THE STRATIGRAPHY AND SEDIMENTOLOGY OF THE DUNSCOMBE MUDSTONE FORMATION (LATE TRIASSIC) OF SOUTH-WEST ENGLAND

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The mid to late Triassic Mercia Mudstone Group exposed on the east Devon coast between Sidmouth and Seaton consists of *c*. 450 m of predominantly red mudstones that were deposited in low-relief sabkha environments in hot deserts. In marked contrast to this, the Dunscombe Mudstone Formation in the middle part of the group consists of 35-40 m of interbedded and interlaminated green, purple and grey mudstones, breccias, muddy limestones and lenticular siltstones/sandstones that were deposited in a wetter, possibly cooler climate. The formation is poorly exposed inland, but the striking colour difference from that of the adjacent formations enables its outcrop to be traced more or less continuously from the Devon to Somerset coasts. A detailed study of the sedimentology and ichnology of the formation, in particular that of laterally impersistent arenaceous members in its lower part, has shown that it was deposited in a succession of shallow, freshwater lakes in a low-relief topography that was at times crossed by broad shallow distributary channels. A combination of palynology and magnetostratigraphy is interpreted to represent that the Dunscombe Mudstone Formation is a condensed succession that occupied most of the late Triassic Carnian Stage, about 11.5 million years. It was deposited at a time of active tectonic subsidence, as a result of which it is laterally highly variable in thickness. In its extensive subcrop in the Wessex and Bristol Channel basins it locally reaches over 150 m in thickness in the more rapidly subsiding graben areas by the addition of halite. The northern boundary of the depositional area roughly followed the Variscan Front, along the line of the present-day Mendip Hills and South Wales coast.

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INTRODUCTION

The mid to late Triassic Mercia Mudstone Group in south-west England crops out on the east Devon coast, in the floors of the deeper valleys in east Devon beneath an unconformable cover of Cretaceous rocks, and over a broad area of south Somerset (Figure 1). It is divided into four formations in this region, in ascending order the Sidmouth Mudstone, Dunscombe Mudstone, Branscombe Mudstone and Blue Anchor formations (Gallois, 2001). About 380 m of the group total of *c*. 450 m exposed on the east Devon coast between Sidmouth and Seaton consists of relatively structureless red mudstones (Sidmouth and Branscombe Mudstone formations) that were deposited in low-relief sabkha environments in hot deserts. In contrast, the intervening Dunscombe Mudstone Formation consists of up to 43 m of interbedded and interlaminated green, purple and grey mudstones, breccias, limestones, siltstones and sandstones that were deposited in a wetter, possibly cooler climate.

In the east Devon cliffs, the most prominent Dunscombe Mudstone Formation lithology is a friable-weathering green mudstone, that contrast with the red-brown mudstones of the underlying and overlying formations. Woodward and Ussher (1911) referred to this as a conspicuous "hard greenish band", and Warrington and Scrivener (1980, figure 3) incorrectly identified it as a 20 m-thick sandstone. This was formally named the Weston Mouth Sandstone Member by Warrington *et al*., (1980).

Lenticular beds of siltstone and fine-grained sandstone are present in the lower part of the Dunscombe Mudstone Formation at several localities in south-west England, but they represent only a small percentage by volume of the formation. At outcrop on the Devon coast, the thickest of these units has been named the Lincombe Member (Porter and Gallois, in press). In Somerset, sandstones in the Taunton-North Curry and Sutton Mallet areas (Ussher, 1908) have been named the North Curry Sandstone Member (Warrington *et al*., 1980) and Sutton Mallet Sandstone Member (Porter and Gallois, in press) respectively.

OUTCROP DETAILS

The Dunscombe Mudstone Formation is wholly exposed in a series of disconnected sections in the cliffs adjacent to Weston Mouth on the east Devon coast, and its outcrop can be traced intermittently from there to the Devon-Somerset border north of Luxton (Figure 1). It emerges from beneath the Cretaceous rocks of the Blackdown Hills south of Taunton and has a more or less continuous outcrop, albeit displaced in part by faulting, between there and Stathe. Northwards from there, the outcrop is broken by faulting and the formation is largely obscured by the Recent sediments of the South Somerset Levels (Figure 1). It crops out in a fault-bounded outlier on the north side of the Levels between Moorlinch and Sutton Mallet, and is cut out by faulting between there and the Somerset coast. Blocks of green mudstone and fragments of sandstone are exposed in a fault breccia at the junction of the Sidmouth and Branscombe Mudstone formations at St Audries Bay on the Somerset coast.

Inland sections in the Dunscombe Mudstone Formation in Devon and Somerset are confined to a small number (< 10 recorded) of natural exposures and a few overgrown quarries and sunken lanes. None of these expose the full thickness of the formation and most expose only a small part of it. The most complete inland sections currently extant in Devon are in a stream bed (SY 160 995) at Littletown, Honiton and a sunken lane (ST 166 047) at Penny Thorn Cross, Luppitt.

The Lincombe Member is well exposed at the type section, but has not been recorded inland in Devon. In Somerset, lenticular sandstones in the lower part of the formation give rise to prominent topographical features notably between Lipe Hill and Norton Fitzwarren (Ruffell and Warrington, 1988), between Knapp and Stathe (Ussher, 1908; Warrington and Williams, 1984) and between Moorlinch and Sutton Mallet (Ussher, 1908; Ruffell, 1990). The thicker sandstones were formerly quarried for building purposes, notably in the North Curry area and at Sutton Mallet. They remain the best exposed part of the formation in Somerset, partly because a few of the quarry sections have survived and partly because the sandstones form

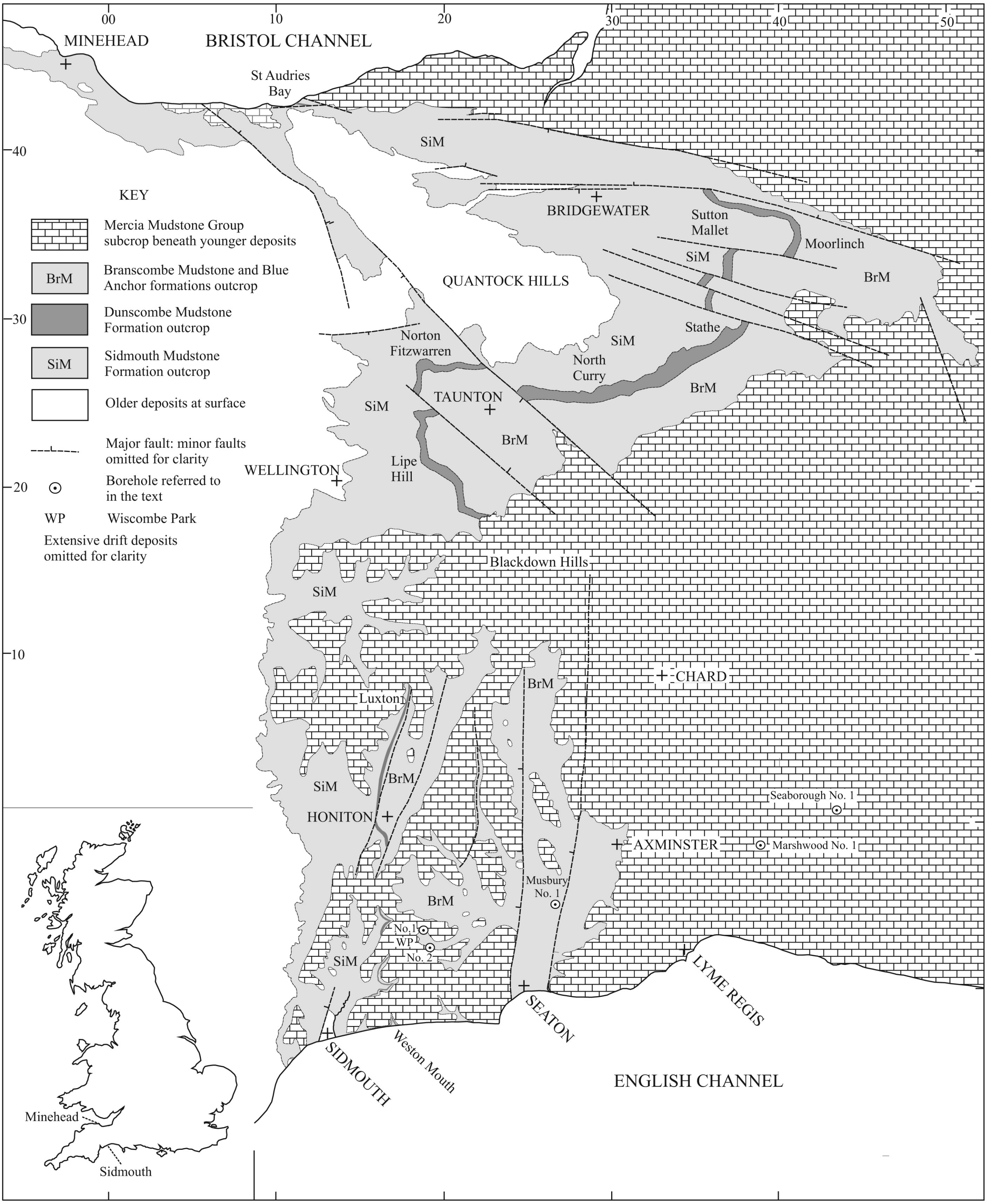

Figure 1. *Geological sketch map showing the distribution of the Mercia Mudstone Group and Dunscombe Mudstone Formation in the south-west England and the positions of localities and boreholes referred to in the text.*

a topographical feature that is traversed by several sunken lanes. At each locality, the sandstones are overlain by 20+ m of predominantly green mudstones that make up the bulk of the Dunscombe Mudstone Formation.

The Dunscombe Mudstone Formation was partially cored in two boreholes at Wiscombe Park (SY 1819 9382 and SY 1845 9273), about 5 km north of the east Devon coast sections (Figure 1). The formation has an extensive subcrop in the Wessex Basin where it has been proved in the uncored parts of numerous hydrocarbon-exploration boreholes (Gallois, 2003), and a less well explored subcrop in the Bristol Channel Basin.

TYPE SECTION

The type section of the Dunscombe Mudstone Formation is a series of cliff faces below Weston Cliff (SY 168 880 to 171 880) which, taken together, expose the full thickness of the formation (Figure 2). The original type section of the formation was defined (Gallois, 2001) as a series of sections below Higher Dunscombe Cliff (SY 152 877 to 156 878). However, these are difficult to access safely and subsequent work has shown the higher part of the formation there is cut out by the unconformity at the base of the Upper Greensand Formation. The positions of the best exposures vary over relatively short periods (5 to 20 years) due to landslip and a variable covering of weathered material derived from the overlying beds. However, Jeans' (1978) description of the succession made in the 1970s is similar to that made in 2001-2005 by the present authors (Figure 3). In recent years the base of the formation has been well exposed below Higher Dunscombe Cliff [SY 1544 8780], adjacent to Lincombe [SY 1584 8796], and below Weston Cliff (sections 1, 2, 4 and 8 in Figure 2). The top of the formation is well exposed over c. 250 m of cliff below Weston Cliff (sections 4 to 8 in Figure 2).

The total thickness of the Dunscombe Mudstone Formation exposed in the cliffs at and adjacent to the type section varies from c. 35 to 43 m. This variation is due to two principal factors: the presence of the lenticular Lincombe Member (1.5 to 4.0 m thick) in the lower part of the formation, and laterally impersistent beds of breccia at several levels. The breccias in the lower part of the formation probably formed penecontemporaneously by the repeated growth and dissolution of gypsum/anhydrite. Some of those in the upper part probably formed by the dissolution of gypsum and possibly salt some considerable time after deposition.

The base of the formation is defined as the base of a thin (20 to 50 mm thick) bed of dark grey laminated mudstone that rests with marked lithological contrast and sedimentary break on red-brown mudstone at the top of a thick (c. 200 m) succession of red-brown mudstones in which beds of green mudstone thicker than 200 mm are rare and grey mudstones and limestones are absent. The junction with the overlying Branscombe Mudstone Formation is taken at the base of a thick (c. 150 m) succession of red-brown mudstones that contains few green beds and no limestones or dark grey mudstones. In the type section the junction is marked by an erosion surface that rests on a muddy limestone with calcite-lined vugs.

The calcareous beds (A to N in Figure 3) form prominent, pale weathering marker beds in the cliffs. Several of these have been recorded inland in weathered and/or disturbed sections in stream beds, but in the absence of palaeontological control they cannot be correlated with individual beds in the type section. Correlations can, however, be made with some of these beds in the continuous cores of the Wiscombe Park Borehole where the mudstone colours and distinctive sedimentary features are preserved. Inland, the calcareous horizons dissolve in the weathered zone and the brecciated horizons and purple-red mudstones form red-brown subsoils that differ little in colour or texture from those derived from the Sidmouth and Branscombe mudstone formations. The recognition of the Dunscombe Mudstone Formation in poorly exposed inland areas is, therefore, largely dependent on the presence of the thicker beds of green mudstone.

Comparison of the few exposures in the Lincombe Member, North Curry Sandstone and Sutton Mallet sandstones and the adjacent strata, shows that although they are all in the lower part of the Dunscombe Mudstone Formation they are not necessarily at the same stratigraphical level (Figure 4).

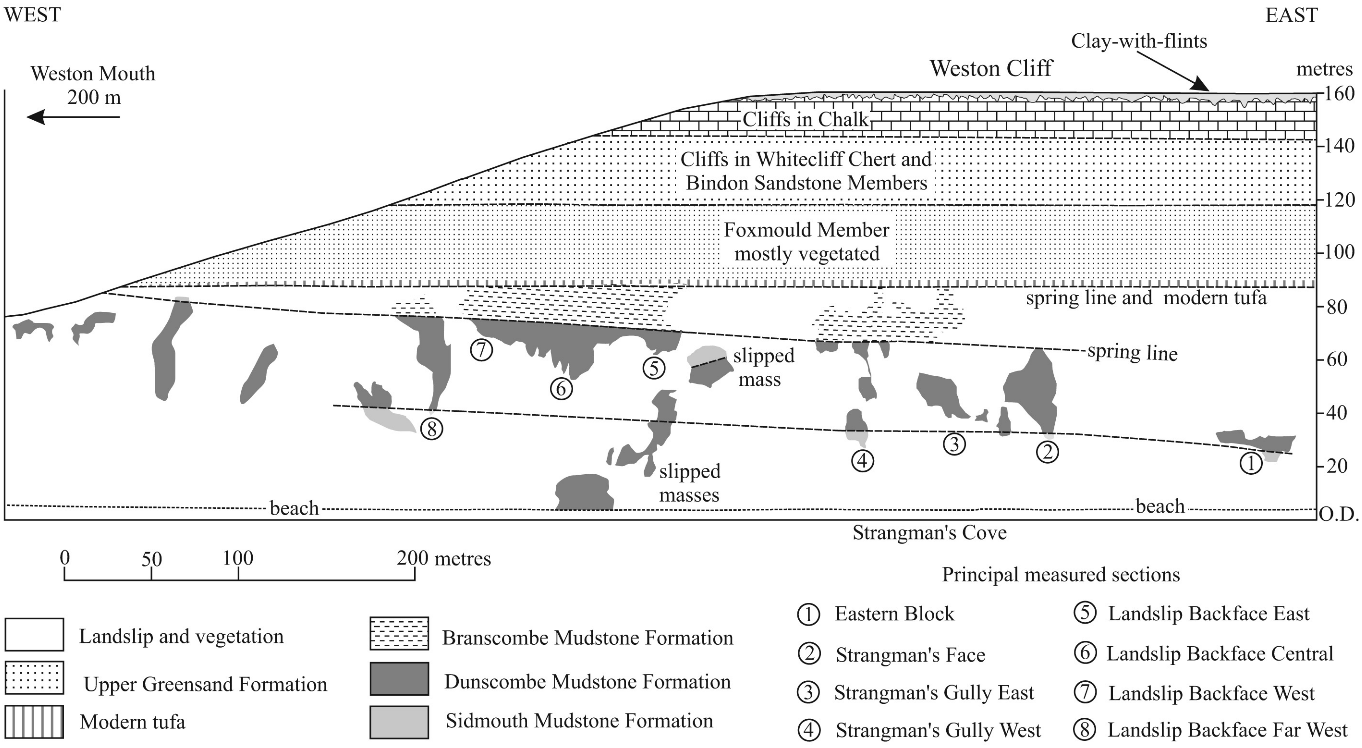

Figure 2. *Type section of the Dunscombe Mudstone Formation below Weston Cliff, Devon based on photographs taken in May 2004.*

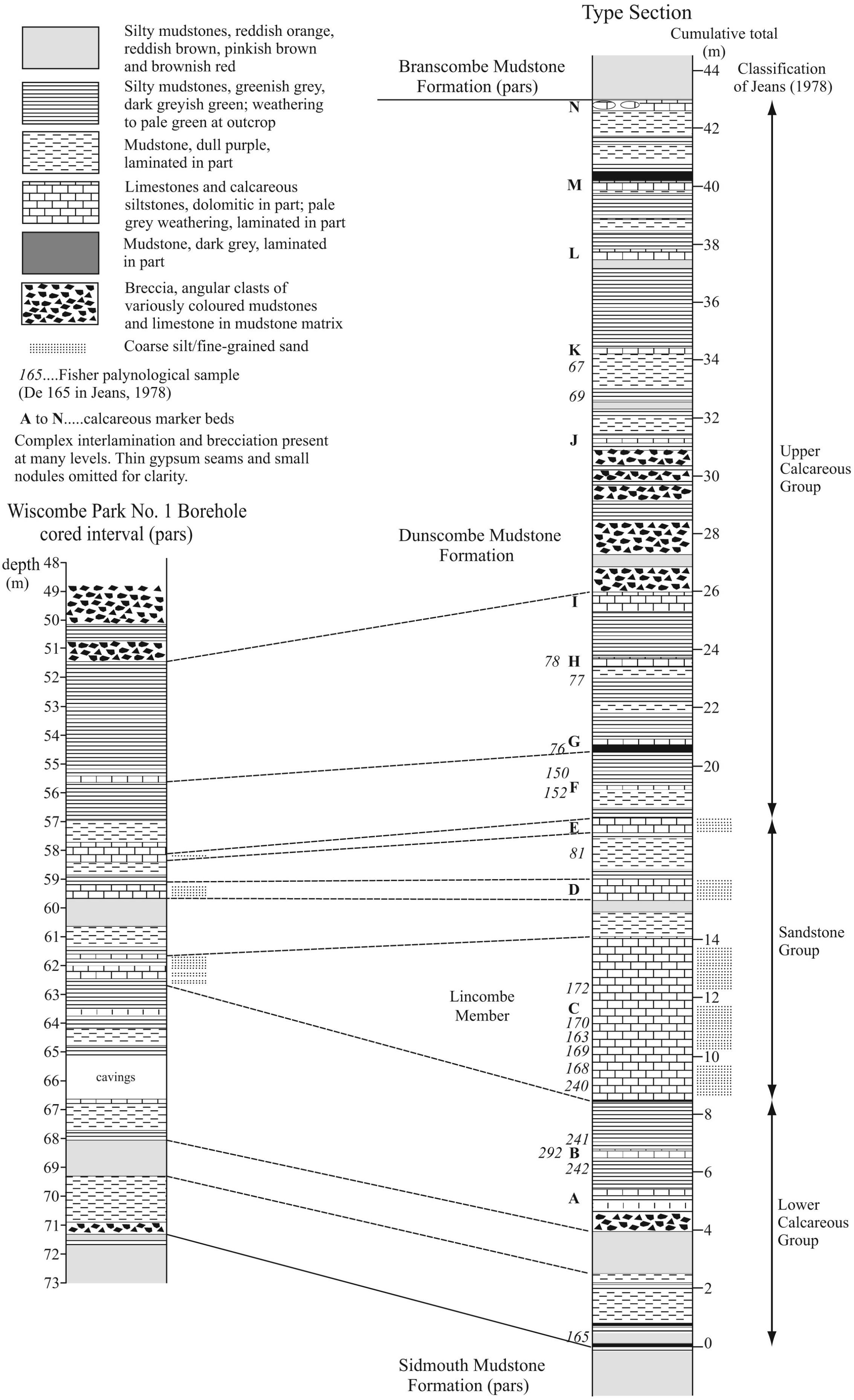

Figure 3. *Correlation of the Dunscombe Mudstone succession exposed at the type section below Weston Cliff (1660 8810 to 1730 8810) with that proved in the cored interval of the Wiscombe Park No.1 Borehole.*

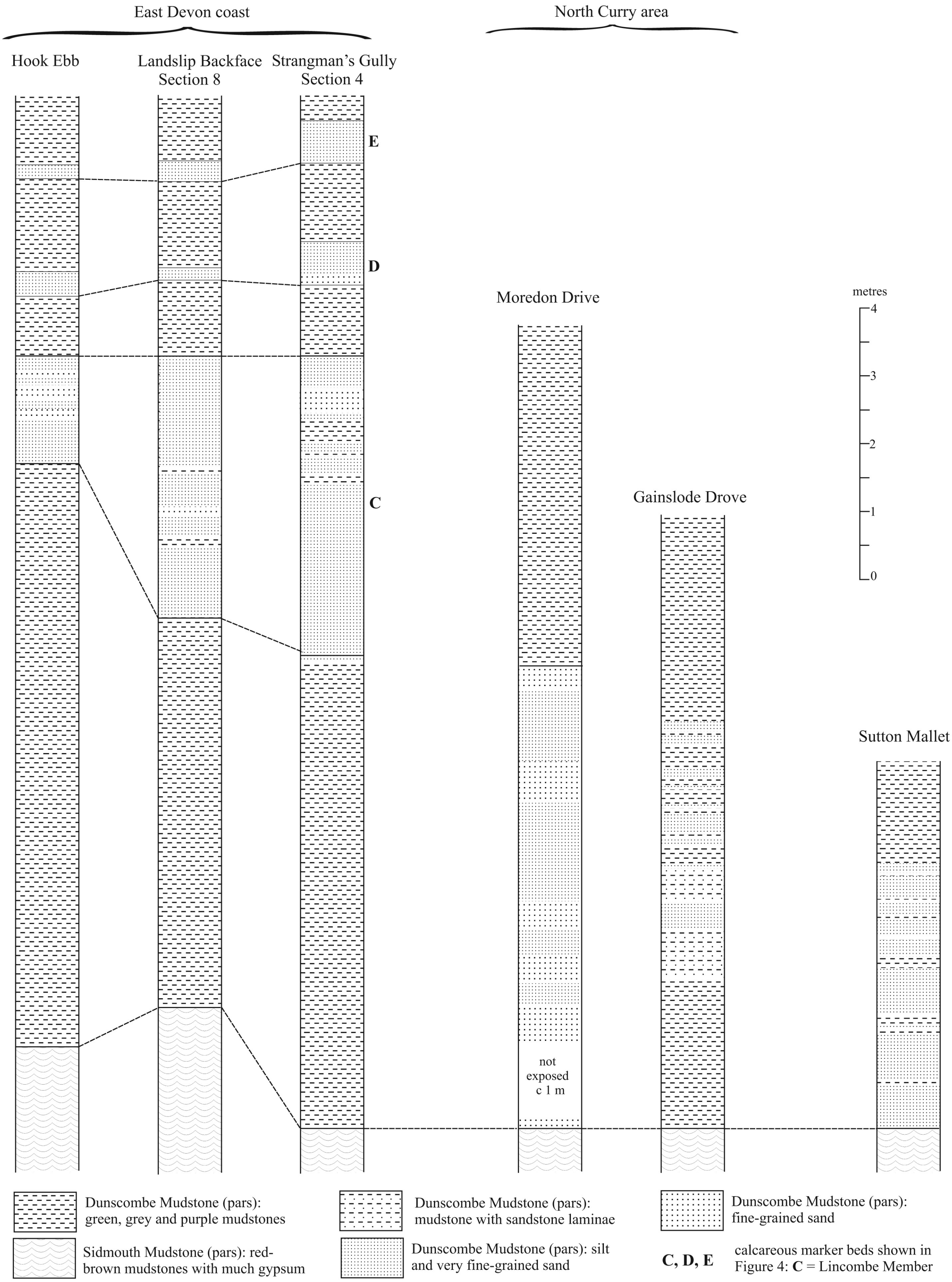

Figure 4. *Comparison of the generalised lithologies and stratigraphical positions of the more prominent arenaceous units in the Dunscombe Mudstone Formation in south-west England.*

The Lincombe Member is separated from the erosion surface at the base of the formation by up to 9 m of laminated mudstones and breccias. There is good evidence to suggest that the rate of sedimentation of the Dunscombe Mudstone Formation at the type section was *c.* 300 ka per metre (see below). The mudstones below the Lincombe Member at Hook Ebb (Figure 4) could therefore represent *c.* 2.7 Ma of sedimentation. In contrast, the North Curry Sandstone and Sutton Mallet Sandstone members locally rest directly on the underlying Sidmouth Mudstone Formation. When traced laterally from its type section at Moredon Drive (ST 326 258) to Gainslode Drove (ST 357 282), a distance of about 3.5 km, the North Curry Sandstone Member consists of thinly interbedded siltstones and green mudstones that are underlain by 2 m of green Dunscombe Mudstone Formation.

Several interpretations are possible, but there is insufficient palaeontological data to distinguish between them. If the arenaceous units are contemporaneous, then the successions at North Curry and Sutton Mallet are less complete than that at the type section, either because of erosion at the base of the sandstone members or because deposition of the Dunscombe Mudstone Formation sedimentation started later in those areas. Alternatively, the North Curry Sandstone and Sutton Mallet Sandstone members may differ in age from the Lincombe Member.

Comparison of the lithological succession of the Mercia Mudstone Group exposed on the east Devon coast with the geophysical-log signatures of the comparable strata in the nearby Wiscombe Park boreholes enables the coastal succession to be identified in more distant boreholes in the Wessex Basin (Figure 5).

SEDIMENTOLOGY

Much of the Dunscombe Mudstone succession contains bedding and bioturbation stuctures, in marked contrast to the generally structureless nature of the Sidmouth and Branscombe mudstone formations. Lamination is present throughout, and cross bedding, ripples, slump structures and bioturbation are common at some levels. Evidence of condensed deposition includes pedoturbated horizons, bioturbated and mineralised surfaces, hardgrounds and lag deposits. In a study that concentrated on the sedimentology and ichnology of the more arenaceous parts of the formation Porter (2006) recognised fourteen lithofacies and two sub-lithofacies. They include intra-formational conglomerates, cross-bedded, contorted-bedded, massive, ripple-bedded and laminated sandstones, massive and laminated mudstones, and breccias.

Jeans (1978) recorded *Chondrites* and other trace fossils in his Lower Calcareous and Sandstone groups (Figure 3) that he concluded were indicative of deposition in brackish-water environments, and other authors (e.g. Barclay *et al.*, 1997) have recorded palaeontological evidence for estuarine and marine environments in the Arden Sandstone Formation of the Midlands, the presumed arenaceous correlative of the Dunscombe Mudstone Formation. The present study has confirmed and expanded on the unpublished observation by Pollard (pers comm., 2003) that the arenaceous units in the Dunscombe Mudstone Formation contain a diverse suite of trace fossils. None of these are indicative of either brackish or marine environments. Most of the forms recorded in the present study have been confined to the coarser lithologies (siltstones and very fine-grained sandstones) of the Lincombe, North Curry Sandstone and Sutton Mallet Sandstone members. Much of the remainder of the Dunscombe Mudstone Formation contains few trace fossils except for indeterminate bioturbation present in some of the laminated beds.

The trace fossil forms and assemblages briefly described here are described in detail in Porter (2006). Two forms of *Skolithos* burrows are present; *Skolithos* isp. A are relatively large diameter (*c.* 12 mm), unlined burrows that are deeply penetrating, sometimes occurring up to depths of 1 m. These commonly descend from omission surfaces and morphologically similar in detail to burrows attributed to burrowing insects by (Stanley and Fagerstrom (1974). A second, much smaller form (mostly 2-3 mm wide and penetrating 5-6 mm), *Skolithos* isp. B, also associated with omission surfaces, has sharply defined walls and appears to have been passively infilled by the overlying sediment. Modern examples are associated with ponds and channel bars that are subject to sub-aerial exposure. These occur in close association with shallow 'U-shaped' burrows that are believed to have been formed by the same, or similar, insect producers (Stanley and Fagerstrom, 1974). Rare horizons are present with intense bioturbation by *Fuersichnus* isp. These largely vertical to sub-vertical, shallow J- to U-shaped retrusive burrows may have been formed by deposit-feeding arthropods, such as insect larvae, in shallow pools prior to desiccation (Bromley and Asgaard, 1979; Knaust and Hauschke, 2005). These burrows are occasionally associated with concentrically striated vertical shafts. Burrows previously attributed to *Chondrites* are identified here as *Planolites montanus*. These may have been formed by vermiform mobile deposit-feeding organisms, which opportunistically colonised a shallow-water body or its subaqueous margins. Occurrences of *Treptichnus pollardi* have also been noted. These consist of a number of joined, straight burrow segments forming a horizontal zigzag path. Where the burrow segments join, small circular pits or raised knobs occur. A deposit-feeding producer similar to that which formed *P. montanus* is envisaged. Rare, vertical protrusive examples of the meniscate backfilled burrow *Taenidium* have also been recorded. They appear to have been formed in a shallow-water body or its margins at times when the water level was fluctuating. Root traces are also present in the Dunscombe Mudstone Formation and in some cases may be associated with desiccation cracks.

By combining the lithofacies and the ichnofaunal assemblages it is possible to recognise six facies associations, one with two sub-associations, in the arenaceous units in the Dunscombe Mudstone Formation (Porter, 2006). The *lacustrine* facies association is dominated by either planar or ripple-interlaminated and thinly-interbedded very fine-grained sandstones and mudstones. No general fining or coarsening upward trends occur within this association, and the sediments are commonly bioturbated by *P. montanus*. A shallow lacustrine origin is preferred as the association does not form part of an overall fining-up sequence above channel sands. If it did, it would suggest deposition in abandoned channels. This association may also be applicable to the laminated mudstones that make up much of the Dunscombe Mudstone succession, although they are mostly without bioturbation. A *lacustrine-margin* facies association has also been recognised. This can be divided into a *perennial lacustrine-margin* association consisting mainly of interlaminated sandstone and mudstone that is dominated by root traces and desiccation, and an *ephemeral playa-margin/mudflat* that is disrupted by mud cracks and micro-faults that produce a brecciated appearance.

The *lake-delta* facies association comprises a combination of predominantly arenaceous lithofacies, including minor trough-crossed bedded sandstones, mudstone lags, ripple-lamination and erosion surfaces, together with a subordinate mudstone component. The lithofacies are laterally highly variable with juxtapositions of sediments deposited under differing flow regimes. The features recorded here compare well with those of the present-day Tulu Bor delta on the edge of Lake Turkana, Kenya (Frostick and Reid, 1986). A *sheet-delta* association, characterised by thin, fining upward units with a basal mudchip lag that passes into ripple-laminated sandstones or sandstones with mudstone partings, is also tentatively identified. The top of the association is usually composed of muddy siltstone and is gradational with the overlying orange-brown/red mudstones. The overall nature of the association is in broad agreement with that produced by reducing flow velocities associated with flash-flood deposits entering a lacustrine system (Smoot and Lowenstein, 1991).

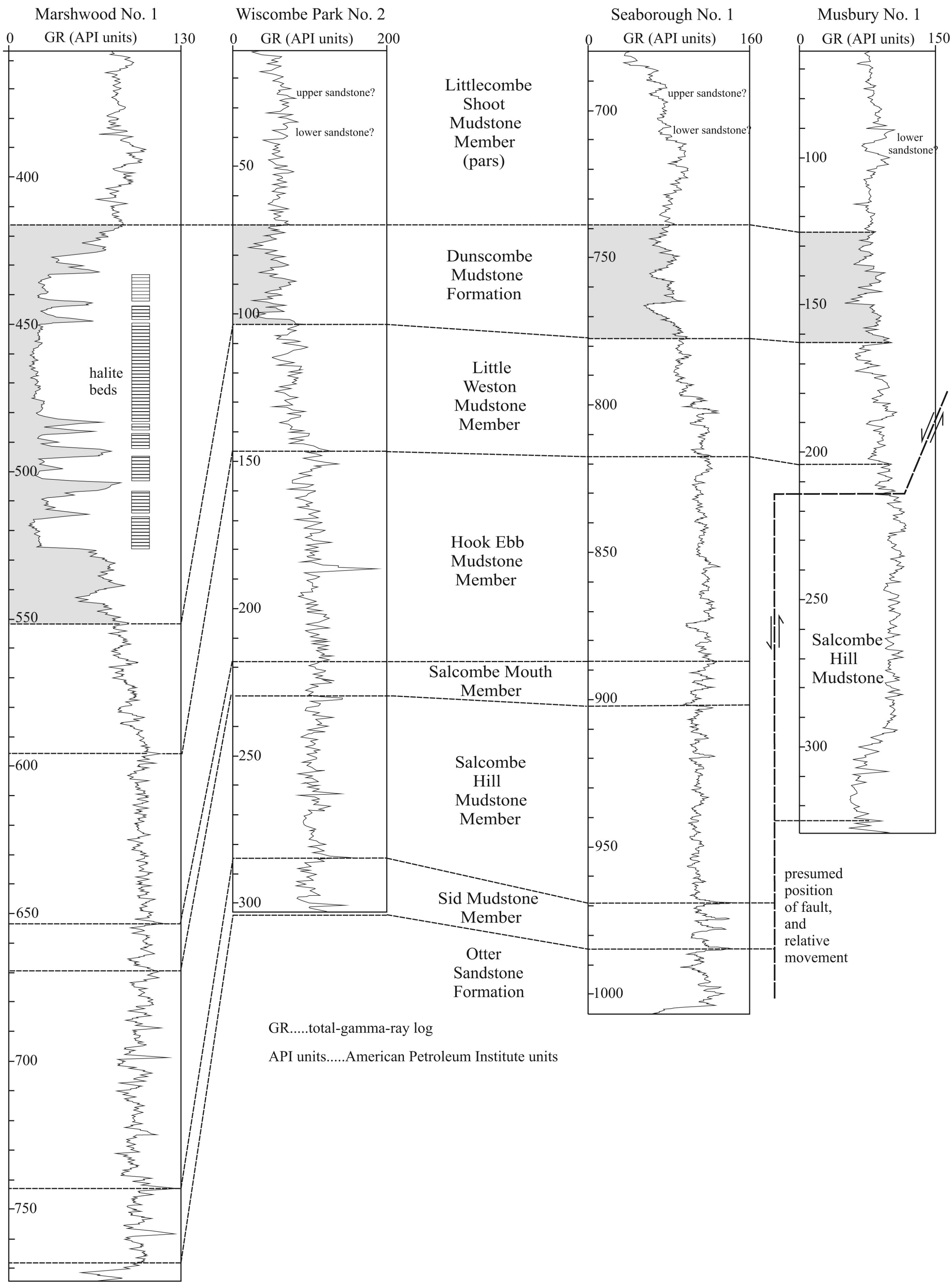

Figure 5. *Correlations based on total-gamma-ray logs of the Mercia Mudstone Group successions in the nearest boreholes to the east Devon coastal exposures.*

A *minor-channel* facies association is recognised by thin fining-upward packages, with bases occasionally marked by a small granular lag within basal scours. This commonly passes into thin packages of trough cross-bedded sandstone that probably represent small-scale in-channel migrating dunes. Mudstone cappings containing comminuted plant fragments and minor bioturbation are possible abandonment fines.

A *floodplain* association consisting of similar lithofacies to the lacustrine association has also been recorded. It is however, usually thinner and is always under- and overlain by the minor-channel association, usually with an erosional upper contact.

STRATIGRAPHY

In contrast to the overlying and underlying formations, the lower part of the Dunscombe Mudstone has yielded diverse palynological assemblages, conchostracans and rare vertebrate remains. It should be noted however, that fossiliferous material has only been obtained from a small number of thin (a few mm thick) beds that probably represent <1% of the total thickness of the formation.

Warrington (1971), Warrington and Williams (1984) and Fisher (1972; 1985) concluded on the basis of the palynomorph assemblages that the formation was Carnian in age. In Devon, only Fisher's (1985) samples were collected against a measured section (that of Jeans, 1978). This has enabled them to be plotted against the type section and has confirmed Fisher's original conclusion (in Jeans, 1978) that there is an older and younger palynomorph assemblage with the boundary between the two placed within the Lincombe Member (between samples De 160 and De 76 in Figure 3). Additional samples collected from the lower part of the type section for the present study have been palynologically analysed by Dr. G. A. Booth. These did not yield any additional age-diagnostic data but they enabled comment to be made on the depositional environments. Samples collected from dark grey mudstones below the Lincombe Member contained abundant palynomorphs and amorphous organic matter indicative of deposition in quiet-water anoxic environments. In marked contrast, those from the Lincombe Member contained few spores but were rich in the chlorococcalean alga *Plaesiodictyon*, suggesting deposition in oxygenated, fresh or low-salinity water. In Somerset, Warrington and Williams (1984) recorded Carnian palynomorph assemblages from the North Curry Sandstone of the North Curry area.

Jeans (1978) recorded *Euestheria* in his Lower Calcareous and Sandstone groups (Figure 3), and Moore (1861) recorded '*Estheria*' in the North Curry Sandstone. Well preserved conchostracans are abundant on a few individual bedding planes in the Lincombe Member and the North Curry and Sutton Mallet sandstones. Specimens of *Laxitextella multireticulata* (Reible) found in the Lincombe Member below Weston Cliff by Dr Heinz Kozur were identified by him as indicative of the early Carnian *L. multireticulata* Zone (pers. comm., 2004). He further noted that this species is abundant in the Lower Carnian Estherienschichten (the 'Estheria Beds' of the upper Grabfeld Formation) in Germany, and that it has been reported from but is rare in the Upper Carnian Schilfsandstein. Other conchostrachan specimens collected during the present study from the Dunscombe Mudstone Formation in Devon and Somerset have been determined by him as *Euestheria* spp. and are not age diagnostic.

Vertebrate remains collected by Moore (1861; 1867) from the North Curry Sandstone included amphibians, reptiles and fish including sharks. The fauna was reviewed by Warrington and Williams (1984) who concluded that it was comparable to that of the 'Weston Mouth Sandstone' of the Devon coast, and that this supported the correlation of the two 'sandstones'. There is no published record of vertebrate remains from the Dunscombe Mudstone Formation of the Devon coast. Material collected during the present study has been identified by Professor M.J. Benton as possible fragments of a shark spine (pers. comm., 2006).

Comparison of the magnetostratigraphy of the Mercia Mudstone Group of the Devon coast with that of the marine successions of Tethys indicates the Ladinian-Carnian stage boundary occurs near the top of the Sidmouth Mudstone Formation and the Carnian-Norian boundary falls within the upper part of the Dunscombe Mudstone Formation (Hounslow *et al.*, 2002). This suggests that the Dunscombe Mudstone is a condensed succession that was deposited over a period of *c.* 11.5 million years (*c.* 328 Ma to 316.5 Ma; Gradstein *et al.*, 2004). Taken together, the palaeontological and magnetostratigraphical evidence suggest that the lithological change at the base of the Dunscombe Mudstone Formation marks the incoming of fluvial environments with locally abundant conchostraca, palynomorphs, bioturbation and sedimentary structures indicative of subaqueous deposition. In Germany, a sedimentary break at a similar stratigraphical level at the base of the Estheria Beds marks a climatic change from arid hypersaline environments to more humid freshwater-lake environments (Heinz, pers. comm., 2004).

Warrington (2004) has called the lowest 20 m of the Dunscombe Mudstone Formation of the east Devon coast (presumably from the base to about marker bed G in Figure 3) the Arden Sandstone Formation, presumably on the false assumption that it is the same as the 20 m-thick Weston Mouth Sandstone of Warrington and Scrivener (1980). There is no lithological reason to make this correlation and no palaeontological evidence to support it. The Arden Sandstone Formation has been identified on the basis of its palynological content as Late Carnian (Tuvalian) in age (Barclay *et al.*, 1997). The palaeontological evidence therefore suggests that its chronological correlative is likely to be within the mudstones in the younger part of the Dunscombe Mudstone Formation.

North of the Mendip Hills, in the Worcester Basin, the Arden Sandstone Formation is laterally impersistent and thin (mostly <5 m thick) (Barclay *et al.*, 1997). It is either a highly attenuated, arenaceous lateral equivalent of part of the Dunscombe Mudstone Formation or a lenticular sandstone member within an attenuated Dunscombe Mudstone Formation that has not been fully recognised in that area. Howard *et al.* (in press) have ignored the obvious lithological differences and have included the Dunscombe Mudstone Formation in the Arden Sandstone Formation, presumably on the tenuous grounds of similar (Carnian) age.

SUMMARY AND CONCLUSIONS

The Dunscombe Mudstone Formation is a lithologically distinctive argillaceous formation that can be traced at outcrop from the Devon coast to the Somerset coast, and in boreholes throughout the Wessex and Bristol Channel basins. The formation is fully exposed at the type section on the east Devon coast, but is poorly exposed inland. It consists of green, purple and grey mudstones, breccias, limestones and sandstones. It expands in thickness from 35-40 m at outcrop to over 150 m in the subcrop by the addition of halite (Gallois, 2003). Much of the succession is laminated and the more arenaceous parts are rich in trace fossils. The evidence from the sparse fauna and flora combined with that from magnetostratigraphy suggests that the formation occupies most of the Carnian Stage (late Triassic), and is highly condensed.

An analysis of the sedimentology and ichnology of the formation indicates that it was deposited in a series of shallow, freshwater environments during a wetter and probably cooler interval than that in which the adjacent 'red-bed' formations were deposited. The relationships between the lenticular arenaceous units in the lower part of the formation, the Lincombe Member in Devon and the North Curry and Sutton Mallet Sandstones in Somerset, have been shown to be more complex than previously thought. The Lincombe Member is interpreted as a geographically isolated sedimentary body that was deposited in a shallow, oxygenated freshwater lake that passed upwards into lake-delta-plain deposits. Inland in Devon, it passes laterally into playa-lake-margin deposits. The North

Curry Sandstone was deposited in a series of broad, shallow channels that crossed a low-relief topography. The channel sands either pass laterally into or terminate against more argillaceous lacustrine deposits. In contrast, the depositional environment of the Sutton Mallet Sandstone is interpreted as relatively small-scale channels with low flows and possible channel switching. The relative ages of the arenaceous units remains unclear.

The northern boundary of the depositional area of the Dunscombe Mudstone Formation appears to have been on the line of the former Variscan Front. It was probably connected at times to the Worcester depositional basin via a narrow corridor along the Severn Estuary fault zone in which a thin (<5 m thick), highly attenuated equivalent of part of the formation was deposited. A series of discontinuous lenticular sandstones of presumed similar age have been traced northwards from there and correlated with the Arden Sandstone Formation of the Midlands (Wills, 1970).

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REFERENCES

BARCLAY, W.J., AMBROSE, K., CHADWICK, R.A. and PHAROAH, T.C. 1997. *Geology of the country around Worcester.* Memoir of the Geological Survey of Great Britain. HMSO, London.

BROMLEY, R.G. and ASGAARD, U. 1979. Triassic freshwater ichnocoenoses from Carlsberg Fjord, East Greenland. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **28**, 39-80.

FISHER, M.J. 1972. The Triassic palynofloral assemblage in England. *Geoscience and Man*, **4**, 101-109.

FISHER, M.J. 1985. Palynology of sedimentary cycles in the Mercia Mudstone and Penarth Groups (Triassic) of southwest and central England. *Pollen et Spores*, **27**, 95-112.

FROSTICK, L.E. and REID, I. 1986. Evolution and sedimentary character of lake deltas fed by ephemeral rivers in the Turkana basin, northern Kenya. In: FROSTICK, L.E., RENAUT, R.W., REID, I. and TIERCELIN, J-J. (eds), *Sedimentation in the African Rifts.* Geological Society, London, Special Publication, **25**, 113-125.

GALLOIS, R.W. 2001. The lithostratigraphy of the Mercia Mudstone Group (mid to late Triassic) of the south Devon coast. *Geoscience in south-west England*, **10**, 195-204.

GALLOIS, R.W. 2003. The distribution of halite (rock-salt) in the Mercia Mudstone Group (mid to late Triassic) in south-west England. *Geoscience in south-west England*, **10**, 383-389.

GRADSTEIN, F.M., OGG, J.G. and SMITH, A.G. 2004. *A Geologic Time Scale 2004.* Cambridge University Press, Cambridge.

HOUNSLOW, M.W., MCINTOSH, G., GALLOIS, R.W. and JENKINS, G. 2002. Anisian, Ladinian and Carnian non-marine magnetostratigraphic reference section: the coastal exposures between Budleigh Salterton and Branscombe, South Devon, U.K. *Geoscience in south-west England*, **10**, 453.

HOWARD, A.S., WARRINGTON, G., AMBROSE, K. and REES, J.G. in press. A formational framework for the Mercia Mudstone Group of England and Wales. *British Geological Survey Research Report.*

JEANS, C.V. 1978. The origin of the Triassic clay assemblages of Europe with special reference to the Keuper Marl and Rhaetic of parts of England. *Philosophical Transactions of the Royal Society of London*, Series A, **289**, 549-639.

KNAUST, D. and HAUSCHKE, N. 2005. Living conditions in a Lower Triassic playa system of Central Germany: evidence from ichnofauna and body fossils. *Hallesches Jahrbuch für Geowissenschaften, Reihe B, Beiheft*, **19**, 95-108.

MOORE, C. 1861. On the zones of the Lower Lias and the *Avicula contorta* Zone. *Quarterly Journal of the Geological Society, London*, **17**, 485-516.

MOORE, C. 1867. On abnormal conditions of Secondary deposits when connected with the Somersetshire and South Wales coal-basin: and on the age of the Sutton and Southerdown series. *Quarterly Journal of the Geological Society, London*, **23**, 449-568.

PORTER, R.J. 2006. *Ichnology and sedimentology of Triassic continental sequences: onshore and offshore U.K.* Unpublished PhD thesis, University of Bristol.

PORTER, R.J. and GALLOIS, R.W. in press. An integrated sedimentology and ichnology of arenaceous members in the Dunscombe Mudstone Formation (Carnian, late Triassic) in Devon and Somerset, U.K. *Palaeogeography, Palaeoclimatology , Palaeoecology.*

RUFFELL, A. 1990. Stratigraphy and structure of the Mercia Mudstone Group (Triassic) in the western part of the Wessex Basin. *Proceedings of the Ussher Society*, **7**, 263-267.

RUFFELL, A. 1991. Palaeoenvironmental analysis of the late Triassic succession in the West Basin and correlation with surrounding areas. *Proceedings of the Ussher Society*, **7**, 402-407.

RUFFELL, A. and WARRINGTON, G. 1988. An arenaceous member in the Mercia Mudstone Group (Triassic) west of Taunton, Somerset. *Proceedings of the Ussher Society*, **7**, 102-103.

SMOOT, J.P. and LOWENSTEIN, T.K. 1991. Depositional environments of non-marine evaporates. In: MELVIN, J.L. (Ed.), *Evaporites, Petroleum and Mineral Resources.* Developments in Sedimentology No. 50, 189-347.

STANLEY, K.O. and FAGERSTROM, J.A. 1974. Miocene invertebrate trace fossils from a braided river environment, western Nebraska, USA. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **15**, 63-82.

USSHER, W.A.E. 1906. *The geology of the country between Wellington and Chard.* Memoirs of the Geological Survey of England and Wales. HMSO, London.

USSHER, W.A.E. 1908. *The geology of the Quantock Hills and of Taunton and Bridgwater.* Memoirs of the Geological Survey of England and Wales. HMSO, London.

WARRINGTON, G. 1971. Palynology of the New Red Sandstone sequence of the south Devon coast. *Proceedings of the Ussher Society.* **2**, 307-314.

WARRINGTON, G. 2004. Red rocks of the west - the tip of the iceberg. *Open University Geological Society Journal*, Symposium Edition 2004, 28-32.

WARRINGTON, G. and SCRIVENER, R.C. 1980. The Lyme Regis (1901) Borehole succession and its relationship to the sequence of the east Devon coast. *Proceedings of the Ussher Society*, **5**, 124-32.

WARRINGTON, G. and WILLIAMS, B.J. 1984. The North Curry Sandstone Member (late Triassic) near Taunton, Somerset. *Proceedings of the Ussher Society*, **6**, 82-87.

WARRINGTON, G., AUDLEY-CHARLES, M.G., ELLIOTT, R.E., EVANS, W.B., IVIMEY-COOK, H.C., KENT, P.E., ROBINSON, P.L., SHOTTON, F.W. and TAYLOR, F.M. 1980. A correlation of Triassic rocks in the British Isles. *Geological Society of London Special Report*, No 13.

WILLS, L.J. 1970. The Triassic succession if the central Midlands in its regional setting. *Quarterly Journal of the Geological Society of London*, **126**, 225-286.

WOODWARD, H.B. and USSHER, W.A.E. 1911. *The geology of the country near Sidmouth and Lyme Regis.* Memoirs of the Geological Survey of England and Wales. HMSO, London.