protected sites as a framework for interpreting Warwickshire's Jurassic history - which is summarised below with reference to the SSSIs and RIGS.

Lower Jurassic

The oldest beds are still exposed at Wilmcote Quarry SSSI (SP151594) and Temple Grafton Quarry RIGS (SP121539). These sites still expose several metres of mudstone interbedded with fine-grained laminated limestone (Wilmcote Limestone Member; late Rhaetian - early Hettangian; planorbis Zone). The beds were deposited predominantly as poorly oxygenated muds during the earliest phase of the Jurassic marine transgression (Wignall & Hallam, 1991). When in work, the quarries yielded beautifully preserved fossils including crustaceans, insects, fish, marine reptiles and land plants (Brodie,

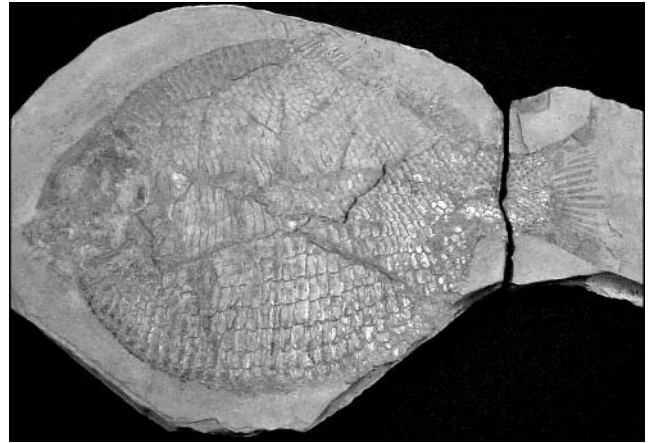


Figure 5. Fossil fish (*Dapedium cf. angulifer* (Agassiz)) from the Rhaetian up to Hettangian Wilmcote Limestone Member (Blue Lias Formation) of Wilmcote, near Stratford-upon-Avon, Warwickshire. Warwickshire Museum specimen G384. The slab is 450 mm long.

1868, 1897), mainly from lower beds than those currently exposed (Simms *et al.*, in press). Some are housed within the Warwickshire Museum (Fig. 5). Basal mudstones of the Wilmcote Limestone were formerly exposed at Round Hill road cutting RIGS, near Wootton Wawen (SP143618). They are thought to lie within the planorbis Zone, suggesting local attenuation in the vicinity of the Vale of Moreton Axis (Old *et al.*, 1991).

On the shelf area to the east, earliest Jurassic (planorbis Zone) sediments are either absent or represented by mudstones (Old *et al.*, 1987; Ambrose, 2001). Southam Cement Works Quarry RIGS, Long Itchington (SP418630), exposes the Saltford Shale and Rugby Limestone members above latest Triassic (Rhaetian) Langport Member limestones (Fig. 6). The Saltford Shale (approximately 15 m thick) is dominated by dark-coloured mudstones enclosing limestone nodules and thin, laterally persistent limestone beds. Some nodules preserve concentrations of well-preserved schlotheimiid ammonites (Fig. 7; indicating the liasicus and angulata Zones) and fish debris, as well as sporadic bivalves, nautiloids and marine reptile remains. The ammonites are commonly imbricated, suggesting that the skeletal debris accumulated under the influence of weak currents. Wignall & Hallam (1991) and Radley (2002) invoked an essentially dysaerobic setting for the Saltford Shale at Southam, given the scarcity of macrobenthos and the abundant lamination. However, boreholes drilled nearby by the British Geological Survey (Harbury Quarry Borehole, SP392589; Stockton Locks Borehole, SP430648; Old *et al.*, 1987) have revealed a number of sedimentary cycles within the unweathered strata. These comprise fissile mudstones that pass up into blocky calcareous mudstones and limestones. The presence of relatively massive, calcareous beds suggests that the seafloor became periodically oxygenated (K. Ambrose, *pers comm*).

The lower part of the overlying Rugby Limestone Member (angulata up to bucklandi Zone; about 25 m seen at Southam Cement Works) is also exposed at the Southam by-pass RIGS (SP419627). This comprises the well-known 'Blue Lias' facies of rapidly alternating mudstones, calcareous mudstones and argillaceous limestones (Fig. 6). The Rugby limestones differ from those of the Saltford Shale in their relatively bioturbated and fossiliferous character, suggesting greater overall oxygenation. The fossils include large bivalves, pleurotomariid gastropods, rhynchonellid brachiopods and echinoderms. Relative shallowing during the late Hettangian is supported by the cessation of sediment onlap onto the London Platform at this time (Donovan *et al.*, 1979).

Weedon (1986) presented evidence to suggest that the cyclic alternations of argillaceous and relatively calcareous beds within the Rugby Limestone resulted from changes in orbital precession and obliquity, affecting prevailing climate ('Milankovitch' cyclicality). He took the fissile, argillaceous intervals to signify wetter phases and increased runoff from nearby land, 'drowning' carbonate deposition (also see Radley, 2002). This model has gained considerable popularity, although elsewhere at least, certain Blue Lias limestones are probably wholly diagenetic in origin.

The Rugby Limestone is overlain by the Charmouth Mudstone Formation. This is developed in Warwickshire as a thick (up to around 170 m), poorly exposed succession of fossiliferous grey mudstones, calcareous mudstones and thin limestones, spanning much of the Sinemurian-Pliensbachian interval (bucklandi up to davoei Zone). Field mapping (Geological Survey of Great Britain (England and Wales), 1982) suggests that the lower part of the formation might be represented at the Ettington road cutting RIGS (SP264492).



Figure 6. Northern end of Southam Cement Works Quarry RIGS (SP420633). The face exposes alternating mudstones and limestones of the Rugby Limestone Member (Hettangian-Sinemurian; approximately 8 m preserved), underlain by mudstone-dominated strata of the Saltford Shale Member (Hettangian).



Figure 7. Limestone nodule enclosing a concentration of schlotheimiid ammonites. Hettangian Saltford Shale Member (Blue Lias Formation), Southam Cement Works Quarry RIGS (SP419629). Warwickshire Museum specimen G15588/1. The nodule is 213 mm long.

Here, pale, weathered, sparsely fossiliferous mudstones appear to be underlain by, or faulted against, darker mudstones containing common *Gryphaea arcuata* Lamarck.

In recent decades, field and subsurface investigations by the British Geological Survey have established the presence of calcareous, shelly, marker horizons within the higher, Pliensbachian part of the central English Charmouth Mudstone. These include Horton & Poole's (1977) '70', '85' and '100' Marker members (Fig. 2). They form topographic benches in southern Warwickshire, in part formerly interpreted as remnants of a proglacial lake margin (Dury, 1951; Ambrose & Brewster, 1982). Fenny Compton RIGS (SP4352) comprises one such feature.

Several metres of the Charmouth Mudstone are still exposed at Napton Industrial Estate RIGS (SP455616), below the site of the former Napton brickworks (partly preserved as Napton Hill Quarry SSSI). Mudstone and limestone nodules have yielded a rich macrofauna of brachiopods, gastropods, bivalves, ammonites, belemnites and crinoids. Amongst the ammonites, *Liparoceras cheltiense* (Murchison), *Acanthopleuroceras valdani* (d'Orbigny) and *Tragophylloceras ibex* (Quenstedt) prove the presence of the valdani Subzone (M. Howarth, personal communication). A bioclastic limestone bed crops out at the top of the section, packed with *Gryphaea* cf. *gigantea* J. de C. Sowerby, *Hippopodium ponderosum* J. Sowerby and other thick-shelled bivalves. This might represent the '85' Marker of Horton & Poole (1977) which lies at the top of the valdani Subzone (Howarth, 1980a).

The rich benthic fauna of the Charmouth Mudstone at Napton indicates that it was deposited in a relatively shallow, well-oxygenated sea. The bioclastic limestone seems to mark a phase of heightened winnowing, possibly due to shallowing (Old *et al.*, 1987). The resulting coarser-grained shelly substrates allowed establishment of the *Gryphaea*-dominated community. In this way the

sediment became progressively enriched in shell debris, facilitating further epifaunal colonisation.

Overlying the Charmouth Mudstone, the Dyrham Formation (margaritatus Zone, up to around 65 m thick; Williams & Whittaker, 1974) marks significant late Pliensbachian regional environmental change. General shallowing is indicated by the increased silt and sand content. Parts of the Dyrham Formation are seen at Avonhill Quarry RIGS (SP417507), near Avon Dassett. Here, about 6 m of mudstones, siltstones and sandstones yield a rich invertebrate fauna including the sub-zonal ammonite *Amaltheus subnodosus* (Young and Bird) (Martill & Blake, 1984). Sawn sandstone blocks provide an opportunity to study the internal sedimentary fabrics. A diverse ichnofossil assemblage occurs, as well as scours filled with shell debris. The latter suggest storm current influence in shallow water (Sellwood, 1972; Howard, 1984).

The top of the Dyrham Formation is seen at the Edgehill Quarry and nearby A422 (Starveall Barn) RIGS (SP372468 and SP378454). The highest metre comprises shelly mudstone, cross-bedded bioclastic limestone and a layer packed with worn belemnite rostra (Fig. 8). The latter is a good example of a 'belemnite battlefield' and proves a phase of reduced sedimentation, allowing concentration of skeletal remains (Doyle & Macdonald, 1993). The base of the succeeding Marlstone Rock Formation is marked by a widespread pebble bed (Walford, 1899; Edmonds *et al.*, 1965), well exposed at the Edge Hill quarries (see above) and the nearby Burton Dassett Hills RIGS (SP3952-3931). It is partly made up of cobbles and worn slabs of shelly ironstone and sandstone, derived from the underlying strata. The coarse-grained oolitic and bioclastic matrix yields a rich fauna of thick-shelled epifaunal bivalves (mainly oysters and pectinids) and spiriferid, rhynchonellid and terebratulid brachiopods and belemnite rostra.



Figure 8. 'Belemnite battlefield'. An accumulation of belemnite rostra, uppermost Dyrham Formation (Pliensbachian), Edgehill Quarry RIGS (SP372468). Scale is provided by pen.



Figure 9. Sawn slab of 'Hornton Stone' (Pliensbachian possibly up to Toarcian Marlstone Rock Formation) at Edgehill Quarry RIGS (SP372468). Note the 'nest' of predominantly fully articulated terebratulid brachiopods. Scale is provided by pen.

The more worn fossils display a range of invertebrate borings and grazing traces. The latter indicate a former cover of algae and cyanobacteria on shallow, photic substrates (Radley & Barker, 2001).

Overlying the pebble bed, the Marlstone Rock Formation (Pliensbachian spinatum Zone, possibly up to Toarcian tenuicostatum Zone) shows subtle differences when traced through the Warwickshire outcrop. Close to the Vale of Moreton Axis, Ilmington (Dairy Ground) RIGS (SP207429) exposes richly fossiliferous flaggy, sandy, ironstone. At Edge Hill (SP3747) the Marlstone reaches its maximum local thickness of approximately 7.5 m and is developed as an unusually pure chamositic oolitic ironstone, weathering to limonite (Whitehead *et al.*, 1952). Here it yields brachiopods, bivalves, belemnite rostra and wood fragments (Fig. 9). Cross bedding is especially evident at the Burton Dassett Hills and Avonhill sites. The Marlstone gains an appreciable sand content to the north-east, as at Napton Hill Quarry SSSI.

The Marlstone signifies a greater overall rate of sediment accumulation, following the strongly erosive phase represented by its basal pebble bed. It has been central to the controversy concerning the origin of oolitic ironstones. It is now generally thought that the iron was derived from terrestrial laterite soils, implying a warm, humid early Jurassic climate (Hallam & Bradshaw, 1979). The pure, relatively thick ironstone development seen at Edge Hill suggests that it was deposited in a semi-isolated depocentre (Edmonds *et al.*, 1965; Chidlaw, 1987).

The overlying Whitby Mudstone Formation is poorly exposed and spans part of the Toarcian Stage (falciferum possibly up to variabilis Zone). It is thickest to the west of the Axis (up to 60 m) where the highest part is arenaceous (Williams & Whittaker, 1974 and above). The basal beds are seen at Avonhill Quarry RIGS, resting sharply on

the Marlstone (Fig. 10). They comprise weathered brown mudstone (about 2 m preserved) enclosing beds of fine-grained ammonite-rich limestone (Cephalopod limestones; Edmonds *et al.*, 1965). Amongst the ammonites, *Harpoceras* spp. within the lower part of the succession indicate the *exaratum* and *falciferum* Subzones of the *falciferum* Zone. The highest layers yield *Dactyloceras commune* (J. Sowerby) and *Hildoceras sublevisoni* Fucini, indicating the *commune* Subzone of the *bifrons* Zone (Martill & Blake, 1984). The abrupt reappearance of fine-grained ammonite-rich strata indicates early Toarcian deepening (Hallam, 1997). This widely recognised event is thought to have had an underlying tectono-eustatic cause (Hallam, 2001).

Middle Jurassic

West of the Vale of Moreton Axis, Toarcian sands foreshadow the development of lower Aalenian shallow-water oolitic and bioclastic limestones (Birdlip Limestone Formation). The limestones were formerly quarried on Ebrington Hill (SP188427) near Ilmington. Only the basal, Leckhampton Member (= 'Scissum Beds') is preserved east of the Axis, lying on an eroded surface of the Whitby Mudstone. The Leckhampton Member passes eastwards into the Northampton Sand Formation (Horton *et al.*, 1987; Barron *et al.*, 1997). The transitional region of southern Warwickshire has attracted the attention of numerous workers including Judd (1875) and Richardson (1922). The lithologies present include arenaceous limestones ('Scissum Beds' facies), yielding a shallow water fauna of corals and serpulids at Brailes Hill RIGS (a ploughed field; SP294392). Ferruginous sandstone is seen at Winderton road cutting RIGS (SP341408). Fine-grained, calcareous sandstone (*Astarte elegans* Bed; Richardson, 1922; Edmonds *et al.*, 1965) occurs at Windmill Hill Quarry RIGS, Tysoe (SP332426).

Superimposed upon the overall Middle Jurassic shallowing trend, the transgressive Upper Bajocian *Clypeus* Grit (*parkinsoni* Zone) crosses the Vale of Moreton Axis onto the shelf, where it rests on units as old as the Whitby Mudstone (Horton *et al.*, 1987). Several metres of the Grit are exposed at Cross Hands Quarry SSSI, on high ground near Little Compton (Fig. 11). It consists of pale-coloured oolitic and pisolitic micrites, capped by a richly fossiliferous muddy layer (Cox & Sumbler, 2002). The latter yields serpulids, corals, bryozoans, brachiopods, gastropods, bivalves, echinoids (including *Clypeus ploti* Salter, Fig. 12) and many other fossils. The fauna signifies colonisation of stabilised shallow water substrates. The *Clypeus* Grit thins to the east and north as it passes into marginal ferruginous and conglomeratic facies (Horton *et al.*, 1987).

The overlying Great Oolite Group (Chipping Norton Limestone possibly up to Forest Marble Formation; zigzag up to ?discus Zone) continues the pattern of shallow water deposition across the Vale of Moreton Axis (Sellwood & McKerrow, 1974; Horton *et al.*, 1987; Sumbler, 1996). The Warwickshire Great Oolite represents part of a mosaic of shallow-water carbonate-dominated settings that spread to cover much of central and southern England at this time (Bradshaw & Cripps, 1992; Cox & Sumbler, 2002). The succession is dominated by oolitic and bioclastic limestones, interspersed with mudstones and finer-grained, micritic limestones (Edmonds *et al.*, 1965; Sellwood & McKerrow, 1974; Horton *et al.*, 1987).

The Chipping Norton Limestone is well exposed at Cross Hands Quarry SSSI and Weston Park Lodge Quarry RIGS (SP285340), resting erosively on the *Clypeus* Grit at the former (Fig. 11). It comprises fine-grained, flaggy bedded, oolitic limestone, penetrated by *Diplocraterion* burrows and containing plant debris. Farther east into Oxfordshire, onto the general region of the London

Figure 10. Basal Whitby Mudstone (Toarcian) overlying Marlstone Rock Formation (Pliensbachian possibly up to Toarcian) at Avonhill Quarry RIGS (SP417507). Quarry face is about 5 m high.





Figure 11. Basal Chipping Norton Limestone Formation (Bathonian) that is overlying the Clypeus Grit Member (Bajocian) at Cross Hands Quarry SSSI (SP269290).

Platform, it passes into marginal facies (Horsehay Sand Formation) and oversteps the Clypeus Grit to rest on the Northampton Sand Formation (Cox & Sumbler, 2002).

In southern Warwickshire, patches of relatively pale sand locally overlie the Northampton Sand. The British Geological Survey mapped these as ‘Lower Estuarine Series’ (Edmonds *et al.*, 1965; Horton *et al.*, 1987). However, it seems likely that they represent decalcified Chipping Norton Limestone, and/or Horsehay Sand (M.G. Sumbler, *pers comm*).

A couple of metres of shelly mudstone and limestone are seen above the Chipping Norton Limestone Formation at Rollright Quarry RIGS, just over the Oxfordshire border (SP282307). These represent the lower part of the Sharp’s Hill Formation and yield corals, brachiopods, oysters, nerineid gastropods and irregular echinoids. A similar thickness of weathered Great Oolite limestone (possibly representing the Taynton Limestone) is seen at Traitor’s Ford Quarry RIGS, close to the Oxfordshire border (SP336362). Warwickshire’s Jurassic story concludes at Broomhill Farm, near Epwell (SP342413) where the British Geological Survey mapped the Forest Marble Formation (Edmonds *et al.*, 1965). This is not currently exposed but deserves renewed reinvestigation.

The future

Southern Warwickshire’s protected geological sites demonstrate key lines of evidence for Lower-Middle Jurassic palaeoenvironmental change. This body of information will be augmented by future selection of Jurassic sites as RIGS or SSSIs, and documentation of temporary exposures, subsurface records and museum collections. Above all, the detailed stratigraphy, sedimentology and overall palaeoenvironments of the mudstone formations remain poorly understood. The Charmouth Mudstone Formation in particular, is poorly documented, potentially concealing evidence for Sinemurian-Pliensbachian sea-level fluctuation and

palaeoecological response (Sellwood, 1972; Hesselbo & Jenkyns, 1998). Taphonomic and isotopic studies, clay mineral analyses, micropalaeontology and ichnology are a largely untapped source of palaeoenvironmental data, potentially applicable to many protected and currently unprotected sites. The prospects for palaeobiological study are similarly good, given the recognition of spectacular fossil concentrations (Fig. 7) and also the wealth of unresearched fossil material from local sites retained in museum collections. Progress will rely partly upon ongoing mineral extraction, exposure documentation, public awareness, education and funding. A number of the most fossiliferous nineteenth century sites still exist, albeit in an overgrown and/or partly filled state. They deserve re-excavation, detailed documentation, protection, and planned management as resources for education and research.



Figure 12. Irregular echinoid (*Clypeus ploti* Salter; partly an internal mould) from the Clypeus Grit Member (Salperton Limestone Formation; Bajocian) of Cross Hands Quarry SSSI (SP269290). Warwickshire Museum specimen G8839. Specimen is 97 mm in diameter.

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