Field workshop on the British Triassic: relationships between the British and German Triassic (10-17th August, 2004).

Introduction to the British Triassic

The British Triassic is fragmented into a number of separate basins, between which local highs seem to have provided some sediment input (Fig. A1). These basins to a large extend have different sedimentary and subsidence histories, particularly for the Lower and Middle Triassic. Many of the basins have a subsidence history starting in the Permian (or even the late Carboniferous in NW basins). The Triassic in eastern England is strongly linked to the southern North Sea succession, and is not a direct focus of this field workshop. The structural control on basin geometry is largely dictated by basement structure, so that UK western and north-western basins have a grain strongly dictated by Caledonide features and NW-SE cross-faults and transfer zones, opened up during North Atlantic stretching, which probably initiated the North Sea Basin. The Eastern Irish Sea Basin, probably preserves the thickest UK Triassic succession, and is most similar to the Southern North Sea Basin, in that it contains a Zechstein equivalent. South of the Variscan front the basin geometry is often strongly inherited from E-W Variscan structures (Fig. A1).

The UK Triassic is divided into the Sherwood Sandstone Group, the Mercia Mudstone Group and Penarth Group. Regional differences in successions are most marked for the Sherwood Sandstone Group, which shows general northward thickening in all UK western basins. Progressively through the Ladinian, Carnian and Norian, this N-S regional difference disappears so that by the time of the late Norian and Rhaetian, regional differences are rather small.

The Lower Triassic

The Sherwood Sandstone Group can be broadly divided into an upper and a lower unit, at the level of a widely recognized intra-Sherwood Sandstone disconformity perhaps within the uppermost Lower Triassic (Fig. A2). This disconformity separates two quite distinct environmental systems. This disconformity is widely assumed to be equivalent to the Hardegsen disconformity of the central European/Southern North Sea Basin, although the age of this disconformity is not constrained with biostratigraphy.

Below the intra-Sherwood Sandstone disconformity

These deposits are dominated by evidence of a major river system, which Wills (1970) termed the ‘Budleighensis’ river system. Within the western onshore basins this river system seems to have been one which was sourced from the Variscan mountains of Brittany and the southern English Channel, and then flowed northwards through the Wessex Basin through the Worcester Basin, the various midland basins (Needwood, Stafford, Cheshire etc) and on into the East Irish Sea Basin. A second branch probably flowed eastwards into the southern North Sea (?). This Budleighensis river system is evident by the generally northwards directed palaeocurrents in these basins (Steel and Thompson, 1983; Chisholm et al., 1988; Rees & Wilson, 1998; Jones and Ambrose, 1994), and the southerly source of pebbles and heavy minerals.

Within the central England basins (Needwood, Stafford, Cheshire), these deposits are dominated by pebbly sandstones and conglomerates (Chester Pebble Beds, Wilmslow and Wildmoor Sandstones; Fig A2), which have been interpreted as the deposits of a braided river, within well-confined channels (Steel and Thompson, 1983). This river system probably had large seasonal changes in discharge, evident by cross-bedded-sandstones deposited at stages of lower flow, although it is perhaps doubtful if this system was ephemeral in nature (Smith, 1990), for there is relatively little evidence of aeolian sandstones in basinal settings in the Midlands (Rees and Wilson, 1998). Within each of the basins it is clear that locally sourced material was also an important component of the river systems (Chisholm et al., 1988; Rees and Wilson, 1998; Smith and Edwards, 1991), indicating the relief of the basin margins.

In the more northerly basins (Eastern Irish Sea, Solway-Firth and Eden basins) the lower Triassic river system was sand dominated- evidence of the lower flow regime of the river system ?. Deposited in these basins are stacked channel sandstones, formed predominantly by a low sinuosity sandy-braided river system (Jones and Ambrose, 1994), but locally containing minor aeolian, sand-sheet and play-type environments (Meadow and Beach, 1993). The aeolian-derived component of these sandstones may increase upwards in frequency until they make a major component in some basin-margin situations, such as in West Cumbria (Jones and Ambrose, 1994). The Budleighensis river system may have terminated in the Eastern Irish Sea or Solway Firth basins as a series of playa basins (but where's the evaporites ?), or perhaps flowed westwards (or northwards) across Ireland to join the marginal marine lower Triassic sequences west of Ireland (Croker and Shannon, 1987), NW of Scotland or offshore Norway.

Biostratigraphic control on the age of these units is mostly lacking (or not published), and their age is inferred from lateral correlation. Magnetostratigraphy provides one of the key tools for inferring age of these units.

Above the intra-Sherwood Sandstone disconformity

The 'Budleighensis' river system still flowed northwards through the Wessex and Midlands basins, evident by the palaeocurrent trends (Henson, 1973; Ireland et al., 1978; Meadows and Beach, 1993), but the depositional style was changed, from one which was sandstone dominated in the midlands and southern basins, to one which had extensive aeolian depositon in the northern basins. This shift was perhaps a consequence of a major reduction in the gradient of the Budleighensis river system, perhaps through the thermal collapse of the northern part of the Variscan mountain range. The Otter and Bromsgrove sandstones of the midland and southern basins are mostly stacked channel sandstones (Fig. A2), formed in sinuous to straight channeled river system, which produced copious amounts of intraclastic debris, both from pedogeneic carbonates and erosion of overbank mudstones. The abundance of pedogenic carbonates in these Anisian sandstones indicates that stable landscape surfaces were able to develop.

For the first time in the UK Triassic significant faunal and floral elements are found including plants, invertebrates, arthropods , fishes and reptiles, all evidence of a

fluvial landscape punctuated by lakes, and more extensive plant growth, within this landscape (Benton et al. 2002; Purvis and Wright, 1991; Spenser and Storrs, 2002). River systems from locally derived sources were still important at basin margins locations as in evident by locally sourced breccias and conglomerates forming the major part of some fluvial sequences (Bridge et al., 1998).
In the northern basins (Cheshire, EISB, etc) a mixture of fluvial channel sandstones and aeolian sandstones dominate the succession. The location of the fluvial systems in the EISB seems to have been located adjacent to bounding faults, probably due to fault activity (Meadows and Beach, 1993). At the basin margin in west Cumbria, the river systems flowed into the EISB in a WSW direction either due to control by wind-aligned linear dune systems or due to the local palaeoslope. These river systems were part of large low gradient sand-flat systems, which seasonally flooded, and strongly controlled the geometry of the aeolian bedforms both within the EISB and further south in the Cheshire basin (Goodall et al., 2000; Mountney and Thompson, 2002). The aeolian dune systems were produced by westward to SW directed wind systems which seem to have been a fairly typical feature in England and Wales (Mountney and Thompson, 2002, Jones and Ambrose, 1994). These aeolian sand seas seem to have been most prevalent in basin margins locations such as those fringing the Lake District (Arthurton et al., 1978).

In the east midlands, and Southern North Sea some authors suggest the ‘upper’ unit of the Sherwood Sandstone Group may be absent and the Mercia Mudstone Group rests directly on the “Hardegsen” disconformity.

The Mercia Mudstone Group

The lithostratigraphy of the Mercia Mudstone Group has recently been rationalized (Howard et al., 2002), and this is mostly used in Fig. A3. The old terminology applied to the same units is shown in Fig. A4.

During the Middle to Upper Triassic extensive mostly lacustrine-playa basins developed in the UK, which are largely represented by the Mercia Mudstone Group. This is mostly characterised in non-marginal areas by thick successions of calcite and dolomite bearing red mudstones, with occurrences of green or grey mudstones, anhydrite layers and veins, occasional thin sandstones and in the deeper basin centres often thick occurrences of halite. The lower boundary of the Mercia Mudstone Group, on the basis of miospore, magnetostratigraphic and log correlations appears to be diachronous (Fig. A3). The mudstone dominated successions of Anisian age in the Northern basins, and in the southern North Sea, are probable the terminal playa systems of the Anisian Sandstone successions of the midlands and southern UK basins.

There are broadly four major mudstone facies present in the Mercia Mudstone Group in non-marginal successions. An additional ‘waterstones facies’ is also present in the Tarporley Siltstone Formation (Ireland et al., 1978; Rees & Wilson, 1998; Howard et al., 2002).

a) Blocky mudstone facies. This is calcareous silty-mudstone, which often weathers at outcrop to small blocks 1mm to several cm in size (Arthurton, 1980). Colour is dark to pale browny red to pale grey to dark greenish grey. It is a mixture of quartz silt, clay, dolomite and sometimes calcite, with occasional isolated, well-rounded aeolian sand grains. It often contains on sectioned surfaces mm-or sub-mm- scale structures evident by small changes in clay/silt or carbonate content. It may display microstructures including blocky structure (peds ?), clay coatings on coarser grains and void, branching clay films, wispy or ghost-like vague laminae and clay breccias (Talbot et al., 1994). Rarely do the blocky mudstones contain macro structures, which can be easily observed at outcrop, other than cyclical variations in the degree of blocky-ness, or fissility (weathering induced ?). In unweathered sections it units it may contain gypsum veins, nodules or dispersed gypsum grains (Wilson & Evans, 1990; Wilson, 1990, 1993; Talbot et al., 1994).

b) Laminated Facies. This is a heterogeneous mudstone and siltstone facies defined by siltstone (or sandstone) laminae, sometimes graded. Siltstones may be cross laminated, display current or wave-ripples, load structures, clay-breccias, channel-like structures, bioturbation, polygonal mud -crack networks, slumping, psuedomorphs after anhydrite and halite. Colour varies from dark red to pale grey to dark grey, although the laminated facies is predominantly non-red. This facies appears to be more common in basinal successions such as in the Eastern Irish Sea, or Cheshire basins, but is also common in units approximately at the horizon of the Arden Sandstone Fm (Dunscombe Mudstone Fm), or below.

c) Carbonate facies. These are typically very pale grey to white beds, rich in calcite or dolomite. In many respects these are a carbonate end-members of the laminated or blocky mudstone facies, displaying a similar range of macro-scale sedimentary structures, including graded laminae, wave and current ripples, intraformational breccias, channel structures and mud cracks. They may contain primary detrital carbonate grains such as concretional carbonate and ooids (Talbot et al., 1994). This facies is not common, but we will see beds of it at St Audrie's Bay on day 3.

d) Evaporites, either gypsum or halite. Gypsum (and celestite) occurs as either nodules, or more substantial beds, sometimes interbedded with mudstones (Curtis, 1982). It may display chicken wire-texture, or enterolithic texture (Tucker, 1978), or display replacement by dolomite. These textures have been commonly interpreted as a result of formation in ground-waters, due to 'pedogenic' activity (Wright and Sandler, 1994). Halite is present as both relatively pure layered halite or as interbed of mudstone and halite, with halite crystals. This later Hasgebirge lithology, probably indicates the halite was produced insitu within the mudstones, by saline groundwaters (Arthurton, 1973). The Northwich Halite contains large desiccation cracks showing evidence of prolonged growth (Tucker, 1981). Halite beds may also show evidence of penecontemporaneous solution, erosion and collapse. Such beds can be examined in the Dunscombe Mudstone Fm, during day 5.

Interpretation Problems ?

There has been much debate about the environmental origin of the blocky mudstone facies. They have been interpreted as; a) palaeosols, b) the deposits of distal alluvial playas (Tucker, 1978; Talbot et al., 1994), b) permanent lakes successions (Leslie & Tucker, 1992; Milroy and Wright, 2000), or c) loessic dust deposits and d) in the case of the Cheshire Basin hypersaline epieric seas

The lack of preservation of macro-scale structures has always posed a problem for interpretation-, which has lead to the wide variety of interpretations. Hence any interpretation must prove explanations of this feature. An aeolian origin of the blocky-mudstone facies is a persistent interpretation from early studies (Wills, 1970), which have suggested this facies is produced by dry deposition from dust storms, much like the Quaternary Australian parna deposits (Jefferson et al., 2000). Pervasive fabric disruption caused by efflorescent halite crusts and/or the activity of plants and animals (in palaeosols, lacustrine mudstones) are possibilities for lack of macro structure?

In all likelihood there are probably a variety of environmental conditions that form the blocky mudstone which range from distal fluvial sheetfloods, lacustrine playas to aeolian, the distinction of which is most important in any succession cannot easily be ascertained. The problem of where the many 100's of metres of mudstones were derived from also has not been adequately addressed, since age equivalent fluvial sources appear to be absent, or limited to laterally restricted marginal alluvial fans.

The laminated and carbonate facies clearly show the imprint of having been formed in a shallow lacustrine environment.

The occurrence of thick halite units within the basinal successions has posed problems of interpretation. These seem to be polarized around either those that either favour, a) marine waters as a source for such halite- through multiple successive flooding events, or b) those that explain such halite units by evaporation in large continental brine pans and lakes, sourced from river inputs (Australian analogue). The visit to the Northwich Halite in the Winsford salt mine, will provide a useful discussion forum for these ideas.

Arden Sandstone Formation/Dunscombe Mudstone Fm

A regionally persistent unit restricted to the midlands and SW UK basins, which contains sandstone/siltstone intervals, interbedded with non-red, sometimes laminated mudstones, has been referred to either as the Arden Sandstone Formation (basins north of the Variscan front) or the Dunscombe Mudstone Fm (Wessex Basin). This unit appears to occupy part or all of the Carnian, and is probably coeval with halite units (Somerset Halite, Wilksley Halite) in basin centers. Its interpretation is problematic - is it a 'wet' (i.e. freshwater) Carnian interlude, or an interval of extensive marine flooding of the lacustrine playas, responsible for producing the halites also? It probably has some relationship to the events responsible for the Schilfsandstein which seems to be about the same age. We will discuss this further on Days 3 and 5.

The Penarth Group

Marine conditions were not generally established in the UK Triassic until deposition of the Penarth Group. However, this change is pre-empted in the UK by the transition from the red mudstones of the Twyning Formation to the lacustrine –dominated sediments of the Blue Anchor Formation, which for the most part throughout the UK are dominated by greenish, to grayish calcareous and dolomitic mudstones, with occasional black or red mudstones and locally sulphate evaporate minerals. Locally, in places such as Warwickshire, and at basin margin locations, the BAF has an erosive relationship to underlying strata (Barclay et al., 1997; Old et al., 1997), or may overstep onto pre-Triassic units; yet, it does not posses a marine micro or macro fauna until the very latest horizons (we will examine this unit during day 3).

The Penarth group is very similar in its overall succession to the Germanic and southern North Basin Exter Formation/Sleen Shale (and its equivalents), in that it contains a lower black shale unit (the Westbury Formation) and an upper grey mudstone or limestone succession (the Lilstock Formation). The limestone succession (the Langport Member of the Lilstock Formation) is largely restricted to southern England. The base of the Penarth Group is a disconformity, probably throughout the UK. Magnetostratigraphic correlations suggest that substantial amounts of time may be missing across the disconformity, in the relatively complete successions in north Somerset (Hounslow et al., in press). A disturbed horizon within the lower parts of the Lilstock Formation has been variously interpreted as due to local seismic disturbance or shock waves from a bolide impact (Simms, 2003), and it may be related to the events responsible for the late Triassic extinctions. The lowest occurrence of ammonites of the genus *Psiloceras* has been used to mark the Jurassic-Triassic boundary in the British Isles within the overlying Lias Group. A relatively complete succession across the Triassic/Jurassic boundary appears to be present in the UK, and therefore these are important in trying to interpret the causes and consequences for the biotic and environmental changes at this boundary, which are naturally a topic of hot debate.