THE STRATIGRAPHY OF THE MERCIA MUDSTONE GROUP SUCCESSION (MID TO LATE TRIASSIC) PROVED IN THE WISCOMBE PARK BOREHOLES, DEVON

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The type sections of the Sidmouth Mudstone, Dunscombe Mudstone and Branscombe Mudstone formations of the Mercia Mudstone Group are the almost complete sections exposed in the cliffs between Sidmouth and Axmouth on the Devon coast. The partially cored Wiscombe Park No. 1 and No. 2 mineral-exploration boreholes, drilled by British Gypsum Ltd in 1972, were sited about 5.8 and 4.7 km north of the cliff sections respectively. The first of these penetrated the whole of the Sidmouth Mudstone and Dunscombe Mudstone formations and the lower part of the Branscombe Mudstone Formation. The lithological succession proved in the cored parts of the boreholes can be correlated with that exposed in the cliffs. Geophysical logs made through the full length of the boreholes enable the complete succession proved there to be correlated with that exposed in the cliffs. The calibrated geophysical logs have been used to correlate the succession at outcrop with those proved in uncored but geophysically logged hydrocarbon-exploration boreholes throughout the Wessex Basin. The Sidmouth Mudstone and Branscombe Mudstone successions proved in the Wiscombe Park boreholes are similar in thickness and lithology to those elsewhere in the Wessex Basin. In contrast, the Dunscombe Mudstone succession in the boreholes expands from 35 m in thickness to over 500 m by the addition of thick beds of halite in parts of the basin.

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INTRODUCTION

The Wiscombe Park No. 1 [SY 1819 9382] and No. 2 [SY 1845 9273] boreholes were drilled by British Gypsum Ltd in 1972 as part of a mineral-exploration programme in east Devon. The boreholes were sited about 1100 m apart on the Wiscombe Park estate, Southleigh (Figure 1). The Wiscombe Park No. 1 Borehole was drilled to a total depth of 164.59 m, of which the interval from 48.77 m to 164.59 m was continuously cored. Note that borehole depths (in feet and inches on the cores) are recalculated to metric here: allowances have been made for core losses.

The Wiscombe Park No. 2 Borehole was drilled to a total depth of 304.80 m, of which 76.20 m to 117.65 m was cored. The cores are housed in the British Geological Survey (BGS) National Geoscience Data Centre at Keyworth, Nottingham. The following geophysical logs were made in both boreholes: caliper, temperature, total gamma ray (GR) and density.

An almost complete section through the *c.* 450 m-thick Mercia Mudstone Group is exposed in the 9 miles (14 km) of cliffs between Sidmouth [SY 129 873] and Culverhole Point, Axmouth [SY 274 893] on the east Devon coast. The previously un-named lower and middle parts of the Mercia Mudstone Group exposed there, has been divided into three formations and nine members (Gallois, 2001, figure 2). The lowest and highest of these formations, the Sidmouth Mudstone (*c.* 195 m thick) and Branscombe Mudstone (*c.* 220 m thick), consist of relatively monotonous red mudstones. In the type section on the coast, the intervening Dunscombe Mudstone Formation consists of a 40 to 43 m-thick succession of laminated green, purple and grey mudstones, limestones and breccias with a lenticular bed of calcareous fine-grained sandstone/siltstone (the Lincombe Member) in the lower part (Gallois and Porter, 2006). Lithologically similar beds of sandstone are present in the lower part of the Dunscombe Mudstone Formation in the Taunton, North Curry and Sutton Mallet areas in Somerset (Ruffell, 1991; Ruffell and Warrington, 1998; Warrington and Williams, 1984), but none of these is laterally persistent over distances of more than a few kilometres.

The Wiscombe Park boreholes and the Mercia Mudstone exposures on the nearby coast are sited on the East Devon structural high, an area bounded by the N-S trending Sid Valley and Axe Valley fault belts in which sedimentation was relatively attenuated in the mid to late Triassic. The lithologies exposed in the coastal sections can be correlated with the geophysical-log signatures of the Mercia Mudstone Group successions proved in inland boreholes throughout the Wessex Basin. This has shown that the Dunscombe Mudstone in some inland borehole successions east of the structural high expands to over 500 m by the addition of thick beds of halite (Gallois, 2003).

SUCCESSION PROVED IN THE WISCOMBE PARK BOREHOLES

Both boreholes were sited on the Branscombe Mudstone Formation close to the base of the unconformable Upper Greensand in an area where the outcrop of the Mercia Mudstone is largely hidden beneath extensive sheets of Head deposits derived from the Cretaceous rocks. The Wiscombe Park No. 1 Borehole commenced at a level in the middle part of the Littlecombe Mudstone Member, and the No. 2 Borehole near the top of the member, close below the Red Rock Gypsum Member (Figure 2). Exposures of the Red Rock Gypsum are confined to rapidly eroding sections on the coast due to the high solubility of the gypsum, and it has not been recorded at outcrop inland.

Coring was confined to the highest part of the Hook Ebb Mudstone and Little Weston Mudstone members and the lower

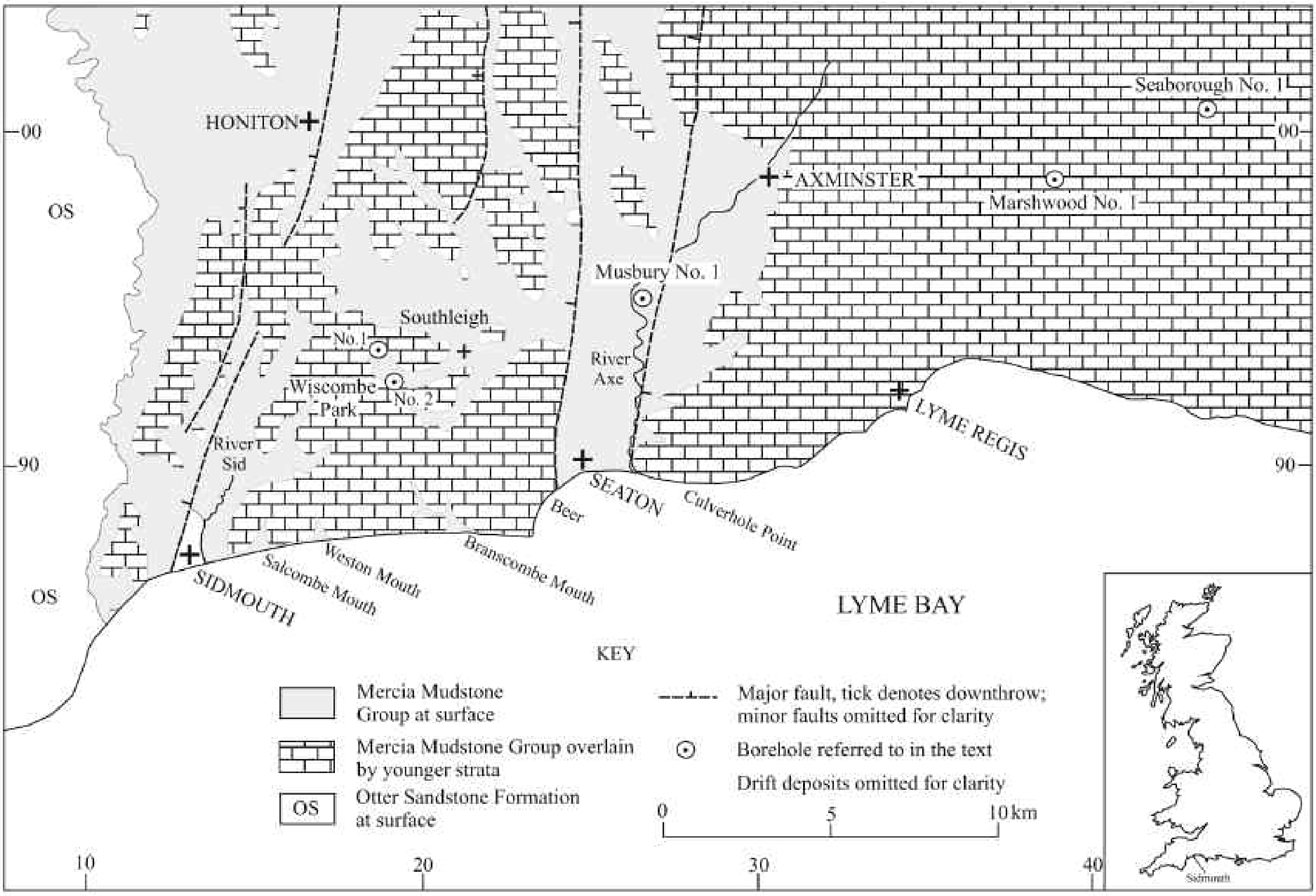

Figure 1. *Geological sketch map of the Mercia Mudstone Group outcrop in south-east Devon and the positions of the Wiscombe Park and other boreholes referred to in the text.*

and middle parts of the Dunscombe Mudstone in Borehole No.1, and to the upper part of the Little Weston Mudstone Member and the lower and middle parts of the Dunscombe Mudstone in Borehole No. 2. The successions proved in the Dunscombe Mudstone Formation in the cored intervals of the boreholes and their correlation with one another are summarised in Figure 2. The geophysical logs, in particular the total-gamma-ray log of the Wiscombe Park No. 2 Borehole, can be matched with the lithologies proved in the cores and the coastal exposures for the whole of the Sidmouth Mudstone, the whole of the Dunscombe Mudstone and the lower part of the Branscombe Mudstone. This has enabled the coastal sections to be correlated with the successions proved in uncored boreholes throughout south west England including the hydrocarbon-exploration boreholes at Marshwood, Musbury and Seaborough (Figure 1) and elsewhere in the Wessex Basin (Gallois, 2001, 2003).

The base of the Sidmouth Mudstone is taken at the top of the highest sandstone bed in an alternating succession of thinly interbedded sandstones and mudstones in the highest part of the Otter Sandstone Formation. The boundary is marked by a sudden upward increase in gamma-ray count in the Wiscombe No. 2 Borehole. In the type section, the Sidmouth Mudstone comprises *c.* 180 m of relatively uniform red-brown mudstones and orange-brown muddy siltstones in stacked sequences of small-scale rhythms, 0.5 to 1.5 m thick, in which fissile-weathering, brownish red, silty mudstones pass up into reddish orange, muddy siltstones. Each rhythm probably reflects a change from a wetter to a drier climate. These rhythms give rise to fluctuating, generally high gamma-ray counts with a few sharp peaks that represent mineralised surfaces.

In the coastal sections, the Hook Ebb Mudstone Member consists of *c.* 40 m of relatively uniform orange-brown and red-brown mudstones and silty mudstones with little structure other than weakly differentiated small-scale rhythms. In unweathered sections the mudstones contain numerous bedding-parallel and cross-cutting veins of fibrous gypsum up to 0.15 m thick. The succession proved in the cores of the Wiscombe Park No.1 Borehole (115.53 to 164.59 m) is lithologically similar to that at outcrop, but with common sub-horizontal and cross-cutting veins of fibrous gypsum up to 0.20 m thick and a few horizons with small gypsum nodules. Thin (mostly < 80 mm thick) laterally persistent green beds occur at several levels in the borehole cores and at outcrop. Some of those in the cores show lamination, but this feature is rarely preserved at outcrop.

In the coast sections the Little Weston Mudstone Member consists of 40 m of markedly rhythmic red-brown mudstones with common fibrous gypsum seams, relatively common green beds, and purplish red mudstones that are rare or absent in the other members in the Sidmouth Mudstone. Gypsum is common throughout, both as fibrous secondary seams and as small nodules (mostly < 0.05 m across). The gypsum/anhydrite contents increase upward in the member and give rise to progressively lower gamma-ray counts (Figure 2). The base of the member is taken at the base of a laterally persistent laminated green mudstone in which the lamination is disrupted by secondary growths of nodular and fibrous gypsum. Locally, the basal bed contains ripples of glauconitic, fine-grained sandstone and widely spaced concentrations of pieces of mineralised wood up to 0.3 m long. Some of the wood has a well-preserved cellular structure and is impregnated with copper, silver and uranium minerals (Gallois *et al.*, 2004). The highest 9 m of the member crops out in the cliffs above the effects of wave action and weathers to porous mudstone rubble due to dissolution of the high gypsum/anhydrite content. These high evaporite contents are a laterally persistent feature in the highest part of the Sidmouth Mudstone

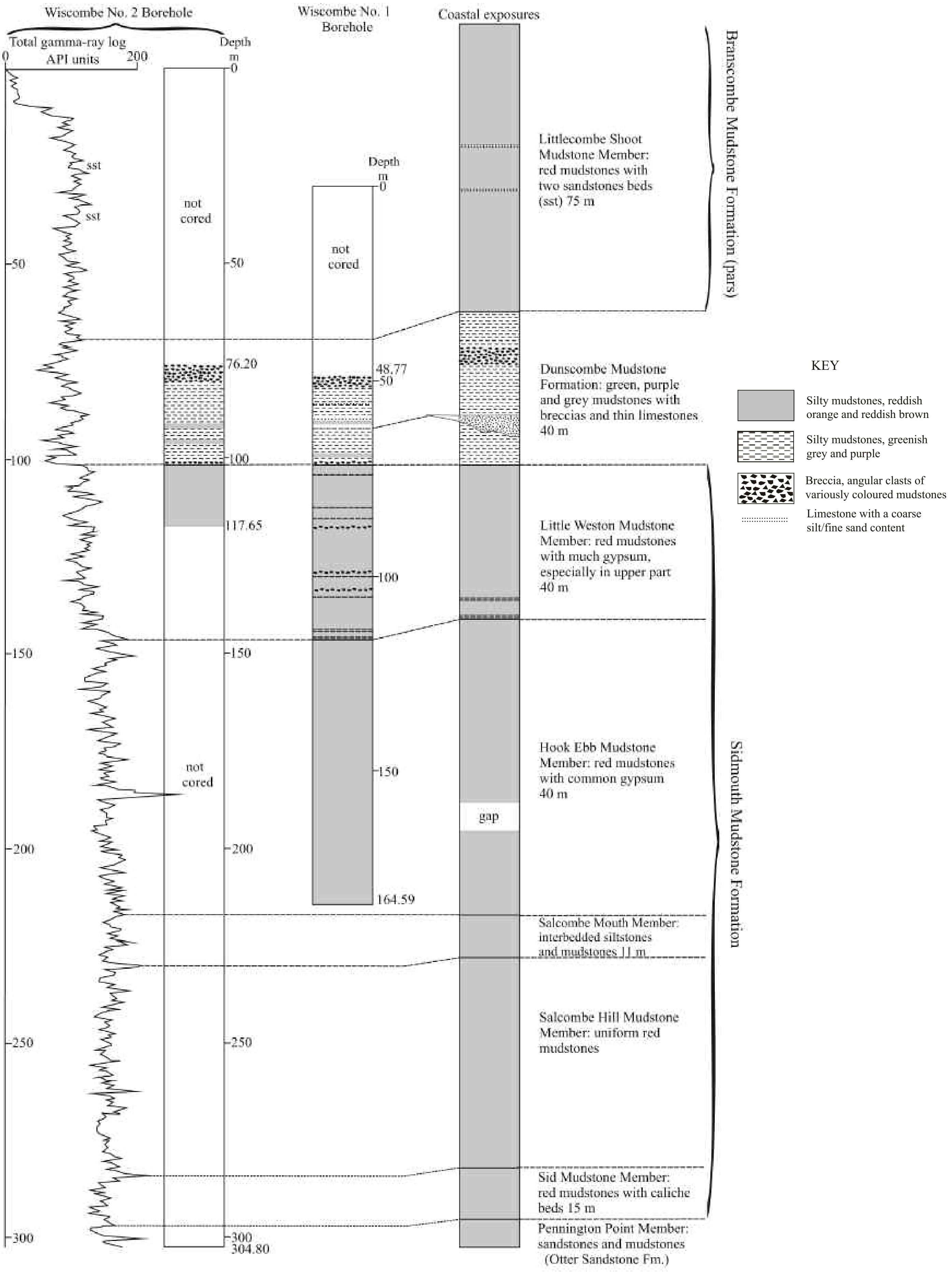

Figure 2. *Correlation of the cored interval and total-gamma-ray log of the Wiscombe Park No. 2 Borehole with the successions exposed in the No.1 Borehole and on the south Devon coast.*

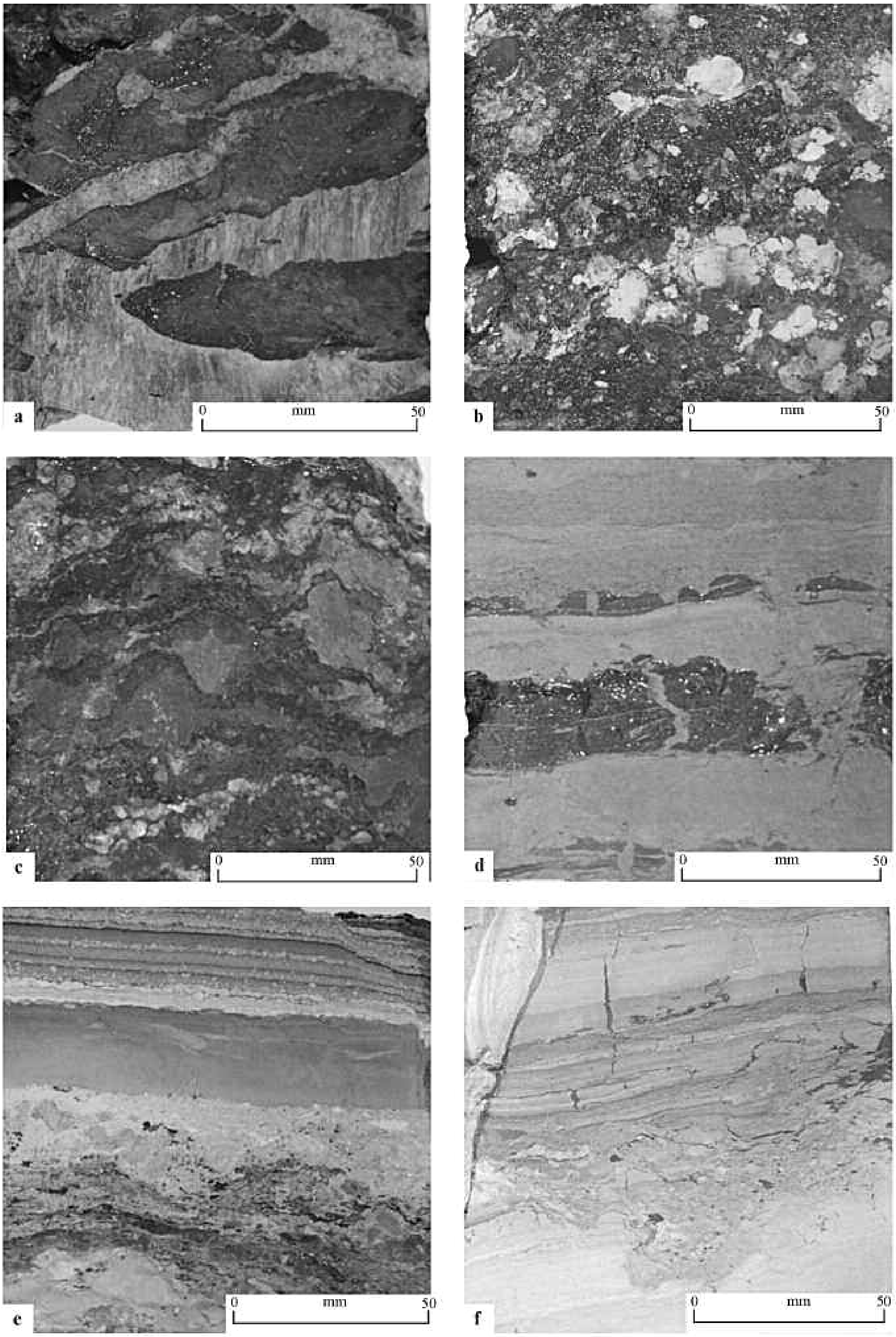

Figure 3. *Wiscombe Park No. 1 Borehole: selected Little Weston Mudstone Member (samples a-c) and Dunscombe Mudstone Formation (samples d-f) lithologies. Depth refers to top of sample. (**a**) 72.54 m depth. Dark reddish brown mudstone with ramifying network of fibrous gypsum veins. (**b**) 95.71 m depth. Dark reddish brown mudstone with several phases of displacive nodular gypsum/anhydrite. (**c**) 73.61 m depth. Dark reddish brown mudstone with autobrecciated texture, nodular and fibrous gypsum/anhydrite and gypsum/anhydrite crusts. (**d**) 63.09 m depth. Laminated pale, sandy dolomitic limestone with thin interbeds of dark green mudstone; very fine- and fine-grained sand and coarse silt concentrated in graded beds and lines of ripples; syneresis cracks and bioturbation at several levels. (**e**) 64.62 m depth. Interlaminated dark green mudstone and pale dolomitic limestone with largely undisturbed laminae resting on brecciated bed of limestone and green and dark grey mudstones which in turn rests on nodular limestone. At outcrop, similar lithological successions occur at several levels where they appear to mark transgressive events across brecciated hardground surfaces. (**f**) 66.60 m depth. Finely laminated off-white limestone overlain by an irregular erosion surface with a scour (or solution) hollow infilled with a limestone/mudstone breccia. This, in turn, is overlain by pale, laminated, silty limestone with syneresis cracks and traces of bioturbation.*

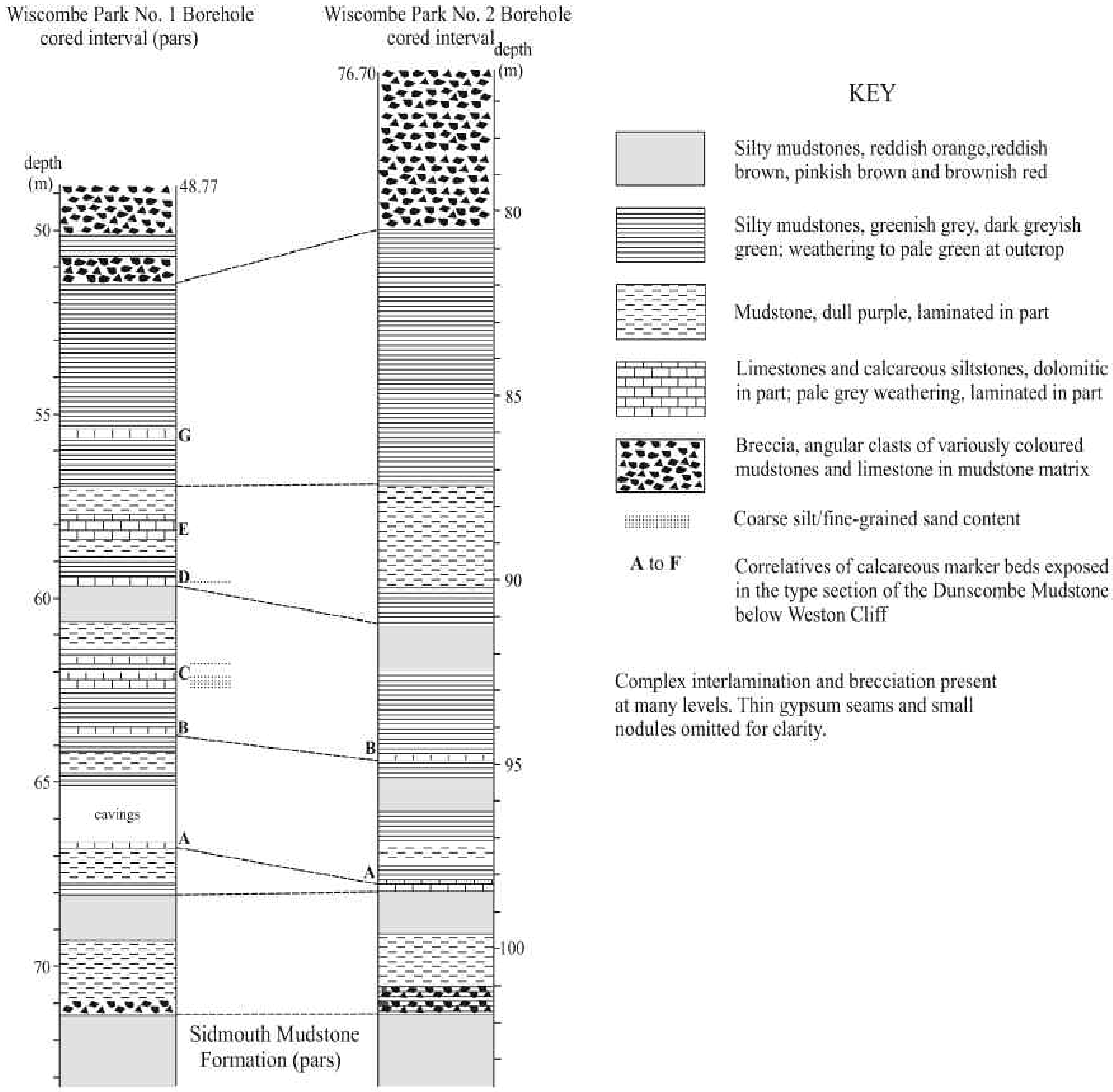

Figure 4. *Correlation of the Dunscombe Mudstone Formation successions proved in the cored intervals in the Wiscombe Park No. 1 and No. 2 boreholes.*

Formation. Similar distinctive dissolution textures are present at this stratigraphical level in inland sections in Devon and have been recorded as far north as Newnham, Glos. [SO 690 114].

The Little Weston Mudstone Member in the Wiscombe Park No. 1 Borehole (71.90 to 115.53 m) is lithologically similar to that at outcrop with the exception that lamination, autobrecciation structures, gypsum veins and nodules (Figure 3a-c), and the rhythmic nature of the succession are well displayed. Beds in which several phases of development of gypsum/anhydrite crusts, dissolution and re-crystallisation have contributed to complex pseudobrecciation are common in the higher part of the member in the cores (Figure 3b-c). The basal beds of the member and the junction with the Hook Ebb Mudstone in the borehole are similar to those at outcrop. In the borehole, a glauconitic sandstone (*c.* 65% quartz) passes up into sandy mudstone (*c.* 35% sand) and slightly sandy mudstone (*c.* 10% sand) over a thickness of 0.12 m. This distinctive marker bed is overlain by a 0.43 m-thick bed of green mudstone in which prominent lamination is disturbed by fibrous and nodular gypsum growth and gypsum autobrecciation. In the borehole, the junction with the Hook Ebb Mudstone is disturbed by bioturbation, possibly due to plant roots. The highest part of the member was also cored in the No. 2 Borehole (101.80 to 117.65 m) where the lithological succession is similar to that in the No. 1 Borehole.

The Dunscombe Mudstone Formation is the most lithologically distinctive part of the Mercia Mudstone Group in Devon. In the coastal exposures it consists of 38 to 43 m of rhythmically interbedded green, purple and orange-brown mudstones with subordinate beds of limestone/calcareous siltstone, dark grey mudstone and breccias (autobreccias and collapse breccias). The same range of lithologies was proved in the cores of the Wiscombe No. 1 (48.77 to 71.20 m) and No. 2 (76.20 to 101.80 m) boreholes, and several marker beds can be correlated between the borehole and cliff sections (Figure 4). A lenticular bed of very fine- and fine-grained sand, cross- and ripple-bedded calcareous sandstone (the Lincombe Member), 1.5 to 4.5 m thick, is present in the lower part of the formation in the type section. The member is presumed here to be represented in the Wiscombe Park No. 1 Borehole by two thin beds (61.80 to 61.90 and 62.30 to 62.50 m) of laminated limestone with ripples and scattered grains of very fine- and fine-grained sand. It was not recorded in the No. 2 Borehole nor in any inland section.

In the cliff sections the more calcareous beds form prominent, pale weathering marker beds in the cliffs. Some of these and several thin beds of dark grey mudstone that overlie erosion surfaces, can be correlated with the successions proved in the borehole cores (Figure 4). However, the presence of erosion surfaces within the formation at outcrop gives rise to lateral thickness variations over short distances

In the coastal sections, the Branscombe Mudstone Formation consists of *c.* 220 m of relatively uniform rhythms of red-brown mudstone and orange-brown muddy siltstone with few marker beds. The lowest member, the Littlecombe Shoot Mudstone, was penetrated by the Wiscombe Park boreholes, but not cored. Two thin (0.15 to 1.4 m thick) lenticular beds of calcareous sandstone are prominent in the cliffs sections. These occur at similar stratigraphical levels to two gamma-ray lows in the No. 2 Borehole (Figure 2).

Depositional environments

The Sidmouth and Branscombe mudstones are largely composed of almost structureless unfossiferous red mudstones, intimate mixtures of clay minerals and quartz silt in varying proportions. They contain too few sedimentary structures to indicate how they were formed, but the ubiquitous presence of red hematite (Fe_2O_3) coatings and the presence of scattered well-rounded sand grains with frosted surfaces, halite pseudomorphs, dessication cracks and calcareous (caliche) concretions indicate deposition in hot dry environments and, at times, exposure to high temperatures on a desert surface. The most common sedimentary structure is brecciation, at both micro and macro scales, due to several inter-related causes. Brecciation is caused by wetting-and-drying effects including repeated precipitation and dissolution of gypsum and salt evaporites, thermal effects including freeze-thaw features and the expansion and contraction of mineral crystals, and plant action. The muds were probably initially waterlain deposits in shallow temporary lakes and mudflats in a low-relief landscape and were subsequently partially redistributed and added to by flash floods and dust storms. Similar deposits are currently being formed in parts of the Australian interior.

The presence of lamination and bioturbation at many stratigraphical levels in the Dunscombe Mudstone are in

Depositional enviroment	Sedimentary features	Lithology
transgressive deposits of shallow lake	lamination; erosion surface with bioturbation at base	mudstone, dark grey sharp lithological contrast
sabkha mudflats, almost permanently dry at surface, moist at depth	blocky and columnar textures with rare rootlet traces and no original sedimenatry structures due to disturbance by evaporite growth/dissolution, insolution and plant action	silty mudstones, reddish orange, reddish brown pinkish brown and brownish red; gypsum nodules and thin bedding-parallel and cross-cutting fibrous seams common passage
sabkha mudflats, periodically wet or damp at surface with relatively high water table at times	blocky and nodular textures with few sedimentary structures due to disturbance by evaporite growth and dissolution, insolution and possible plant action	silty mudstone, orange-brown; gypsum nodules and secondary fibrous seams common locally common passage with mottling
drying out phase of shallow lake	laminated in lower part becoming structureless and/or brecciated in upper part	mudstone, dull purple passage with mottling and interlamination
temporary shallow lake	laminated at most levels with laminae and irregular (washout) lenses of silt at many levels, dessication cracks, rootlets	silty mudstones, greenish grey, greyish green; thin, continuous laminated beds and laterally persistent irregular lenses
alternation of flooded and drying out surface; repeated precipitation and dissolution of evaporites gypsum and salt	brecciated on small (< 2 mm) and large (>10 mm) scales	breccia, angular clasts of variously coloured mudstones and muddy limestone in mudstone matrix; laterally impersistent local mineralised caliche/hardground top
shallow lake with feeder channels, delta, mouthbar and overbank deposits;	lamination, trace fossils, ripples and cross bedding in sandy beds, slump structures, dessication cracks, rootlets	muddy limestone, dolomitic in part; hard, pale-grey-weathering; rich in coarse silt/fine-grained sand locally passage
transgressive deposits of shallow lake	lamination; erosion surface at base	mudstone, dark grey sharp lithological contrast
sabkha mudfalts	mostly structureless; bioturbated surface at top	silty mudstones, reddish orange, reddish brown, pinkish brown and brownish red

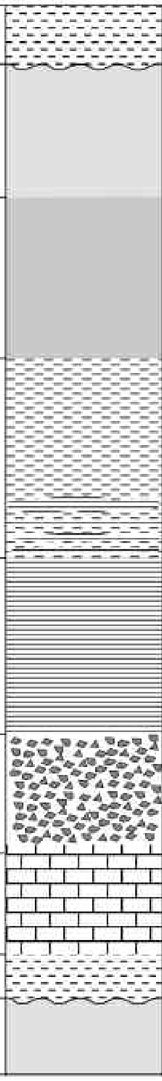

Figure 5. *Idealised rhythm for the Dunscombe Mudstone Formation based on the east Devon coastal sections and the Wiscombe Park boreholes.*

marked contrast to the generally structureless nature of much of the underlying and overlying formations. The lower and middle parts of the formation at outcrop and in the Wiscombe Park boreholes are markedly rhythmic and record a succession of flooding and evaporation events in ephemeral shallow-water environments. Complete rhythms are mostly 1.0 to 1.5 m thick, but are rarely preserved because of the presence of a large number of sedimentary breaks and erosion surfaces. Thick (up to 1.5 m) beds of green mudstone and red-brown mudstone were formed during longer periods of immersion and emergence respectively.

The idealised complete rhythm (Figure 5) begins with laminated and/or bioturbated dark grey mudstone overlain by off-white, finely laminated limestone (calcilutite). This passes up via green and purple mudstones into structureless orange-brown mudstone with common gypsum/anhydrite concretions and veins. Each rhythm is capped by an erosion surface that rests on a calcitised hardground, caliche or gypsum crust depending on the nature of the underlying sediment. The lithology of the deposit on which the erosion surface rests is dependent on the degree to which erosion has removed the underlying sediment and/or the depositional completeness of the underlying rhythm. At some levels, the erosion surface is overlain by a basal lag deposit that contains coarse sand and granules of quartz, glauconite *sensu lato*. and phosphates including vertebrate debris (Porter, 2006). At outcrop on the coast, the rhythms are less obvious in the upper part of the formation due to the presence of thick, laterally impersistent beds of porous breccia that may have formed by a combination of penecontemporaneous salt dissolution and modern gypsum dissolution.

Jeans (1978) recorded the conchostrachan *Euestheria, 'Chondrites'* and other trace fossils, and clay-mineral assemblages in the more calcareous beds in the Dunscombe Mudstone that he interpreted as indicative of deposition in relatively stable sub-aqueous, environments that were close to normal salinity. Fisher (1985) came to a similar conclusion based on palynological analysis. In a detailed analysis of the sedimentology and trace fossils of the Lincombe Member and its correlatives in Somerset (the North Curry Sandstone Member and Sutton Mallet Sandstone Member) Porter (2006) recognised 13 lithofacies and 6 ichnofabrics that indicated deposition in similar fluvio-lacustrine settings. He interpreted the depositional environments of all three arenaceous units as oxygenated freshwater lakes that were fed by broad, shallow channels in a low-relief topography. The Lincombe Member is a geographically isolated sand body that passes upwards and laterally into lake-margin and delta-plain deposits. Similar deposits are currently being formed around the edges of ephemeral lakes in South Australia, notably at Lake Eyre (Lang *et al*., 2004).

SUMMARY AND CONCLUSIONS

The cored intervals and geophysical logs of the Wiscombe Park No. 1 and No. 2 boreholes can be correlated in detail with the outcrop of the lower and middle parts of the Mercia Mudstone Group on the nearby east Devon coast. The boreholes therefore provide an important link between the coastal succession, the type section of the group, and the successions proved in uncored but geophysically logged boreholes throughout south west England. The Wiscombe Park borehole cores preserve sedimentological details that are commonly destroyed by weathering at outcrop. These indicate that the monotonous red mudstones that make up almost the whole of the Sidmouth Mudstone Formation succession were deposited by flash floods and dust storms in ephemeral playa-lake environments in hot deserts.

A sedimentary break and sudden upward change to laminated grey, green and purple mudstones at the base of the Dunscombe Mudstone Formation marks a change to a wetter climate that produced shallow fluvial environments that were colonised by aquatic organisms including insects and plants. Some of the mudstones in the lower and upper parts of the formation have yielded palynomorph assemblages indicative of early and late Carnian ages respectively (Fisher, 1985). The palynological dates combined with the sedimentology suggest that the Dunscombe Mudstone is a highly condensed deposit that spans much of the Carnian Stage (217±2 Ma to 228±2 Ma).

ACKNOWLEDGEMENTS

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