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Palaeoenvironmental analysis of the late Triassic succession in the Wessex Basin and correlation with surrounding areas

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Palaeoenvironments in the Mercia Mudstone Group (late Triassic) of the Wessex Basin range from non- to fully marine, and freshwater to strongly evaporitic. Widely traceable, fossiliferous and arenaceous sediments of late Carnian age are present. Exposure of channel bedforms in this unit are described, together with facies reconstruction. Correlation with European and North American late Triassic successions is made, and good event correlation can be achieved from the Tethyan successions of Italy to the early rift sediments of the North Atlantic. This implies regional control on sedimentation, basin-wide events being most noticeable in the late Anisian, late Carnian and early Rhaetian. Sea level, modified by tectonism and climatic change may be involved.

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Introduction

The late Triassic Mercia Mudstone Group of the United Kingdom is a thick and widespread succession consisting predominantly of silty and argillaceous red-beds. Warrington (1970) correlated the group with the European Triassic. Increased knowledge of the successions in Europe, and in the North Atlantic continental margin basins, makes event correlation throughout this area a realistic goal. Whilst some progress has been made in understanding the stratigraphy and sedimentology of the Mercia Mudstone Group in specific areas, such as clay mineralogy (Jeans 1978); lithostratigraphy (Elliot 1964; Audley-Charles 1970); biostratigraphy (Warrington 1970, 1981) and sedimentology (Tucker 1978), only limited interpretations can be made about the thick, often monotonous successions of the group in the study area, the stratigraphy of which is shown in Fig. 1. The lithostratigraphy of the Triassic successions exposed on the western margins of the Wessex Basin (in Somerset, Devon and Dorset; Fig. 3) is however becoming better known through study of borehole successions (Warrington and Scrivener 1980; Lott *et al.* 1982; Warrington *et al.* 1986), seismic data (Donato 1988; Ruffell 1990), and outcrop mapping (Warrington and Williams 1984; Edmonds and Williams 1985; Ruffell and Warrington 1988).

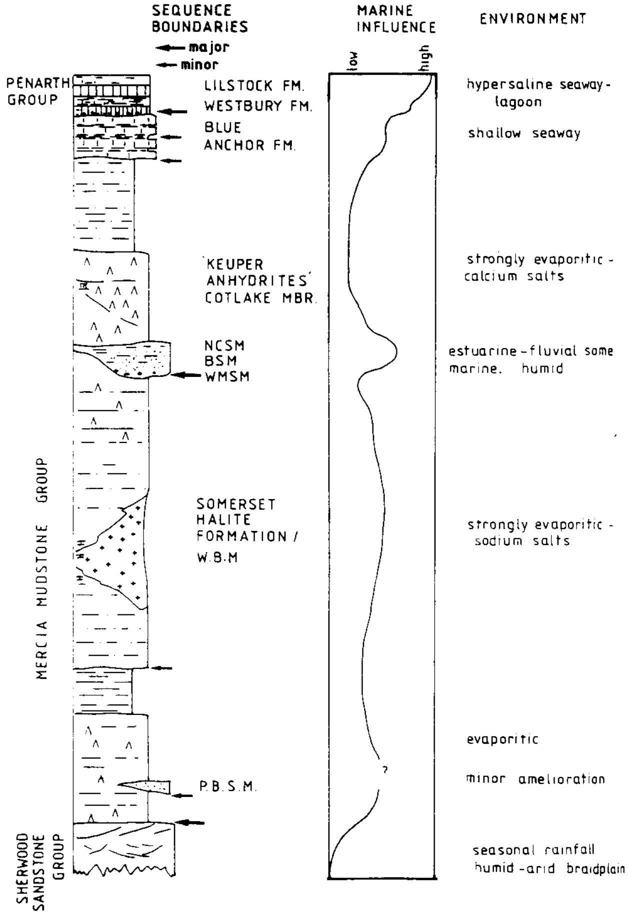

Figure 1. Stratigraphy and palaeoenvironmental interpretation of the Mercia Mudstone Group succession of the western margin of the Wessex Basin (southern England). Stratigraphy from Warrington *et al.* (1980) and Ruffell (1990). NCSM = North Curry Sandstone Member; BSM = Butcombe Sandstone Member; WMSM = Weston Mouth Sandstone Member; WBM= West Buckland Member; PBSM = Poole Brickpits Sandstone Member. Succession varies from 100-400m thick. Sequence boundaries are discussed in text, marine influence after Warrington (1981), adapted.

The Mercia Mudstone Group of the Wessex Basin shows the alternation of evaporitic, argillaceous and silt-sand dominated horizons. As yet however, only individual members or formations have been described, and a complete formal lithostratigraphic nomenclature does not exist, the main problem being defining mappable formations within this often monotonous succession. Within the Mercia Mudstone Group of many parts of the UK is a distinctive arenaceous horizon of late Carnian age, correlatable with similar beds in Germany and France. The position of this member within the succession has been interpreted to be of major palaeoenvironmental significance, either from the change in marine influence suggested to oocur above and below it (Warrington 1981), or possibly associated climatic effects (Simms and Ruffell 1990). Thus it is an ideal horizon on which to concentrate study, with a view to furthering our understanding of the entire group. In the Worcester Graben-Midlands area this arenaceous member is known variously as the Dane Hills, Arden and Newnham Sandstone Member. Its outcrop is well known from mapping in this area. At the western margin of the Wessex Basin, the sandstone is again named variously as the Butcombe, North Curry and Weston Mouth Sandstone Members. The outcrops are also well known, and at all localities the alternating arenaceous and argillaceous sediments yield palynomorphs, sometimes in large numbers and high diversity, of Carnian (late Triassic) age. In addition a variety of sedimentary and bioturbational structures and plant/animal remains occur. The outcrops in the western margin of the Wessex Basin are of especial interest, as there the North Curry Sandstone Member undergoes mappable thickness changes which define broad (1-10km wide) channels, filled with arenaceous and argillaceous sediments up to 15m thick. Between such channel areas, thin arenaceous and cemented beds occur with blue-grey, commonly structureless mudstones (Fig. 4), interpreted to be overbank deposits to the channels. A similar depositional environment has been proposed for this horizons' correlative, the Schilfsandstein of Germany, Luxembourg and France (Wurster 1964a,b).

Stratigraphy of the Mercia Mudstone Group

Fig. 2 summarises the stratigraphical correlation of the Mercia Mudstone Group from the margins of the Wessex Basin to areas close to the late Triassic depocentre of the basin (Sellwood *et al.* 1986; Whittaker 1985). Correlation of the beds described at outcrop (Ruffell 1990) to the divisions made by the analysis of geophysical borehole logs (Lott *et al.* 1982) can be achieved by utilising the North Curry Sandstone (and correlatives) as a datum. This arenaceous and fossiliferous horizon separates Mercia Mudstone Group sediments that are often calcareously cemented at outcrop (eg. Cotlake and West Buckland Members), that pass laterally (in the subsurface) into halite beds (the Somerset Halite Formation) below, and gypsiferous/anhydritic beds above. In the vicinity of Palaeozoic basement rocks exposed in the Mendip and Quantock Hills, the Mercia Mudstone Group cannot be further subdivided and passes laterally into the Dolomitic Conglomerate (Green and Welch 1965). Whether the Dolomitic Conglomerate and Mercia Mudstone Group are wholly, or in part, correlatives is not known. It is thus possible that the North Curry Sandstone-Butcombe Sandstone Members pass laterally into the conglomerate.

Two arenaceous members in the Mercia Mudstone Group show interesting lateral thickness and facies changes (see below). The Poole Brickpits Sandstone Member is an impersistent sandstone body (Ruffell 1990) developed around Wellington in Somerset. It is lithologically similar to the higher North Curry Sandstone Member (Warrington and Williams 1984), which can be traced laterally as a continuous sand body (eg. Matley 1912), or as a series of channels developed at the same stratigraphic horizon in the Mercia Mudstone Group (Fig. 3).

These arenaceous beds mark a vertical facies association and cyclicity to the Mercia Mudstone Group: it is interesting to note the association of the Poole Brickpits Sandstone Member and North Curry Sandstone Member with anhydritic silty mudstones. Deposition of these beds was often followed by mudstone developments (divisions B and E of Lott *et al.* 1982), marking a lower and upper cycle comprising anhydrite-sandstone-anhydrite-mudstone of the Mercia Mudstone Group in the study area. This cyclicity equates with the stratigraphy of the Devon Coast exposures (Jeans 1978). The Somerset Halite Formation does not conform to this cyclicity, occuring as it does within silty mudstones (Lott *et al.* 1982) and marking the point at which the Wessex Basin was most evaporitic. Why sodium salts precipitated at this level and calcium salts at others above and below is not clear.

Determining a chronostratigraphy for the poorly fossiliferous Mercia Mudstone Group is difficult. Best estimates suggest that deposition of the group encompasses the late Anisian/early Ladinian to Rhaetian stages (Warrington *et al.* 1980), of around 30Ma duration (Harland *et al.* 1982). Comparison of this estimated chronostratigraphy with the sequence stratigraphy of the Exxon

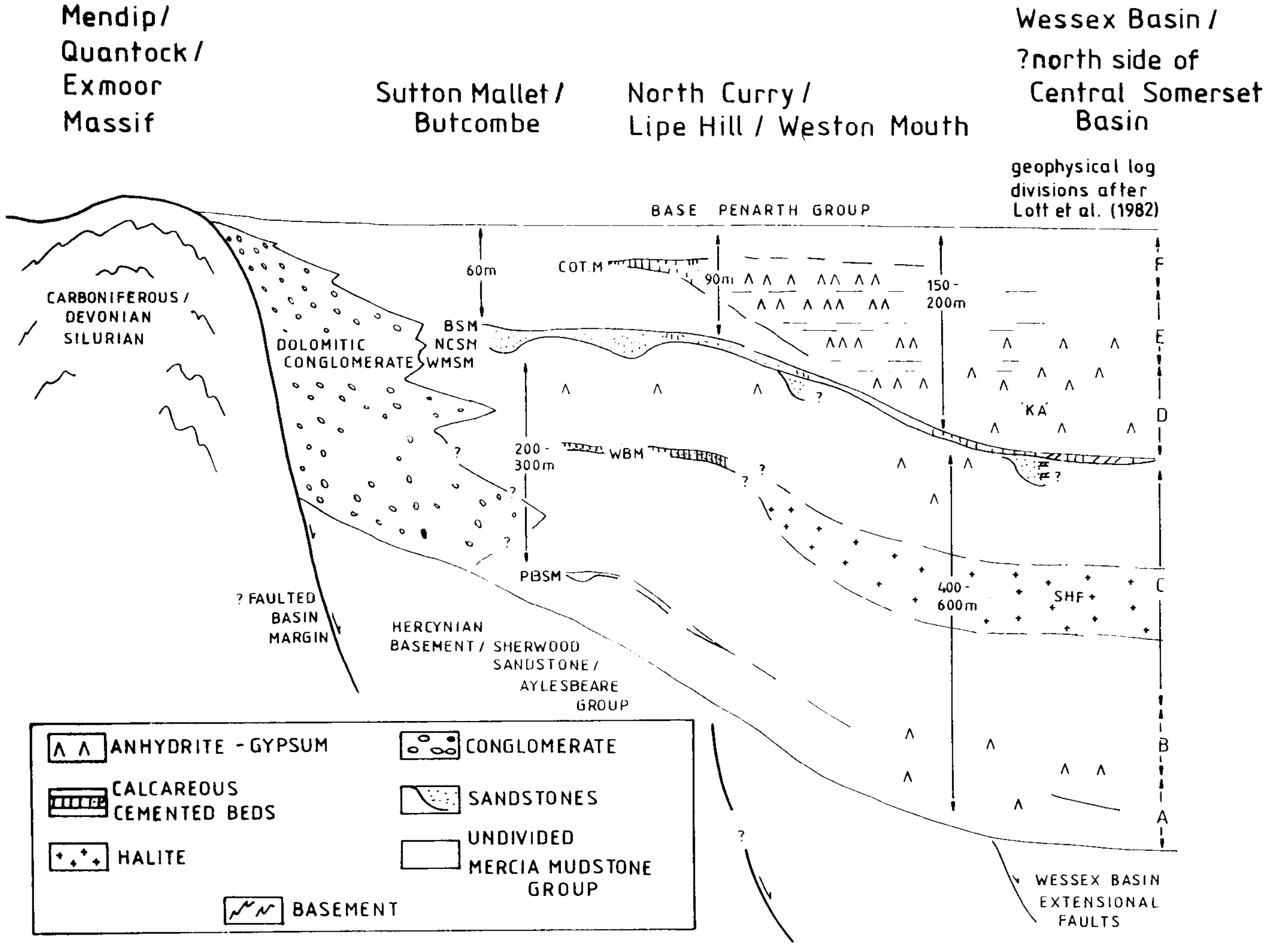

Figure 2. Hypothetical cross-section across the western margin of the Wessex Basin, Vertical scale approximate, known measurements are given. Horizontal scale (basin margins to centre) varies from 30-100km. COT.M = Cotlake Member; 'KA' = 'Keuper Anhydrites'; BSM = Butcombe, NCSM = North Curry; WMSM = Weston Mouth Sandstone Members; SHF = Somerset Halite Formation; PBSM = Poole Brickpits Sandstone Member.

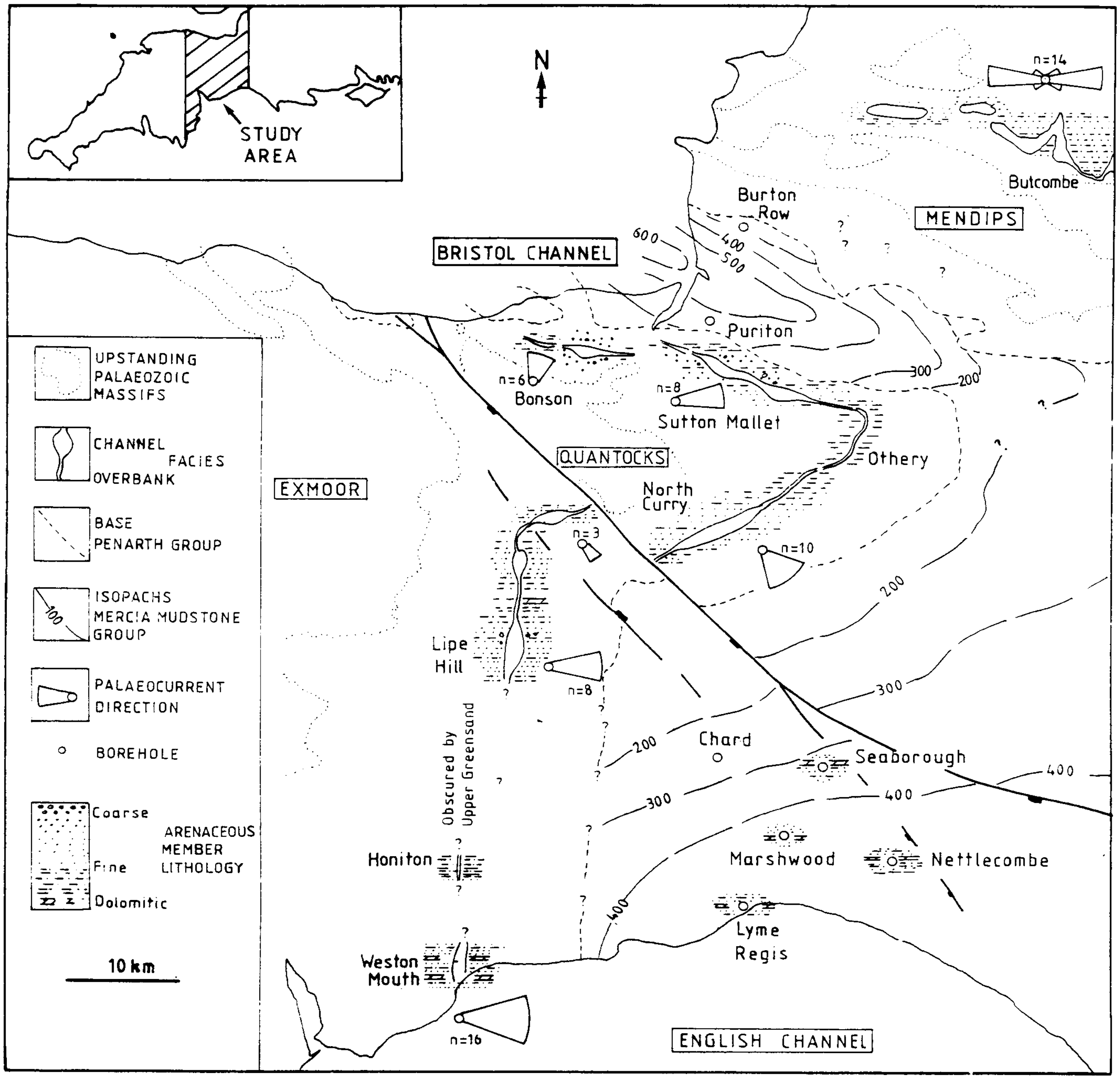

Figure 3. Palaeogeography of the western margins of the Wessex Basin in late Carnian times, with some post-depositional structural information such as isopachs and major faults. Channel outlines have no vertical scale or outcrop pattern.

`Cycle Chart' (Haq *et al.* 1988), suggests that at least two major sequence boundaries (unconformities or their correlative conformities) occur within the group.

Candidate sequence boundaries within the Mercia Mudstone Group can be identified where major facies changes across the basin, that occur concomitantly with erosive or suggested non-depositional episodes, can be compared to the strong seismic reflection horizons known from within the group (Donato 1988; Ruffell 1990), and the abrupt shifts in response from borehole geophysical logs (Lott et al. 1982). Poorly dated sequence boundaries are thus thought to exist at the Sherwood Sandstone-Mercia Mudstone Group boundary, at the base of the North Curry Sandstone Member (and correlatives), and at the base of the Penarth Group. Minor sequence boundaries are also evidenced by abrupt lithological changes at the level of the Poole Brickpits Sandstone Member (Ruffell 1990), and at the base of Lott *et al.'s* (1982) division C. An abrupt shift in gamma-ray and sonic log signatures is also found at the base of their division F, corresponding to the alternating grey cemented and red uncemented beds of the Blue Anchor Formation below the Penarth Group. Mayall (1981) documented a major facies change and/or truncation at this level in north Somerset, whilst Ruffell (1990) thought it probable that the base of the Penarth Group truncated mappable markers in the Mercia Mudstone Group below, to the east of Taunton.

These major changes in late Triassic deposition accord with the analysis of Warrington (1981), who suggested greater marine influence below the Carnian North Curry Sandstone Member (and correlatives), returning in the Penarth Group/Rhaetian. Warrington's times of change in marine influence occur at the levels thought here to be sequence boundaries from other evidence.

Palaeoenvironmental descriptions for various levels in the Mercia Mudstone Group of the Wessex Basin are shown in Fig. 1 after Whittaker (1972), Jeans (1978), Warrington (1981) and Simms and Ruffell (1990). The most contentious level in the group is the North Curry Sandstone Member (and correlatives), which Jeans

(1978) and Fisher and Jeans (1982) ascribed to increased marine influence, but which Simms and Ruffell (1990) preferred to describe as part of a Europe-wide climatic change. Warrington (1981) documented this level as the change from poorly bedded Mercia Mudstone Group below, to well-bedded lithologies above, and suggested a decrease in marine influence. The similarity of the North Curry Sandstone Member to the 'Waterstones' lithologies of the Colwick Formation in Nottinghamshire (Warrington *et al.* 1980) supports Jeans (1978) interpretation that marine influence had a control on the beds' deposition. This, however, is supported by corollary only, as evidence of marine influence is well-known in the Waterstones (Warrington 1967; Ireland *et al.* 1978), but is not documented in the North Curry Sandstone Member or its correlatives, of the Wessex Basin, and is very infrequent and not unequivocal elsewhere. However, as Anderton *et al.* (1979) point out for the Waterstones, an increase in open marine influence under 'transgressive' conditions also led to climatic amelioration (Walker 1968). The same scenario could be developed for the North Curry Sandstone Member and its correlatives to reconcile the views of Jeans (1978), Warrington (1981) and Simms and Ruffell (1989).

Exact depositional environments for much of the Mercia Mudstone Group are still poorly defined and range from `playa lakes' (Petrie *et al.* 1990; Simms and Ruffell 1989) and 'epeiric seaways' (Warrington 1981) to evaporitic lakes (Jeans 1978). These descriptions seem to indicate a hypersaline seaway over much of Europe. Careful palaeoenvironmental reconstruction of the North Curry Sandstone Member (and correlatives), the horizon with good correlation potential and fossils/sedimentary structures, is an obvious target for understanding the depositional environment of the whole group, and its vertical facies and sequence stratigraphic changes.

Sedimentology of the North Curry-Weston Mouth-Butcombe Sandstone Members

The mapped occurrences, palaeontology and stratigraphy of the arenaceous beds found usually 50-100m beneath the base of the Penarth Group (Arden, North Curry Sandstone Members, etc.) are well-documented and summarised in Warrington (1991). What is evident in the Somerset-Devon area is that arenaceous beds undergo gross thickness changes (1-20m) over distances of 1-5km; that the beds usually show an erosive base, with some internal erosion surfaces and a conformable top; and that these arenaceous beds fringe the upstanding Palaeozoic massifs of the present day (Warrington and Williams 1984). Palaeocurrent data from the area (Warrington and Williams 1984; Ruffell and Warrington 1988; Ruffell 1990; Warrington 1991) have been supplemented by 65 further measurements from aligned plant debris and macrofossils (eg. Euestheria); cross-stratification; ripple-drift laminations and channel orientations (Fig. 3). These suggest that current flow was away from the upstanding massifs of the west of England and Wales, but toward the London Platform. Grain-size variations within the arenaceous beds are uncommon, just as Wurster (1964a) discovered in the beds' equivalents in Germany (the Schilfsandstein). A notable departure from medium to coarsegrained sands occurs in the Sutton Mallet area north of Bridgwater in Somerset (Ruffell 1990), which is closer to the Quantock 'landmass' to the west (Fig. 3). This palaeogeography fits well the isopach evidence of Whittaker (1973), wherein the NE flowing palaeocurrents of the Bonson locality (Fig. 3; locality details in Edmonds and Williams 1985) are directed toward the depocentre of the Central Somerset Basin, and the east-flowing palaeocurrents of Sutton Mallet and North Curry flow toward the depocentre of the Wessex Basin. The channel-like outcrop of the beds in the Wessex Basin also seems to be a function of proximity to depositional basin margins and thinner successions, being less common in the Arden Sandstone Member of the Midlands (Matley 1912).

Few thick arenaceous beds are recorded from the subsurface of the Wessex Basin at this horizon. This may be a product of hydrocarbon tests being drilled on 'high' structures and possibly explains why the Weston Mouth Sandstone Member at the type locality is thick (over 14m) and preserved within a thick, possibly basinal succession (Fig. 2). There is evidence that the broad channels of the North Curry Sandstone Member etc. in the Somerset area were contemporaneous depositional features and not due to post-depositional erosional effects. Warrington and Williams (1984) and Ruffell and Warrington (1988) showed that thick arenaceous successions pass laterally into thin (around one metre thick) blue mudstones, with occasional cemented sandstone beds (Fig. 4). Such facies changes are easily traced by virtue of the strong topographical feature formed by the channel-centre beds, and its diminution where associated with the thin, argillaceous beds found in intervening areas. These may be termed 'overbank' or 'interchannel' areas. This observation, first made in the Taunton area of Somerset (at the type locality of the North Curry Sandstone Member: Warrington and Williams 1984), is borne out by the excellent exposures at Sutton Mallet, north of Bridgwater (see Ruffell 1990 for localities). The schematic development of such facies change across the North Curry Sandstone channels is shown in Fig. 4.

Excellent exposure of the 'overbank' facies occurs in a cutting at Sharpenton Hill near Bridgwater (ST 39933575), which shows the blue mudstones to have a series of curvilinear planes at 90° to 40° through the bed, reminiscent of vertisol profiles (Wright 1990). Vertisols are produced by successive wetting and drying of soil horizons, a process considered likely for the palaeo-environment envisaged (see below). The Sutton Mallet and Bonson exposures of the North Curry Sandstone Member occur on the south side of the Glastonbury Syncline/Central Somerset Basin (Whittaker 1973, 1985). In the Triassic outcrop to the north of the syncline, where the Mercia Mudstone Group is 3 to 4 times as thick (Green and Welch 1965) as that fringing the Mendips, Quantocks and Exmoor, the North Curry-Butcombe Sandstones are absent. This is a situation in which depositional thinning into a basin depocentre, such as that thought to occur in the Wessex Basin to the south (Fig. 2) can be demonstrated for the sandstones.

Summary of late Carnian depositional conditions

The channel-like formation of the North Curry Sandstone and equivalent members; its ichnofauna (Warrington and Williams 1984; Ruffell and Warrington 1988) and its similarity to the Waterstones (Ireland *et al.* 1978) suggests an estuarine channel or fluvial delta environment of deposition. A strong terrestrial influence on deposition is also suggested by the abundant plant debris, reptile fauna, kaolinite and coarser grade arenites adjacent to contemporaneous landmasses. In conflict to this, the beds contain clay minerals interpreted to form under marine influence (Fisher and Jeans 1982). The broad palaeoenvironmental analysis of Warrington (1981) suggests that marine influence waned in the Norian, after deposition of the arenaceous members. The sequence stratigraphic analysis of the succession (Fig. 1) uses evidence of erosion at the base of the North Curry Sandstone Member as representing a major break in deposition. This would require a sea level fall, as predicted by the Exxon 'Cycle Chart' (Haq *et al.* 1988). Is the channel-prone incursion of arenaceous sediment in the late Carnian of the Wessex Basin best explained by a

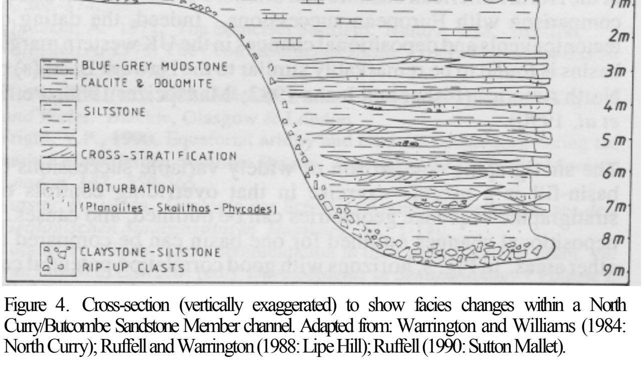

Figure 4. Cross-section (vertically exaggerated) to show facies changes within a North Curry/Butcombe Sandstone Member channel. Adapted from: Warrington and Williams (1984: North Curry); Ruffell and Warrington (1988: Lipe Hill); Ruffell (1990: Sutton Mallet).

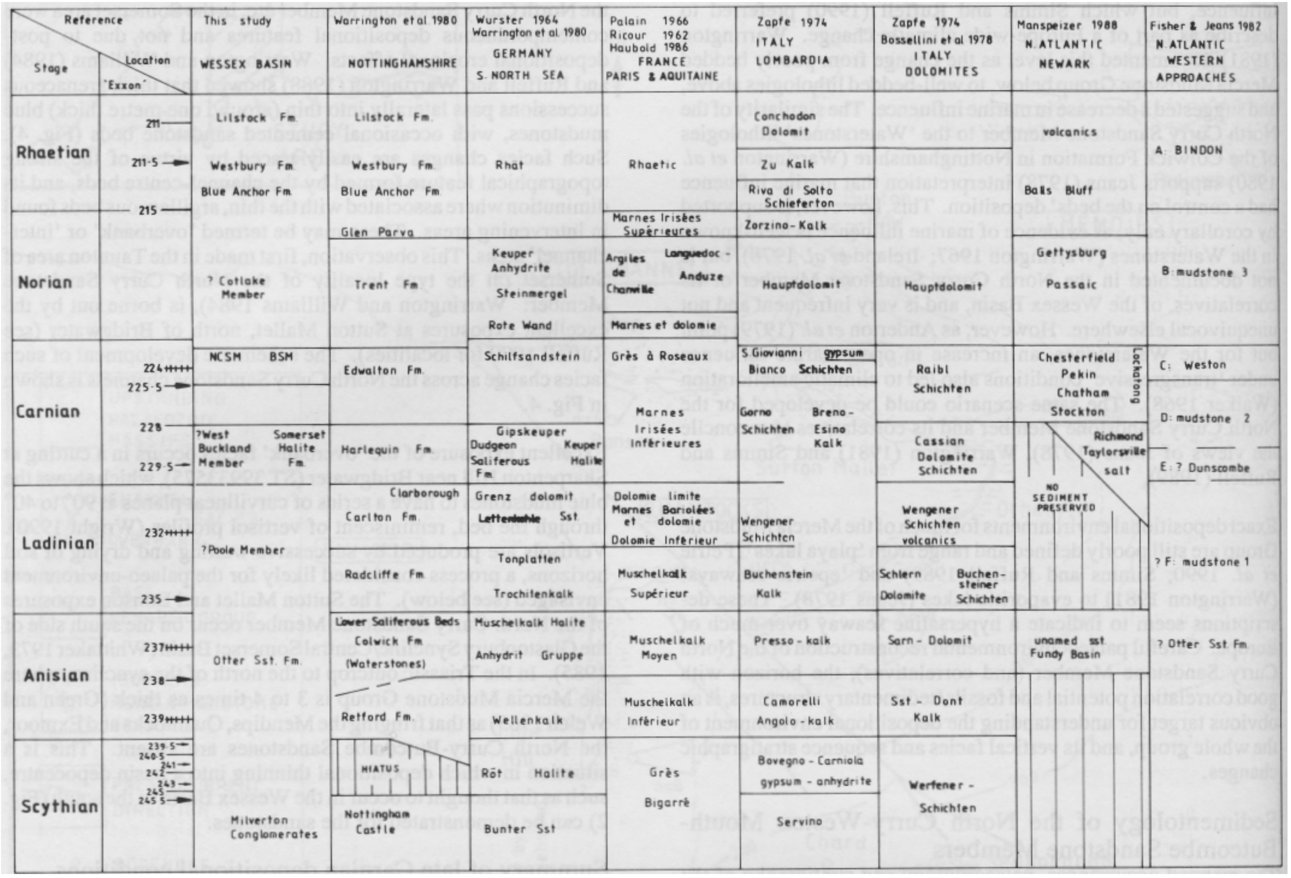

Figure 5. Correlation of the Wessex Basin succession with adjacent Triassic basins. The 'Exxon' column *is* from Haq *et al.'s* (1988) `Cycle Chart'. Cross-hatched lines are type 1 sequence boundaries, plain lines are type 2 sequence boundaries, arrows are maximum flooding surfaces.

Waterstones-type transgression followed by sea level fall, erosion and influx of sand? Examination of the work of Manspeizer (1988) suggests that the Carnian was a time of extensive North Atlantic rifting, and thus a linked tectonic - sea level rise and fall - climatic change might be envisaged whereby early rifting and marine incursion allowed maritime influence to be increased in western England, followed by sea level fall and then a return to an arid climate.

Correlation with adjacent Triassic successions

Within the `Germanic' Triassic of Europe, correlation of the Keuper succession within Germany, France, the Benelux countries and the UK is possible (Wurster 1964a, b; Warrington 1970). Individual horizons can also be correlated with the type sections of the marine Triassic in the Alps, by virtue of their microfossils, although stratigraphic comparison of the entire Triassic between these areas has never been attempted. In addition, our knowledge of the North American onshore and offshore Triassic basins allows comparison with European successions. Indeed, the dating of tectonic events and depositional changes in the UK western margin basins is found to be remarkably similar to the Newark Basin(s) of North America (Fisher and Jeans 1982; Manspeizer 1988; Petrie *et al.* 1990).

The stratigraphic comparison of widely variable successions of basin-fill is a useful exercise in that overriding controls on stratigraphic sequence geometries can be outlined, and causes of depositional changes outlined for one basin can be compared to other areas. In Fig. 5, horizons with good correlation potential can be highlighted: the Muschelkalk-Waterstones horizon of the Anisian and the late Carnian arenaceous influx being good examples. Marine transgression in the Rhaetian provides another useful event, which is well-constrained biostratigraphically.

Halite deposits also make useful subsurface correlatives between basins and suggest an overriding control to their formation. The Rot Halite-Bovegno/Carniola evaporites; the Muschelkalk-Lower Saliferous Beds; and the Richmond/Taylorsville Salt - Dudgeon Saliferous Formation - Somerset Halite Formation are all excellent examples. Their correlation with episodes of sea level rise shown on the Haq *et al.* (1988) `Cycle Chart' suggests that marine transgression is fundamental to their formation.

Depositional changes in the mid to late Triassic deposits of Europe and the North Atlantic continental margins show good correlation with events (such as sequence boundaries and maximum flooding surfaces) thought to be the result of sea level changes in the Haq *et al.* (1988) `Cycle Chart'. It should be noted that the Exxon Group utilise approximations of the absolute age of their events (eg. 214Ma) as a form of notation, when no accurate radiometric dates for these events exist. The actual age-determination of events is derived from the biostratigraphical divisions of a variety of outcrop sections compared to records from seismic stratigraphy (Haq *et al.* 1988). Some of this data has come from sections in the Italian Dolomites, also used in this study (Doglioni *et al.* 1990). Thus there is some danger of circular arguments when discussing this section: the correlation that can be achieved between this Tethyan succession and the `Germanic' Trias sections demonstrates the regional rather than local nature of events.

The use of Exxon's sequence stratigraphic age-notation here is merely to facilitate comparison to Haq *et al.'s* (1988) chart and implies nothing about the absolute age of the horizons discussed. The 239Ma major sequence boundary corresponds to the base Retford Formation hiatus (Warrington *et al.* 1980). The Muschelkalk transgression matches the 238Ma maximum flooding surface. The following elastic inputs to many basins might be representative of the 237Ma major sequence boundary. The age of the Muschelkalk

Superieur compares well to the 235Ma maximum flooding surface of the chart, whilst the following 232Ma sequence boundary is well-represented in the north European Germanic Trias by the Lettenkohle Sandstone and Wengener Schichten. A sequence boundary in the early Carnian of the `Cycle Chart' is difficult to trace, except possibly as Fisher and Jeans (1982) 'Dunscombe Cycle'. The following 228Ma maximum flooding is evident by the widespread development of mid-Carnian evaporites. A maximum flooding surface (225Ma) followed by sequence boundary (224Ma) coincide with the known age-range of the North Curry Sandstone Member (and correlatives); Schilfsandstein; Raibl Schichten and Lockatong Formation. A Carnian-Norian boundary maximum flooding is difficult to trace in the study area. The 215Ma sequence boundary of the Norian-Rhaetian has been discussed above in relation to Somerset and the base of the Penarth Group. The transgression of the 211.5Ma maximum flooding surface and 211Ma sequence boundary are equated (respectively) with the Westbury and Lilstock Formations.

Conclusions

Facies analysis of the late Triassic of the Wessex Basin, and especially of the late Carnian arenaceous sediments, suggests that sea-level control was fundamental in controlling deposition. The rifted North Atlantic provided a route for the transgression of late Triassic shelf seas, possibly for the penetration of marine waters that led to a humid climate in the Carnian. Sea-level control is supported by the good event correlation that can be achieved from North America to the Italian Alps. A good comparison of depositional events with the Exxon `Cycle Chart' (Haq *et a1.* 1988) provides some evidence for global eustatic control, while clear evidence of times of linked tectonics, sea level and climatic change in the late Carnian tend to contradict this.

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