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The stratigraphy of the Mercia Mudstone Group succession (mid to late Triassic) proved in the Wiscombe Park boreholes, Devon.

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The stratigraphy of the Mercia Mudstone Group succession (mid to late Triassic) proved in the Wiscombe Park boreholes, Devon.

Abstract. The type section of the Mercia Mudstone Group is the almost complete exposure in the cliffs between Sidmouth and Axmouth on the south Devon coast. The group comprises four formations, in ascending order the Sidmouth Mudstone, Dunscombe Mudstone, Branscombe Mudstone and the Blue Anchor Formation. The type sections of the three oldest of these are at this locality. The partially cored Wiscombe Park No.1 and No.2 mineral-exploration boreholes, drilled by British Gypsum Ltd (now part of BPB UK Ltd) in 1982, were sited about 5.8 and 4.7km north of the cliff sections respectively. The deeper of these penetrated almost the whole of the Sidmouth Mudstone, the whole of the Dunscombe Mudstone and the lowest part of the Branscombe Mudstone. The lithological succession proved in the cored parts of the boreholes can be correlated in detail with that exposed in the cliffs. This has enabled geophysical logs made through the full length of the boreholes to be correlated with the cliff sections for the cored and uncored parts of the boreholes. The availability of a suite of geophysical logs that has been calibrated against the coastal exposures provides a key correlational link between the outcrop succession and a large number of uncored but geophysically logged hydrocarbon-exploration boreholes throughout the Wessex Basin. Eastwards from Wiscombe Park and the coastal exposures, beneath much of south Dorset, the Dunscombe Mudstone expands from 35m in thickness to over 180m by the addition of thick beds of halite (Gallois, 2003; Harvey and Stewart, 1998).

1. *Introduction.*

The Wiscombe Park No. 1 [SY 1819 9382] and No. 2 [SY 1845 9273] boreholes were drilled by British Gypsum Ltd (now part of BPB United Kingdom Ltd) in 1982 as part of a mineral-exploration programme in east Devon. The boreholes were sited about 1100m apart on the Wiscombe Park estate, Southleigh (Figure 1). The Wiscombe Park No. 1 Borehole was drilled to a total depth of 164.59m[1], of which the interval from 48.77m to 164.59m was continuously cored. The Wiscombe Park No. 2 Borehole was drilled to a

[1] Borehole depths (in feet and inches on the cores) are metricated here: allowances have been made for cores losses.

total depth of 304.80m, of which 76.20m to 117.65m was cored. The cores are housed in the British Geological Survey (BGS) rock store at Keyworth, Nottingham. The following geophysical logs were made in both boreholes: Caliper, Temperature, Total Gamma Ray (GR) and Borehole Compensated Sonic (BHCS).

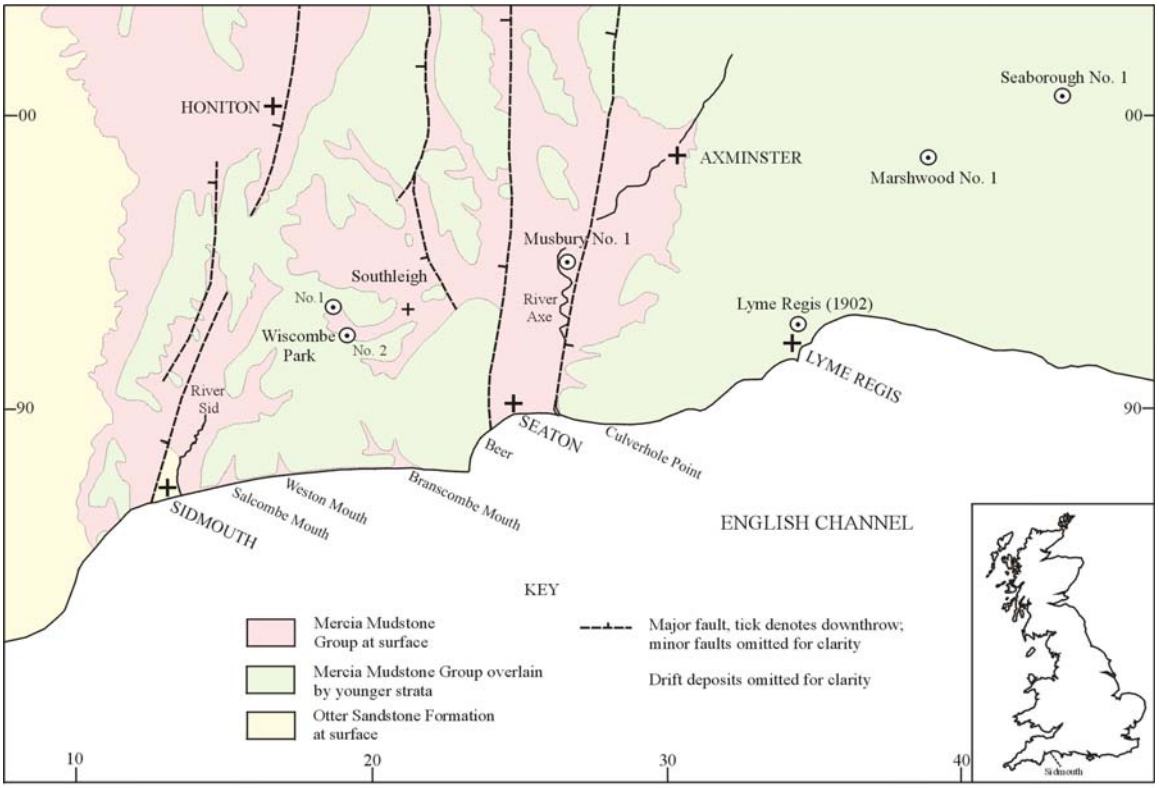

Figure 1. Geological sketch map of the Mercia Mudstone Group outcrop in south-east Devon and the positions of the Wiscombe Park and other boreholes referred to in the text.

An almost complete section through the c. 450m-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 succession dips gently eastwards in a series of long, continuous exposures that enable the lithostratigraphy for the group to be examined in detail. The Triassic succession is overstepped with marked unconformity by the almost horizontal mid Cretaceous Upper Greensand which progressively cuts out the Mercia Mudstone in a westerly direction (Gallois, 2001, fig. 3).

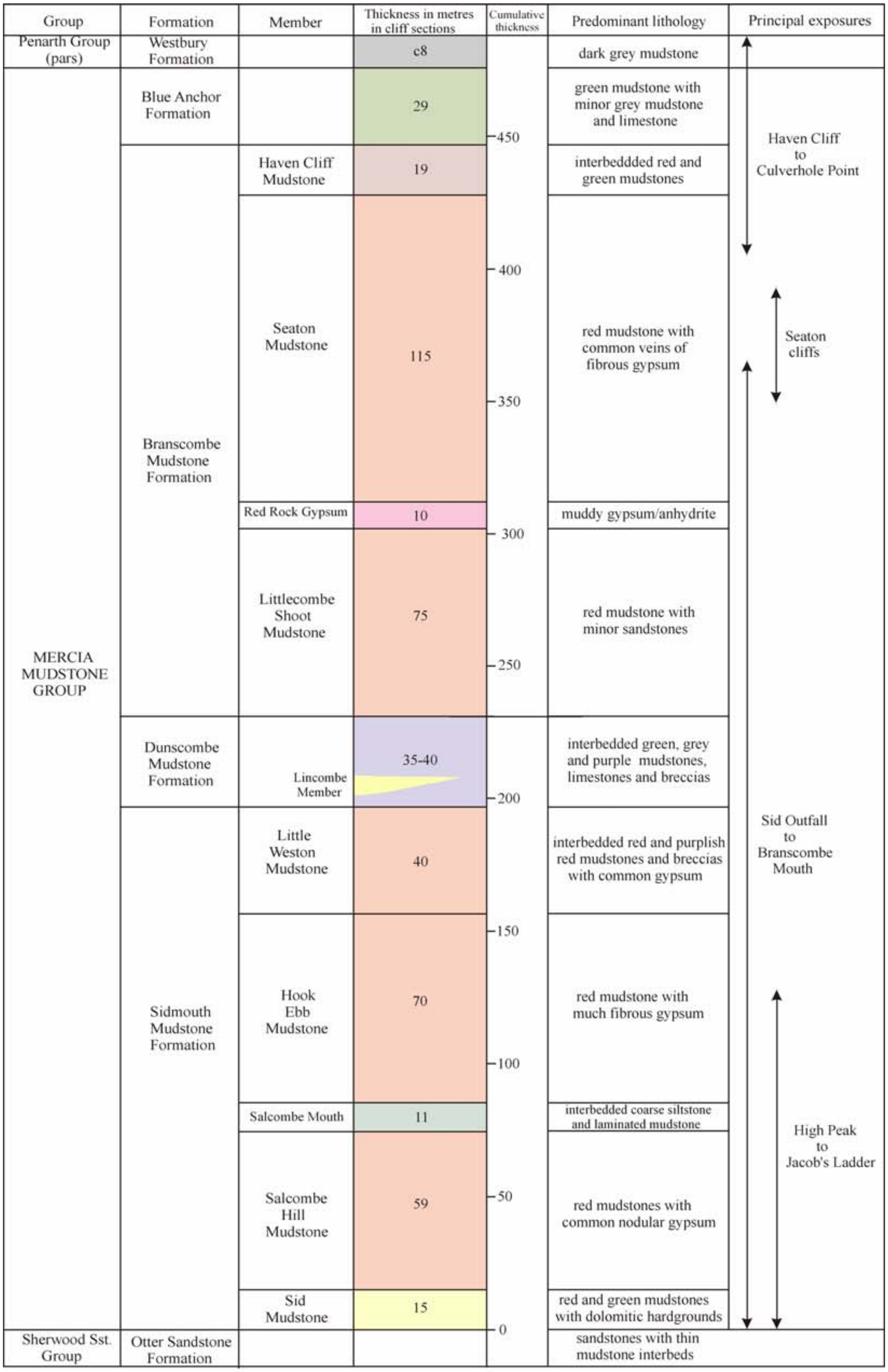

Figure 2. Generalised vertical section for the Mercia Mudstone Group succession exposed on the south Devon coast (after Gallois, 2001).

The previously un-named lower part of the Mercia Mudstone Group (the beds below the Blue Anchor Formation) exposed there has been divided into three formations and nine members based on gross lithology (Gallois, 2001). The lowest and highest of these formations, the Sidmouth Mudstone (c. 195m thick) and Branscombe Mudstone (c. 220m thick), consist of relatively monotonous red mudstones (Figure 2). In the coastal sections the intervening formation, the Dunscombe Mudstone, consists of a 35-40m-thick succession of laminated green, purple and grey mudstones, limestones and breccias with a lenticular bed of calcareous fine-grained sandstone (the Lincombe Member of Porter and Gallois, in press) in the lower part. Sandstone has not been recorded at this stratigraphical level inland in Devon, but lenticular sandstones have been recorded at several levels within the Dunscombe Mudstone inland in south Somerset (e.g. Ruffell, 1991; Ruffell and Warrington, 1978; Williams and Warrington, 1980).

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 180 m by the addition of thick beds of halite (Gallois, 2003).

2. *Lithostratigraphical succession proved in the Wiscombe Park boreholes*

Both boreholes were sited on the Branscombe Mudstone Formation close to the base of the 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 within the Littlecombe Mudstone Member: the No 2 Borehole at about the level of the Red Rock Gypsum Member. Exposures of the latter member 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 Sidmouth Mudstone (Hook Ebb and Little Weston mudstone members) and the lower and middle parts of the Dunscombe

Mudstone in Borehole No.1, and to the upper part of the Sidmouth Mudstone (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 3.

In the coastal sections, the *Hook Ebb Mudstone Member* consists of c. 40m of relatively uniform orange-brown and red-brown mudstones and silty mudstones with little structure other than weakly differentiated small-scale rhythms. In the most actively eroding cliffs, at Hook Ebb [SY 155 877], the mudstones contain numerous bedding-parallel and cross-cutting veins of fibrous gypsum up to 0.15m thick. Between there and Salcombe Mouth [SY 146 877], where the cliffs are protected by a semi-permanent shingle beach, gypsum is mostly absent due to modern dissolution. The Hook Ebb Mudstone proved in the cores of the Wiscombe Park No.1 Borehole (115.53 to 164.59m) is lithologically similar to that at outcrop, but with common sub-horizontal and cross-cutting veins of fibrous gypsum up to 0.20m thick and a few horizons with small gypsum nodules. Thin (mostly <0.08m 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 present at outcrop where it is only preserved in unweathered exposures.

At its type section in the cliff [SY 157 878 to 159 879] that overlooks Little Weston beach, 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 base of the member is taken at the base of a laterally persistent laminated green mudstone in which the lamination is much disturbed 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 0.3m long. At outcrop in the cliffs above the effects of wave action, the highest 9m of the member weathers to porous mudstone rubble due to dissolution of a high gypsum content. This is the least well exposed part of the Sidmouth Mudstone.

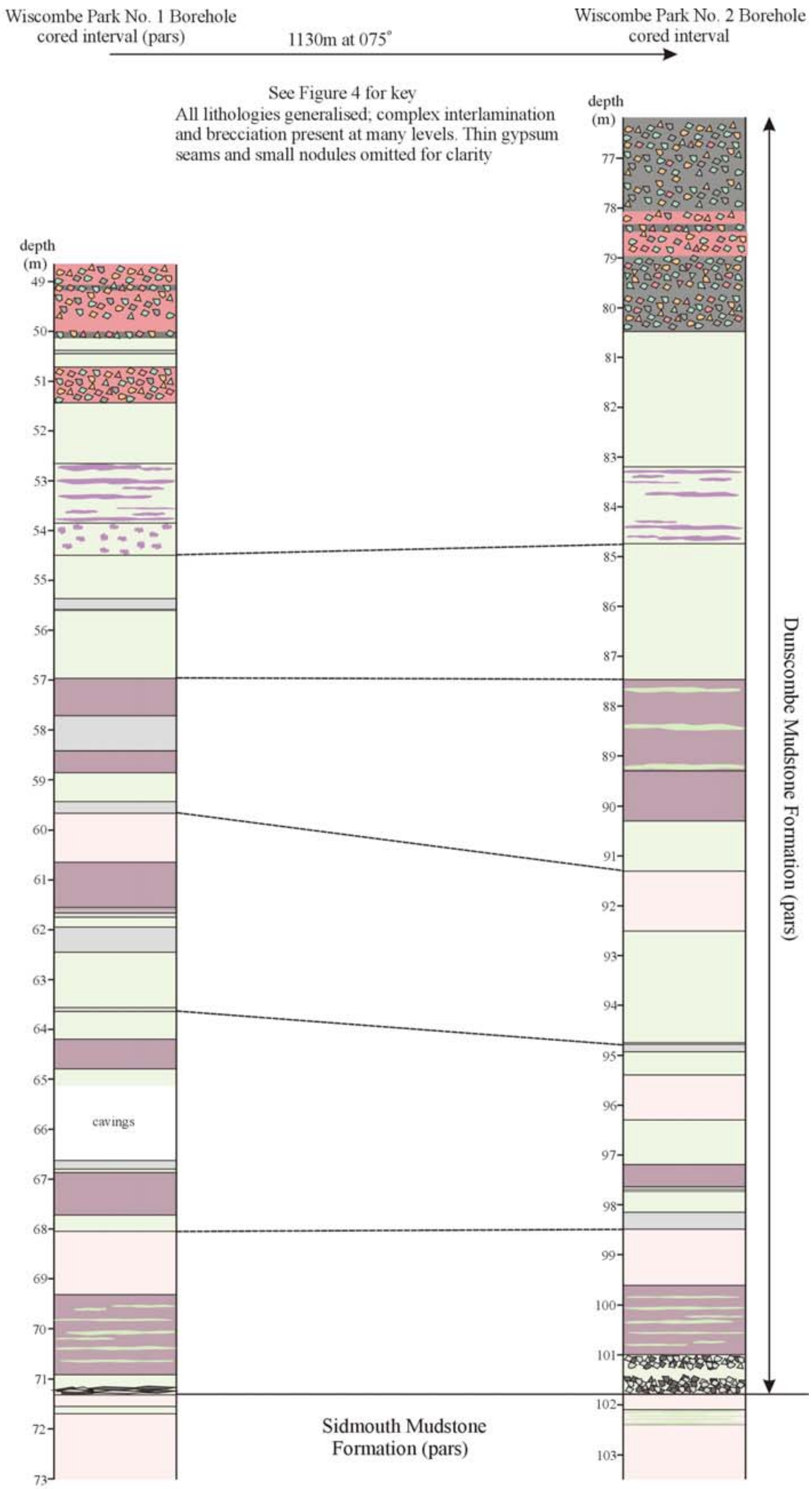

Figure 3. Correlation of the Dunscombe Mudstone Formation cored intervals in the Wiscombe Park No. 1 and No. 2 boreholes.

Figure 4. Key for Figures 3 and 5.

The Little Weston Mudstone succession in the Wiscombe Park No. 1 Borehole (71.90 to 115.53m) is lithologically similar to that at outcrop with the exception that lamination, autobrecciation structures, gypsum veins and nodules, and the rhythmic nature of the succession are better displayed in the borehole cores than at outcrop. 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 (Plate 1). The basal beds of the member and the junction with the Hook Ebb Mudstone in the Wiscombe No.1 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 0.12m. This distinctive marker bed is overlain by a thick green bed 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 member was cored in the No. 2 Borehole (101.80 to 117.65m) where the lithological succession is similar to that in the No. 1 Borehole.

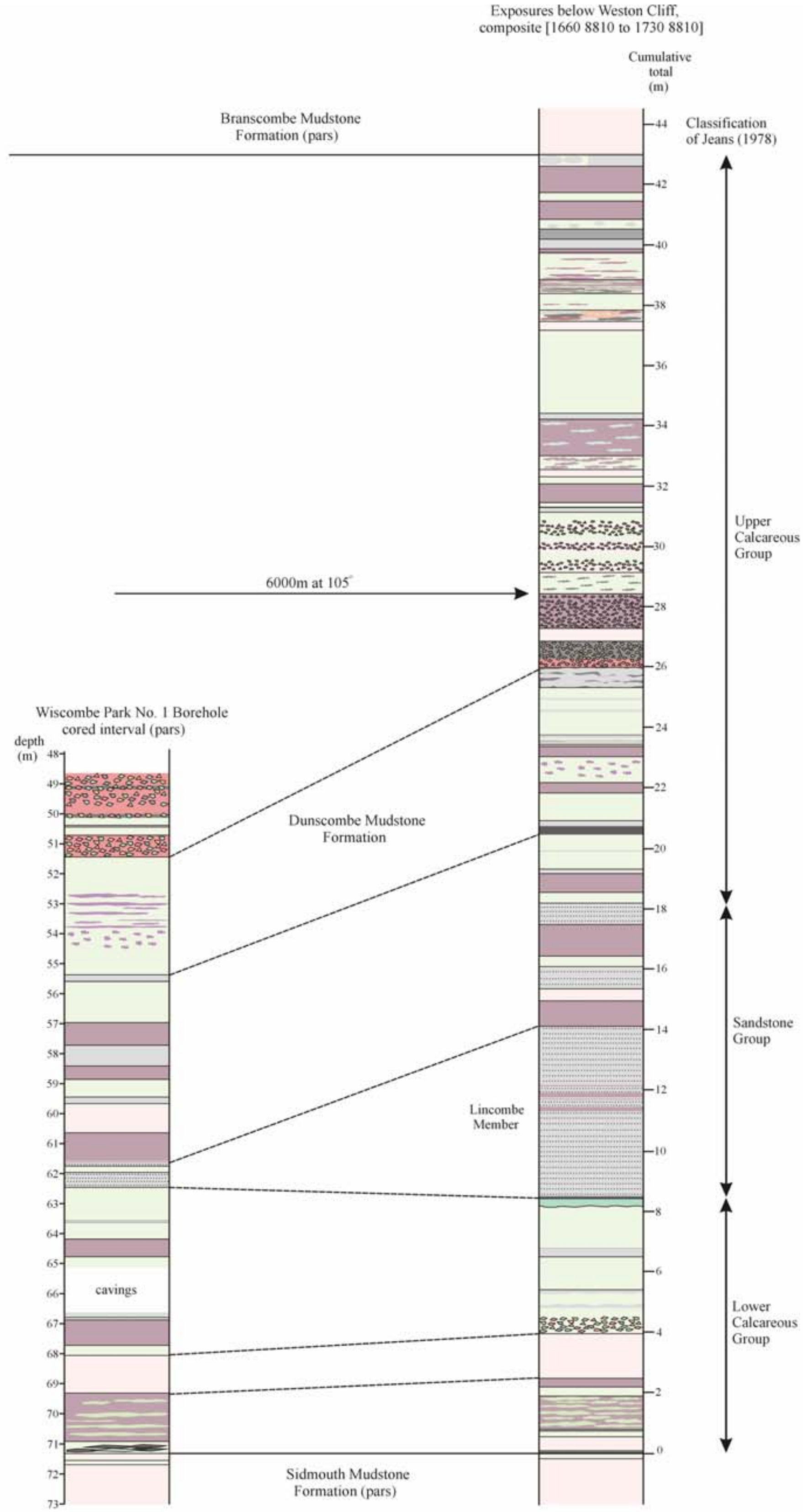

Figure 5. Correlation of the Dunscombe Mudstone Formation succession exposed below Weston Cliff with that cored in the Wiscombe No. 1 Borehole.

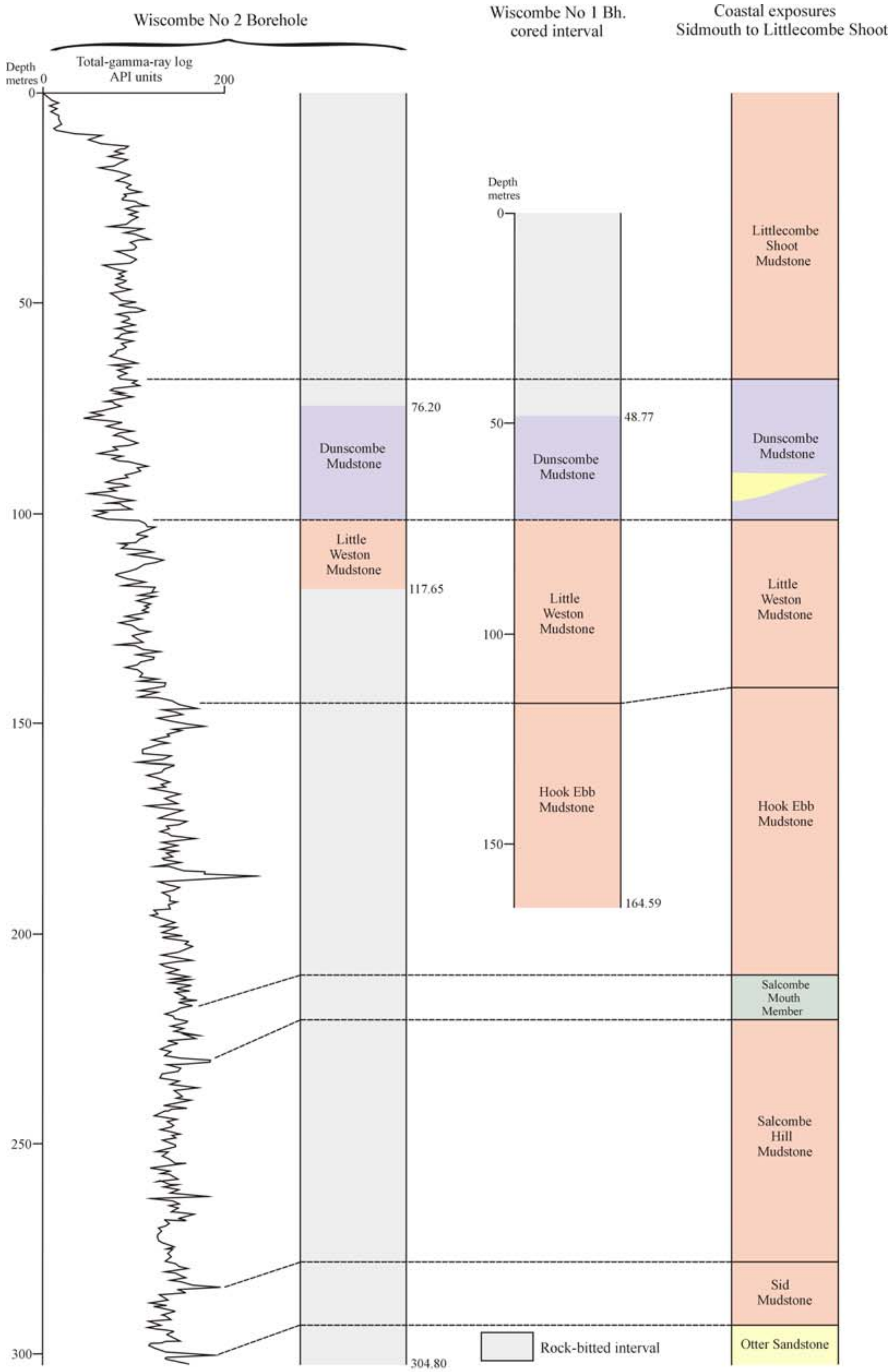

Figure 6. Correlation of the cored interval and total-gamma-ray log of the Wiscombe Park No. 2 Borehole with the successions exposed in the Wiscombe Park No.1 Borehole and on the south Devon coast.

The *Dunscombe Mudstone Formation* is the most lithologically distinctive part of the Mercia Mudstone Group of the east Devon coast. In the coastal exposures it consists of 35 to 40m of rhythmically interbedded green, purple and orange-brown mudstones with subordinate beds of dolomitic limestone/dolomitic siltstone, dark grey mudstone and breccias (autobreccias and collapse breccias). The same range of lithologies was proved in the Wiscombe Park borehole cores (Plates 2, 3 and 4). A lenticular bed of calcareous sandstone (the Lincombe Member) is present in the lower part of the formation in the type section, but this has not been recorded inland.

The overall lithological succession within the Dunscombe Mudstone, in particular the sequence of coloured mudstones, proved in the cores of the Wiscombe No. 1 (48.77 to 71.20m) and No. 2 (76.20 to 101.80m) boreholes can be matched with one another (Figure 3) and with that at outcrop in the cliffs. In addition, several marker beds can be correlated between the borehole and cliff sections (Figure 5). However, the presence of erosion surfaces within the formation at outcrop gives rise to lateral thickness variations over short distances that are more marked than any recorded in the adjacent formations. It should be noted, however, that the lithological uniformity and the scarcity of marker beds within the Sidmouth and Branscombe mudstones make it difficult to detect lateral variation.

The lower and middle parts of the formation are markedly rhythmic and appear to record a succession of transgressive to a regressive phases in which brackish water lacustrine or lagoonal environments were replaced by subaerial sabkhas. The idealised complete rhythm begins with laminated and/or bioturbated dark grey mudstone or off-white, finely laminated dolomitic limestone. 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 *s. l.* and phosphate including vertebrate debris. 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.

The more calcareous beds (limestones and calcareous siltstones) form prominent, pale weathering marker beds in the cliffs. The thickest and most prominent of these beds is the lenticular Lincombe Sandstone Member in the lower part of the formation. In the cliff sections it thickens eastwards for 1.5m in Dunscombe Cliff to 4.8m at its last outcrop before disappearing beneath landslipped material 200m east of Strangman's Cove. It comprises calcareous sandstones and sandy limestones with a few thin (mostly < 30mm) interbeds of mudstone. Overall, the member contains up to 50% of very fine- and fine-grained sand in cross-bedded units and ripple trains. The member is presumed here to be represented in the Wiscombe Park No. 1 Borehole (61.50 to 62.50m) by thin beds of laminated dolomitic limestone with ripples and scattered grains of very fine- and fine-grained sand. It was not recorded in the No. 2 Borehole. Less prominent than the calcareous beds, but also useful for correlation purposes between the borehole cores and the cliff sections, are the thin beds of dark grey mudstone that overlie erosion surfaces (Figure 5).

The presence of lamination and bioturbation at many stratigraphical levels in the Dunscombe Mudstone are in marked contrast to the generally structureless nature of much of the underlying Sidmouth Mudstone and the overlying Branscombe Mudstone formations. Jeans (1978) recorded *Euestheria*, and '*Chondrites'* and other trace fossils indicative of deposition in relatively stable sub-aqueous environments in the Dunscombe Mudstone. Some of the dark grey mudstones have yielded rich palynomorph assemblages. Those from the lower and upper parts of the formation have been interpreted as indicative of early and late Carnian ages respectively (Fisher, 1985). Elsewhere in England, notably in the Midlands, a fluvial interval in the middle part of the Mercia Mudstone Group is represented by the Arden Sandstone Formation, mostly 1 to 8m of sandstones interbedded with green and red mudstones. If Fisher's interpretation is correct, it suggests that the Arden Sandstone Formation, of late Carnian age according to Warrington (in Old et al., 1991), is the correlative of some part of the middle or upper part of the Dunscombe Mudstone.

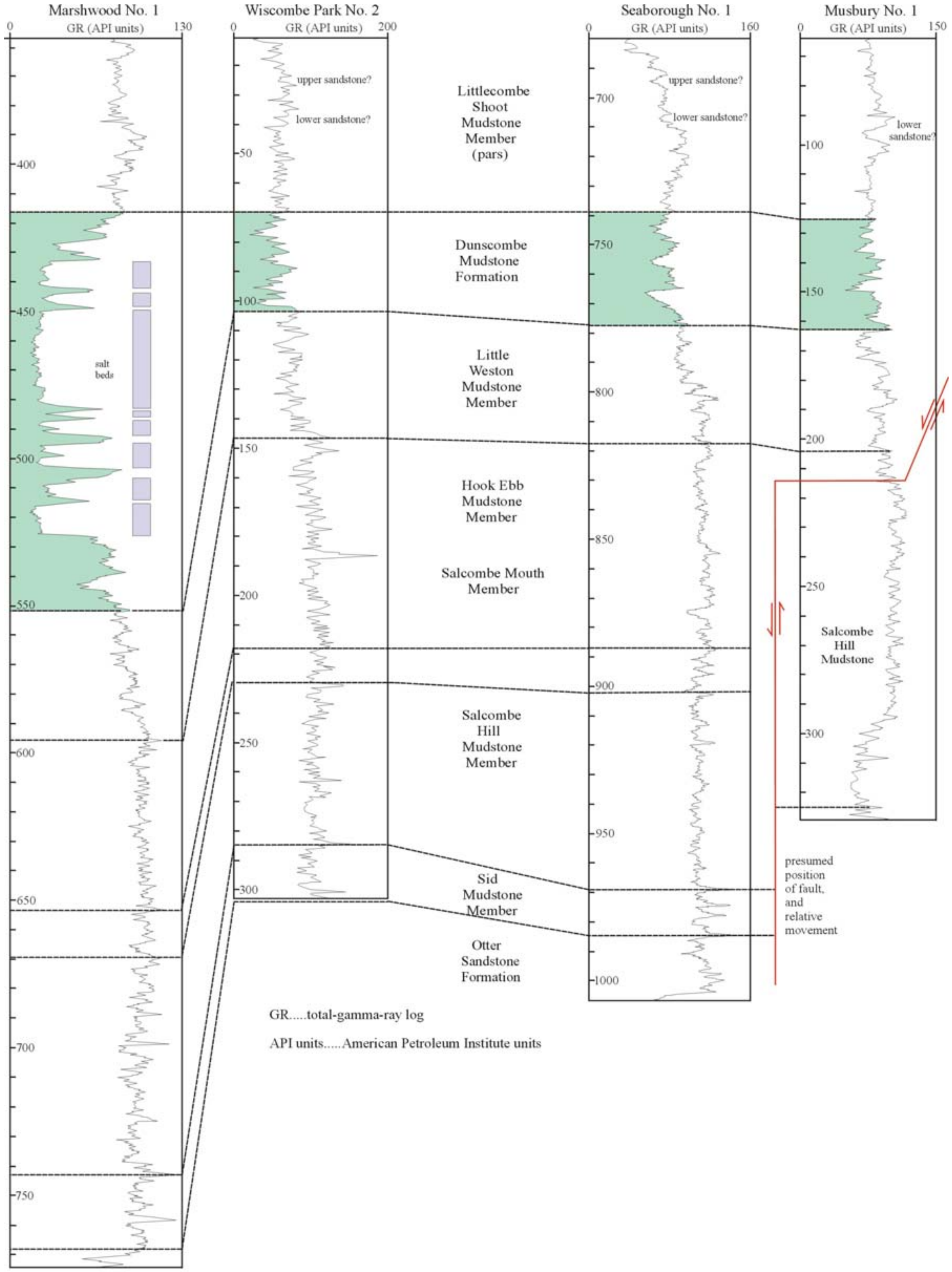

Figure 7. Correlation of the Wiscombe Park No.2 succession with that in nearby boreholes based on total-gamma-ray logs.

In the coastal sections, the Branscombe Mudstone Formation consists of c. 220m of relatively uniform red-brown mudstones and orange-brown muddy siltstones. The lowest member, the *Littlecombe Shoot Mudstone*, comprises 75m of monotonously uniform red- and orange-brown mudstones and silty mudstones with few marker beds The most prominent of these are three lenticular beds of calcareous sandstone, a lower pair (0.15 and 0.6m thick) and a upper bed (up to 1.4m thick). The member was penetrated by the Wiscombe Park boreholes, but not cored. The distinctive signature of the sandstones (low GR, high BHCS) can be recognised in the geophysical logs of the No. 2 Borehole.

2. Geophysical-log correlations with boreholes in east Devon and west Dorset

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 (Figure 6). This enables the coastal sections and the Wiscombe Park boreholes to be correlated with the successions proved in uncored boreholes in the region (Figure 7).

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Figures

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.

2. Generalised vertical section for the Mercia Mudstone Group succession exposed on the south Devon coast (after Gallois, 2001).

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6. 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.

7. Correlation of the Wiscombe Park No. 2 succession with that proved in nearby boreholes based on total-gamma-ray logs.

Plates

All plates at ⅔x. Depth refers to the top of the sample. All lithologies chosen to illustrate textural or sedimentary features. Much of the succession is composed of mudstones in which sedimentary structures appear to be absent or are too weakly displayed for photography.

Plate 1. Wiscombe Park No. 1 Borehole: selected Sidmouth Mudstone Formation (Little Weston Mudstone Member) lithologies.

A. 72.54m depth. Dark reddish brown mudstone with ramifying network of fibrous gypsum veins.

B. 73.61m depth. Dark reddish brown mudstone with autobrecciated texture, nodular and fibrous gypsum/anhydrite and gypsum/anhydrite crusts.

C. 89.18m depth. Dark reddish brown mudstone with autobrecciation and several phases of displacive gypsum/anhydrite

D. 95.71m depth. Dark reddish brown mudstone with several phases of displacive nodular gypsum/anhydrite.

Plate 2. Wiscombe Park No. 1 Borehole: selected Sidmouth Mudstone Formation (Little Weston Mudstone Member) and Dunscombe Mudstone Formation lithologies.

A 67.82m depth. Fine-grained breccia with angular clasts of dolomitic limestone and dark green and purplish red mudstones in a weakly calcareously cemented pale green mudstone matrix.

B 70.26m depth. Laminated and cross-laminated purplish red, purple and green mudstones with lamination disturbed by possible syneresis and/or bioturbation (plant roots?).

C. 71.17m depth. Gypsum/anhydrite-rich breccia in a green and dark grey mudstone matrix. Basal Bed of Dunscombe Mudstone Formation: similar lithologies at outcrop weather to a breccia with streaks of dark grey mudstone.

D. 71.63m depth. Dull reddish brown mudstone with irregular green reduction patches and small gypsum/anhydrite concretions. Highest bed of Little Weston Mudstone Member.

Plate 3. Wiscombe Park No. 1 Borehole: selected Dunscombe Mudstone Formation lithologies.

A and B (parts of same sample) 63.09 and 63.25m depths. Laminated 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.

C 64.62m depth. Interlaminated green mudstone and dolomitic limestone with largely undisturbed laminae resting on brecciated bed of limestone and green and dark grey mudstones which in turn rests on nodular dolomitic limestone. At outcrop, similar lithological successions occur at several levels where they appear to mark transgressive events across hardground surfaces.

D 66.60m depth. Finely laminated dolomitic 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 laminated, silty dolomitic limestone.

Plate 4. Wiscombe Park No. 1 Borehole: selected Dunscombe Mudstone Formation lithologies.

A 49.23m depth. Pervasively brown-stained (due to salt dissolution?) breccia of mudstones and limestone in a mudstone matrix with gypsum/anhydrite nodules and crusts. At outcrop similar lithologies weather to highly permeable breccias.

B 49.99m depth. Fine-grained breccia of predominantly dark grey and green mudstones in a dark grey mudstone matrix, resting on an eroded and patchily cemented surface of green mudstone that passes down into laminated green mudstone; presumed to mark transgression across hardground.

C 50.60m depth. Fine-grained breccia with mudstone and limestone clasts in a green mudstone matrix, in part calcareously cemented.

D 52.88m depth. Interlaminated green and purple mudstones with reduction patches and penecontemporaneous micro faulting.

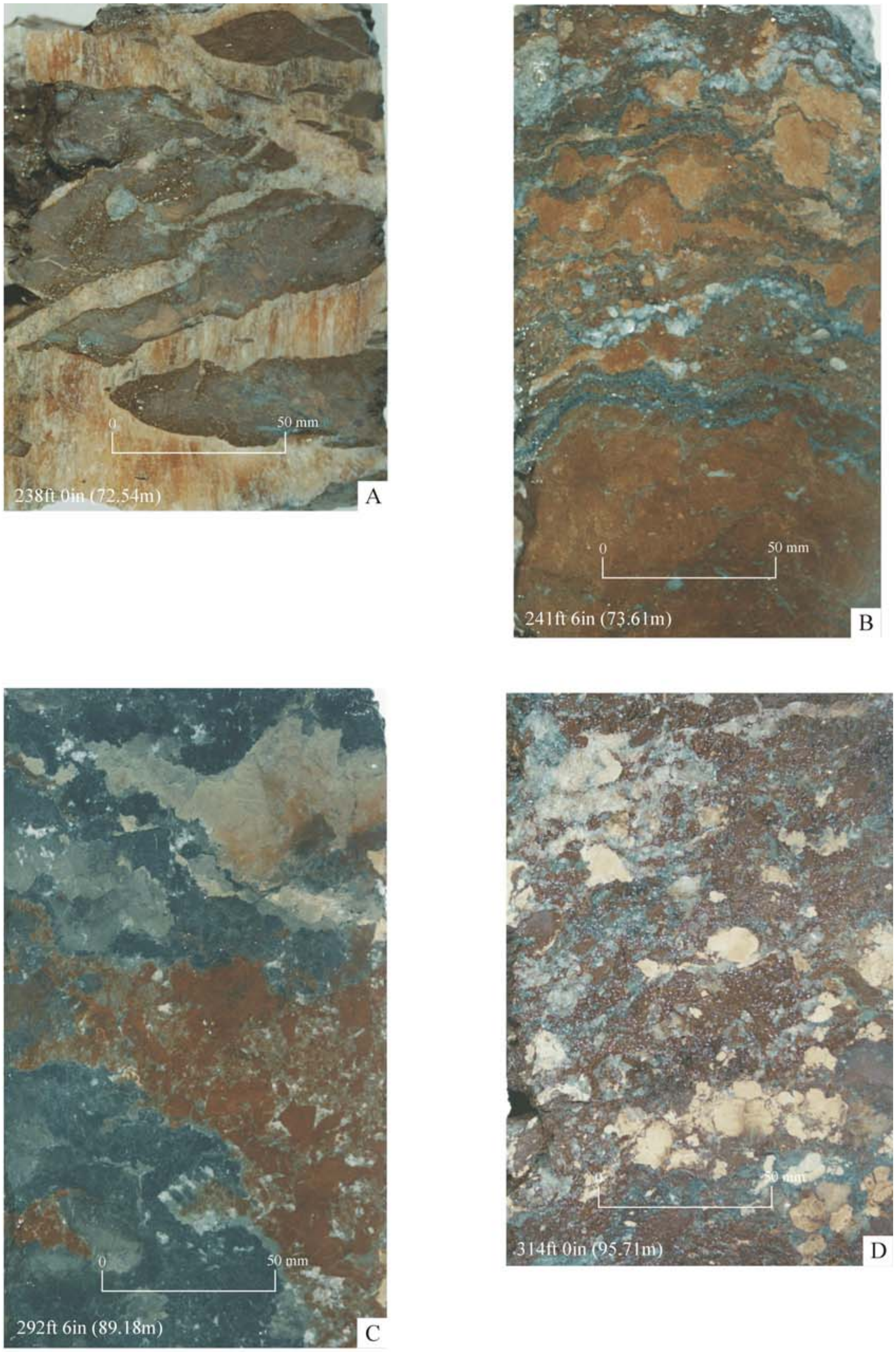

Plate 1. Wiscombe Park No. 1 Borehole: selected Sidmouth Mudstone Formation (Little Weston Mudstone Member) lithologies.

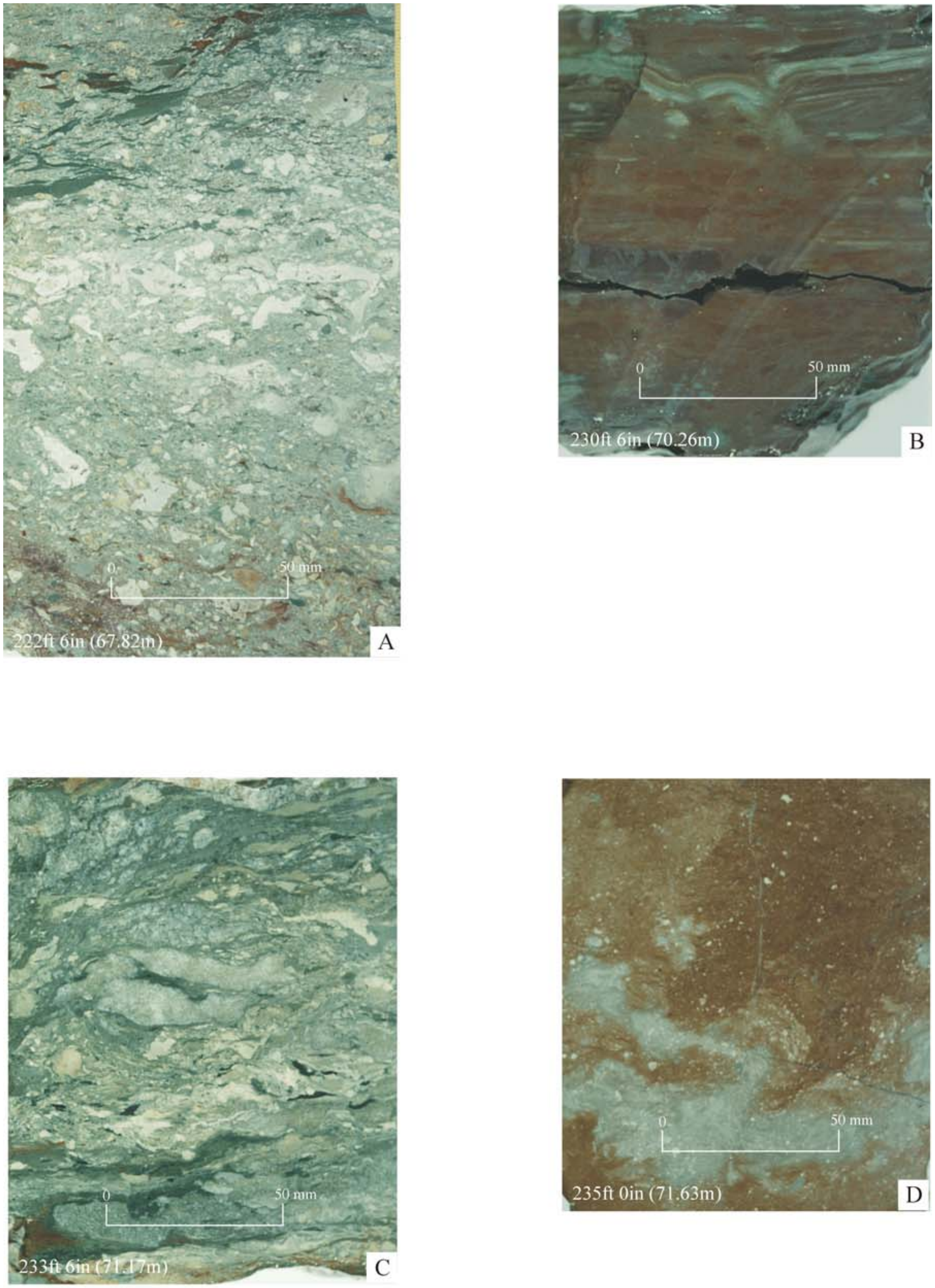

Plate 2. Wiscombe Park No. 1 Borehole: selected Dunscombe Mudstone Formation and Sidmouth Mudstone Formation (Little Weston Mudstone Member) lithologies.

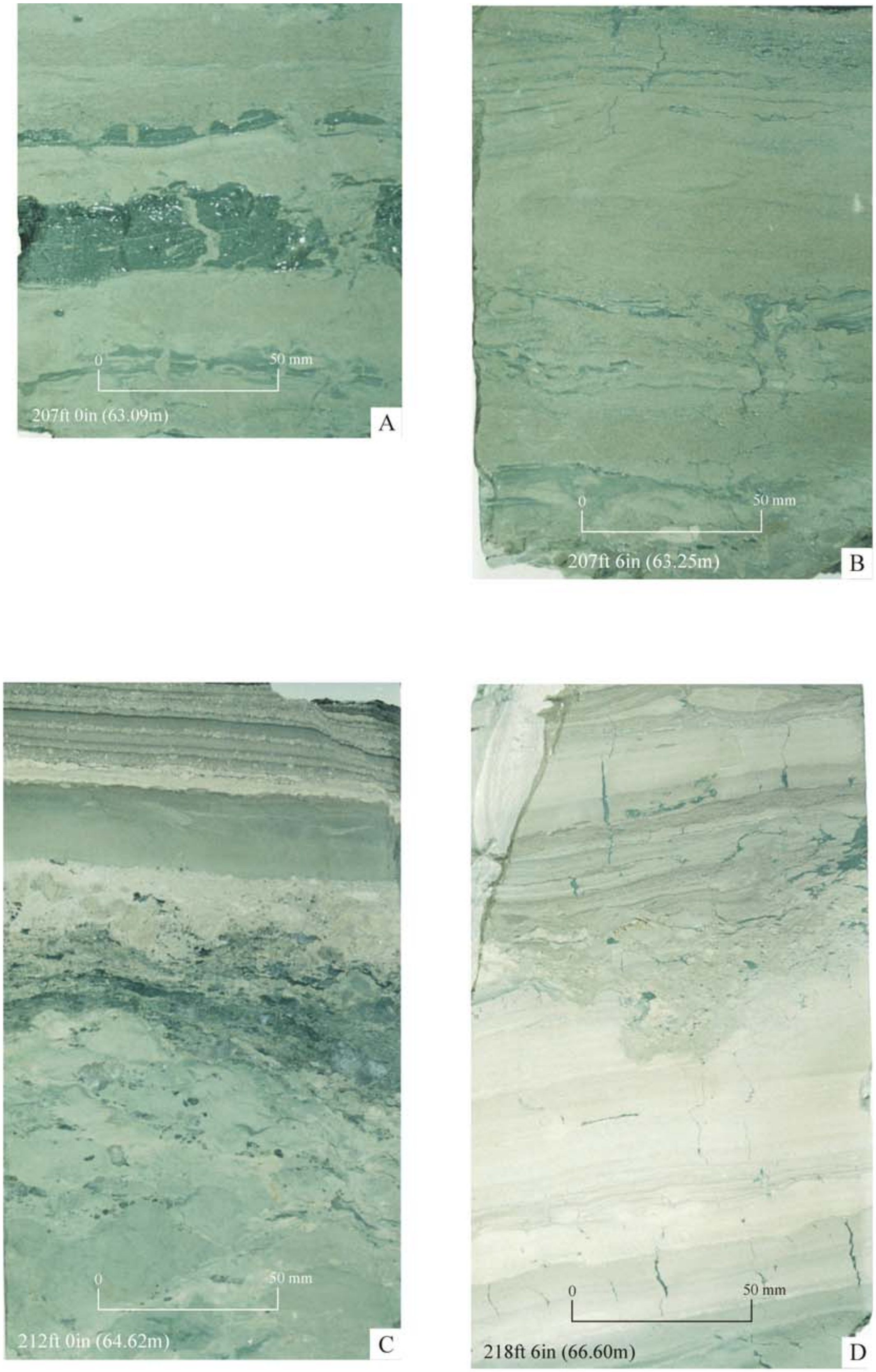

Plate 3. Wiscombe Park No. 1 Borehole: selected Dunscombe Mudstone Formation lithologies.

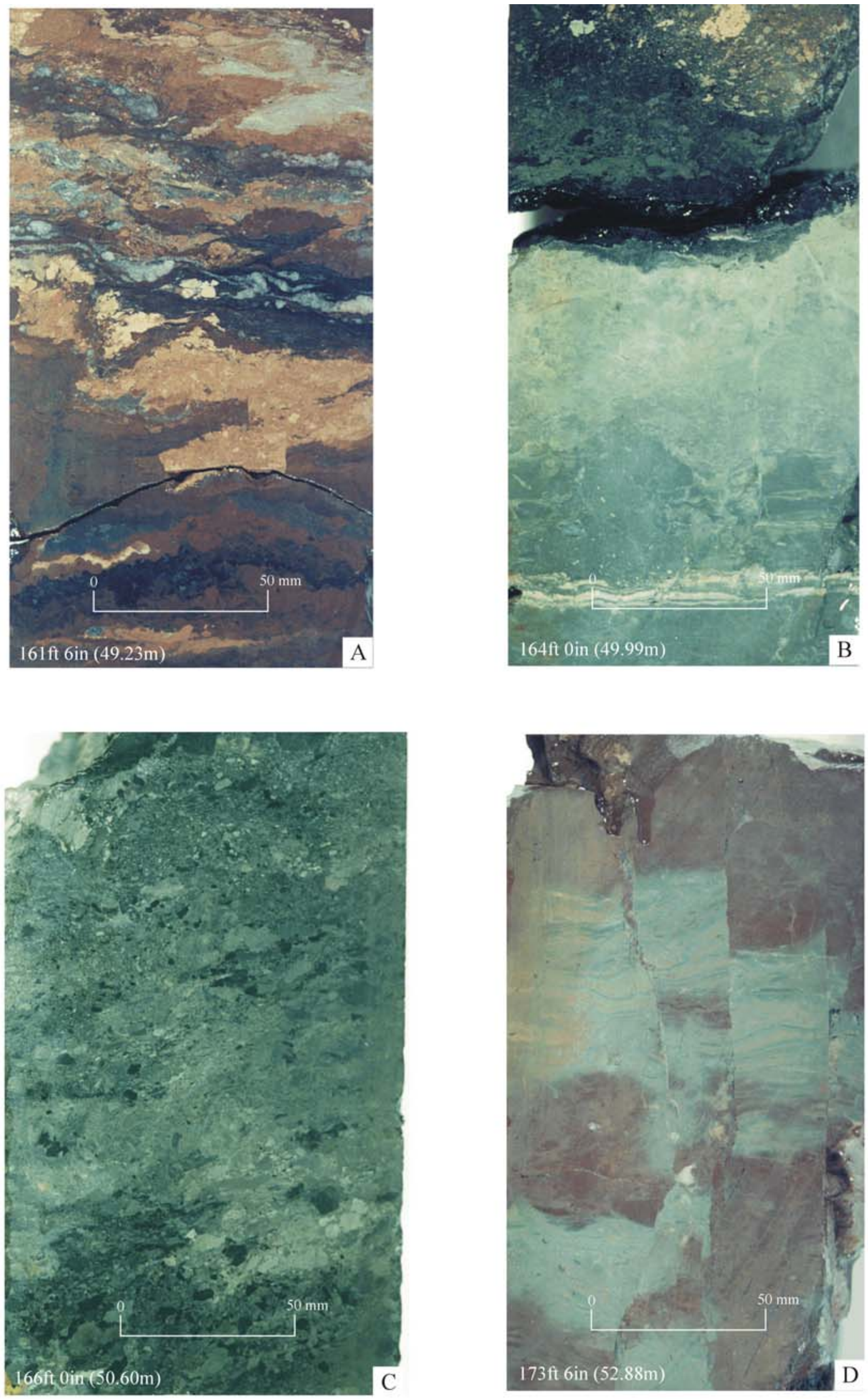

Plate 4. Wiscombe Park No. 1 Borehole: selected Dunscombe Mudstone Formation lithologies.