Correlation of the Triassic and Jurassic successions proved in the Lyme Regis (1901) Borehole with those exposed on the nearby Devon and Dorset coasts

R.W. Gallois

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The Lyme Regis (1901) Borehole was one of numerous coal-exploration boreholes drilled in southern England during the late 19th and early 20th centuries. It is one of the few deep boreholes (>200 m depth) in the east Devon-west Dorset area and, unlike more recent hydrocarbon-exploration boreholes, was continuously cored. The borehole was sited [NGR SY 3364 9297] on the floodplain of the River Lim on the outcrop of the Jurassic Blue Lias Formation, and was continuously cored to a final depth of 396.85 m within the Triassic Mercia Mudstone Group. Selected samples and some of the cores were examined by the Geological Survey geologists Jukes-Browne and Woodward who were working in the area at the time of drilling. The former published a description of the succession based on his and Woodward's notes and the driller's log, and correlated it with the succession of Triassic and Jurassic rocks that are almost wholly exposed in the cliffs between Sidmouth and Lyme Regis. A recent revision of the stratigraphy of the coastal successions has enabled that proved in the borehole to be reassessed and placed more accurately into its regional stratigraphical context.

92 Stoke Valley Road, Exeter, EX4 5ER, U.K.
(E-mail: gallois@geologist.co.uk).

Introduction

The Lyme Regis (1901) Borehole was drilled in an "endeavour to find coal at a place where no geologist would have recommended the attempt" (Jukes-Browne, quoted in Woodward and Ussher, 1911, p. 20). It is one of the few deep boreholes (>200 m depth) in the east Devon-west Dorset area and, unlike more recent hydrocarbon-exploration boreholes, was continuously cored. The borehole was sited [NGR SY 3364 9297] on the floodplain of the River Lim on the outcrop of the Jurassic Blue Lias Formation. It was continuously cored from just below ground level to a final depth of 396.85 m (1302 ft) within the Triassic Mercia Mudstone Group.

Selected samples were examined at the time of drilling by Jukes-Browne, and some of the cores were seen on site by Woodward. Jukes-Browne (1902) provided a description of the succession based on his and Woodward's notes and the driller's log, and correlated it with the succession of Triassic and Jurassic rocks that are almost wholly exposed in the cliffs between Sidmouth and Lyme Regis (Figure 1). The cores were broken up and dispersed to various interested parties. Fifty of the surviving specimens, now in museums in Exeter, Dorchester, Lyme Regis, Taunton and Torquay, were examined by Warrington and Scrivener (1980) who correlated the succession with that exposed on the coast, and 24 of these were sampled for palynomorphs by Warrington (1997).

The recent geological resurvey of the Sidmouth district (BGS 1:50k Sheets 326 and 340, England and Wales) included the first detailed measurements of the Triassic and Jurassic successions (Edwards and Gallois, 2004). The principal aim of the present account is to revise the correlation of the borehole succession with that exposed on the coast. The succession is described here in descending stratigraphical order.

Superficial deposits

The borehole was sited at about 15 m above Ordnance Datum on a veneer of alluvium (<1.5 m thick) resting on Head deposits, sand and gravel rich in chert and flint derived from the Upper Greensand Formation and the Clay-with-flints. Up to 1.5 m of this material is exposed in the river bank adjacent to the borehole site, and up to 5 m of the same material crops out below Horn Bridge [NGR SY 3372 9276], 220 m south of the site, where the stream is more deeply incised. Jukes-Browne (1902) described the highest beds in the borehole as 3.25 m of "gravel, flint and valley deposits": these are interpreted here as predominantly Head deposits.

Jurassic rocks

Blue Lias Formation

The lower slopes of the Lim Valley and the river bed between Uplyme [NGR SY 329 934] and Jericho Weir [NGR SY 3397 9258] are underlain by Head deposits. At both localities, alternating mudstones and limestones of the Blue Lias Formation are exposed in the stream bed (Figure 2). In the intervening area the junction of the formation with the overlying Charmouth Mudstone Formation is obscured by landslip and Head deposits. There is, however, field and borehole evidence to suggest that the Blue Lias Formation subcrops beneath drift deposits along the floor of the Lim Valley everywhere between Lyme Regis and Uplyme, and that the base of the Charmouth Mudstone Formation lies at about 10 m above the valley floor at the borehole site. In the nearest complete cliff sections at Devonshire Head [NGR SY 334 914], 1.6 km SSW of the borehole, the Blue Lias Formation is about 29 m thick. This suggests that the base of the formation should be at about 19 m depth in the borehole. Jukes-Browne (1902) recorded interbedded limestones and mudstones of typical Blue Lias aspect at 3.25 to 7.21 m depth in the borehole, but no marked change in lithology between there and the base of the 'White Lias' at 28.98 m depth (see below).

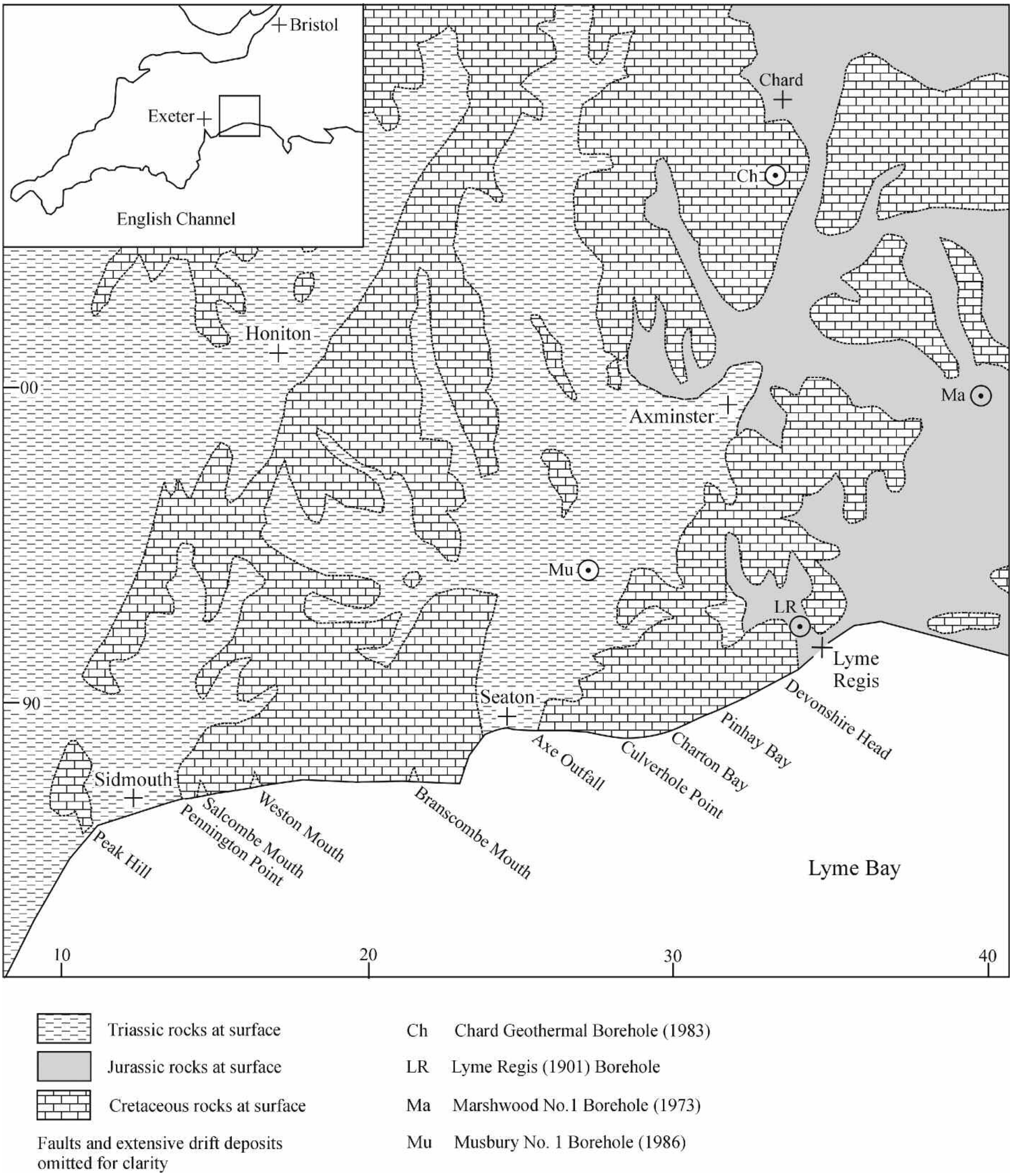


Figure 1. *Geological sketch map of east Devon and west Dorset showing the positions of sections and boreholes referred to in the text.*

TRIASSIC ROCKS

Penarth Group

The junction of the Blue Lias Formation and the underlying 'White Lias' (now the Langport Member of the Lilstock Formation) was not clearly identified in the borehole. Jukes-Browne (1902) recorded the beds from 7.21 m down to a green mudstone at a depth of 28.98 m as 'White Lias', limestones with shale partings. In the cliff sections at Pinhay Bay [NGR SY 318 908], 2.8 km SW of the borehole, and in former quarries in the Uplyme area, the 'White Lias' is about 9 m thick (Edwards and Gallois, 2004). Assuming faulting to be absent, the *c.* 26.7 m of beds proved in the borehole between the base of the drift deposits and the green mudstone probably, therefore, represent the full thickness of the 'White Lias' and the lower *c.* 18 m of the Blue Lias Formation.

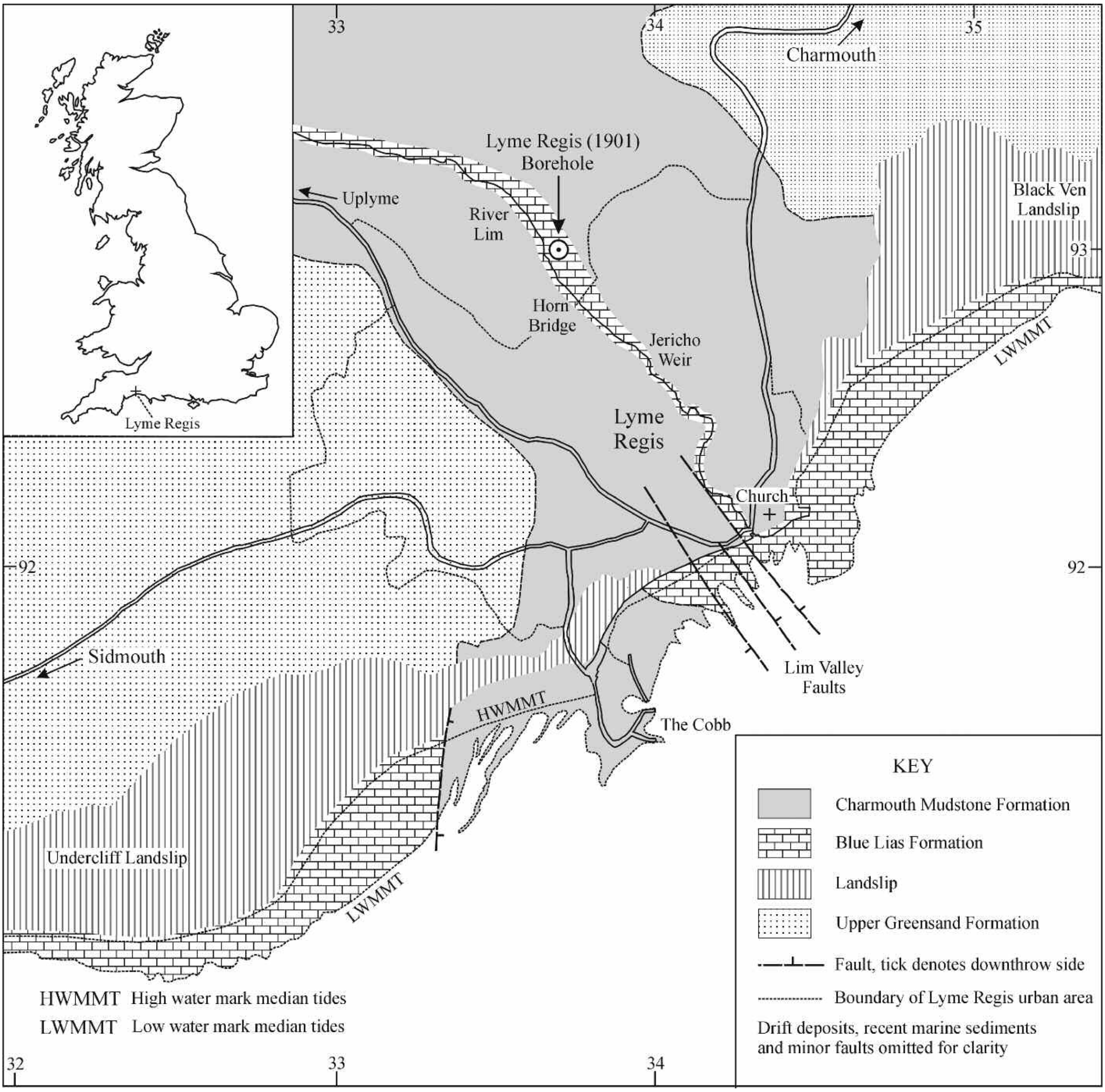


Figure 2. *Sketch map of the solid geology of the Lyme Regis area.*

Jukes-Browne (1902) referred the green mudstone (at 28.98 m to 30.86 m depth) to the Cotham Beds (now the Cotham Member of the Lilstock Formation), and Warrington and Scrivener (1980) agreed with this interpretation. The thickness is similar to that which has been exposed from time to time in the intertidal zone [NGR SY 272 894] near Culverhole Point. The member was underlain at 30.86 m to 40.74 m depth by fossiliferous "dark-blue shale" with a few thin limestone interbeds which can, in part, be lithologically and faunally matched with the Westbury Formation. The base of the formation, which is marked by a remanié bone bed at Culverhole Point (Woodward and Ussher, 1911), was not clearly defined in the borehole account. Warrington and Scrivener (1980) allocated 9.88 m (from 30.86 m to 40.74 m depth) to the formation, but this is probably too much. The best sections in the Westbury Formation in recent years have been at Culverhole Point where up to 5 m of fossiliferous, dark grey pyritic mudstone rest with disconformity on unfossiliferous dark grey mudstones of the Blue Anchor Formation.

Mercia Mudstone Group

The resurvey of the Sidmouth district (Edwards and Gallois, 2004) resulted in a revision of the lithostratigraphy of the Mercia Mudstone Group of the Wessex Basin, which is now divided into four formations (Gallois, 2001). These are, in descending order, the Blue Anchor, Branscombe Mudstone, Dunscombe Mudstone and Sidmouth Mudstone formations.

Blue Anchor Formation

The Blue Anchor Formation, except for a small thickness in the highest part, is fully exposed in the cliffs between the outfall of the River Axe and Culverhole Point [NGR SY 256 898 to 274 894]. The upper half of the formation is also exposed at Charton Bay [NGR SY 298 900]. The two sections can be correlated in bed-by-bed detail, suggesting that there is little thickness or stratigraphical variation over the intervening distance of two kilometres.

Richardson (1906, p. 402) described the section at Culverhole Point as *c.* 23 m thick, but did not make allowance for strata cut out by faulting. More recent measurements (Gallois, 2001) have shown the total to be *c.* 29 m thick with up to 2 m missing from the higher part due to faulting. Warrington and Scrivener (1980) allocated 24.74 m (from 40.74 m to 65.48 m depth) of green and grey mudstones to the formation. The difference in thickness between the outcrop and borehole measurements, 7.2 km apart, are likely to be due to the paucity of sampling in the borehole rather than lateral variation in the Blue Anchor Formation. The base of the formation probably lies between samples described by Jukes–Browne (1902, p. 285) as a "green marl" at 64.62 m and a "red marl" at 73.15 m. This would give a range of thickness for the Blue Anchor Formation of 23.88 m to 32.41 m. Correlation of the coastal succession with those proved in boreholes throughout the Wessex Basin suggests that the formation maintains a relatively constant thickness of 25 to 30 m over most of the region (Gallois, 2003). In the nearest of these to Lyme Regis, the formation was 28 m thick in the Chard Geothermal Borehole [NGR ST 3430 0653].

Branscombe Mudstone Formation

The Branscombe Mudstone Formation consists of relatively uniform red-brown mudstones and orange-brown muddy siltstones. The total thickness at outcrop in the type section between Weston Mouth [NGR SY 168 880] and Culverhole Point [NGR SY 274 893] is *c.* 220 m. Unlike those of the other Mercia Mudstone Group formations exposed on the coast, the outcrop is incomplete due to faulting in the Axe Valley. However, comparison of the exposed succession with that proved in the Chard Geothermal, Marshwood No. 1 [NGR SY 3885 9880], and Musbury No. 1 [NGR SY 2670 9510] boreholes suggests that there is little missing (probably <10 m) from the coastal exposures (Gallois, 2001).

At outcrop, the formation contains lithologically distinctive marker beds at three stratigraphical levels. In the highest part, the Haven Cliff Mudstone Member consists of thinly interbedded red and green mudstones; in the middle part the 10 m-thick Red Rock Gypsum Member (Figure 4D) forms a laterally persistent geophysical marker bed throughout the Wessex Basin (Gallois, 2003); and in the lower part, there are three beds of calcareous sandstone (0.15, 0.6 and 1.4 m thick).

Most of the borehole succession below the Blue Anchor Formation was described as "red and green marls", with no reference to the type of interbedding that might correlate with that of the Haven Cliff Mudstone Member. Jukes-Browne (1902) recorded a concentration of gypsum in beds 0.05 to 0.4 m thick between 126.84 m and 185.95 m depth, and a sample of "solid white crystalline gypsum" at 182.88 m depth. On depth considerations alone, the lower part of these beds appears to be at a similar stratigraphical level to beds with common traces of former gypsum seams (now represented by dissolution residues) immediately above the Red Rock Gypsum Member in the cliffs adjacent to Branscombe Mouth [NGY SY 200 881 to 205 881]. These beds are, however, only marginally more gypsum-rich than parts of the remainder of the formation. Warrington and Scrivener (1980, p. 31) noted a major concentration of sulphates at 165.58 to 180.04 m depth, but this too does not appear to be the correlative of the Red Rock Gypsum Member. The absence of a thick bed of gypsum in the borehole is surprising given that the Red Rock Gypsum Member is one of the most lithologically distinctive and laterally persistent beds in the Mercia Mudstone Group of the Wessex Basin (Lott *et al.*, 1982; Gallois, 2003).

Three beds of fine-grained calcareous sandstone up to 0.38 m thick were recorded between 256.57 m and 263.35 m depth in the borehole, which Jukes-Browne (1902, p. 285) interpreted as "sandy beds intercalated in the Keuper Marl Series". Comparison with the succession exposed in the coastal sections suggests that they are at a similar stratigraphical level to three beds of calcareous sandstone in the Branscombe Mudstone Formation exposed at Cox's Cliff [NGR SY 180 881] (Figure 3). Similar sandstones were recorded at about this stratigraphical level in the nearby Musbury No.1 Borehole.

Warrington and Scrivener (1980, p. 30) interpreted the sandstones proved in the Lyme Regis (1901) Borehole as the correlative of a 20 m-thick sandstone unit that Warrington *et al.* (1980, p. 62) had formally named the Weston Mouth Sandstone Member. At the proposed type section at Weston Mouth, the proposed member consists of interbedded green, purple and orange-brown mudstones (the Dunscombe Mudstone of Gallois, 2001: see below).

Dunscombe Mudstone Formation

The Dunscombe Mudstone Formation is the most lithologically distinctive part of the Mercia Mudstone Group of the east Devon coast. At outcrop in Higher Dunscombe [NGR SY 154 878] and Weston [NGR SY 168 881] cliffs, the formation consists of 35 to 38 m of interbedded green, purple and orange-brown mudstones with subordinate beds of calcareous sandstone/siltstone, dark grey mudstone and common brecciated beds (Figure 4C). Three lenticular beds of laminated, muddy sandstone/siltstone form a prominent group of marker beds in the lower part (the 'Sandstone Group' of Jeans, 1978, figs 34, 37 and 38). Correlations with inland boreholes in the Wessex Basin and offshore boreholes in the English Channel Basin suggest that the breccias pass laterally into thick beds of salt (Gallois, 2003). A total of eighty metres of halite was recorded within the Dunscombe Mudstone Formation in the Marshwood No.1 Borehole, 8 km NE of Lyme Regis.

Between 292.20 m and 323.62 m depth, Jukes-Browne (1902, pp. 285-286) recorded 'blue, brown, grey and red marls' with common gypsum. The lithologies can be loosely matched with those of the Dunscombe Mudstone Formation, and the thicknesses are in relatively close agreement with those exposed in the cliffs (Figure 3). The presence of thin beds of limestone at 314.78 m and 328.27 m is also indicative of the Dunscombe Mudstone as limestones are confined to this formation in this part of the Mercia Mudstone Group.

Determinable fossils are extremely rare in the Mercia Mudstone Group except at selected horizons in the Dunscombe and Blue Anchor formations. Fisher (1985) recorded palynomorphs indicative of the Carnian Stage from thin beds of dark grey mudstone in the lower and middle parts of the Dunscombe Mudstone at outcrop below Weston Cliff, and Dr Heinz Kozur (*pers comm*., 2004) has recorded the Carnian branchiopod *Laxitextella* in the lower part of the formation at the same locality. Warrington (1997) recorded assemblages of Carnian palynomorphs within the interval of 'coloured mudstones' in the borehole, both of which are likely to have come from the Dunscombe Mudstone Formation.

Sidmouth Mudstone Formation

The Sidmouth Mudstone Formation is wholly exposed in the cliffs between Sidmouth and Weston Mouth [NGR SY 129 873 to 164 881] where it comprises 165 m of relatively uniform red-brown mudstones and muddy siltstones with a few thin beds (up to 0.3 m thick) of green mudstone, and common gypsum veins at some levels (Figure 4A). The base of the formation is taken at a sharp lithological change from sandstone to mudstone at the top of the Otter Sandstone Formation.

The most lithologically distinctive part of the formation (the Salcombe Mouth Member) is an 11 m-thick unit of thinly interbedded red, purplish red and orange-brown mudstones with four beds of grey, coarse siltstone/fine-grained sandstone that make up about 15% of the total succession at outcrop at Salcombe Mouth (Figure 4B). Jukes-Browne (1902) recorded an interval (369.7 to 374.9 m depth) of grey, more silty/sandy beds that might in part be the correlative of the Salcombe Mouth Member (Figure 3). If it is, then about 35 m of the Sidmouth Mudstone Formation is cut out by faulting in the borehole.

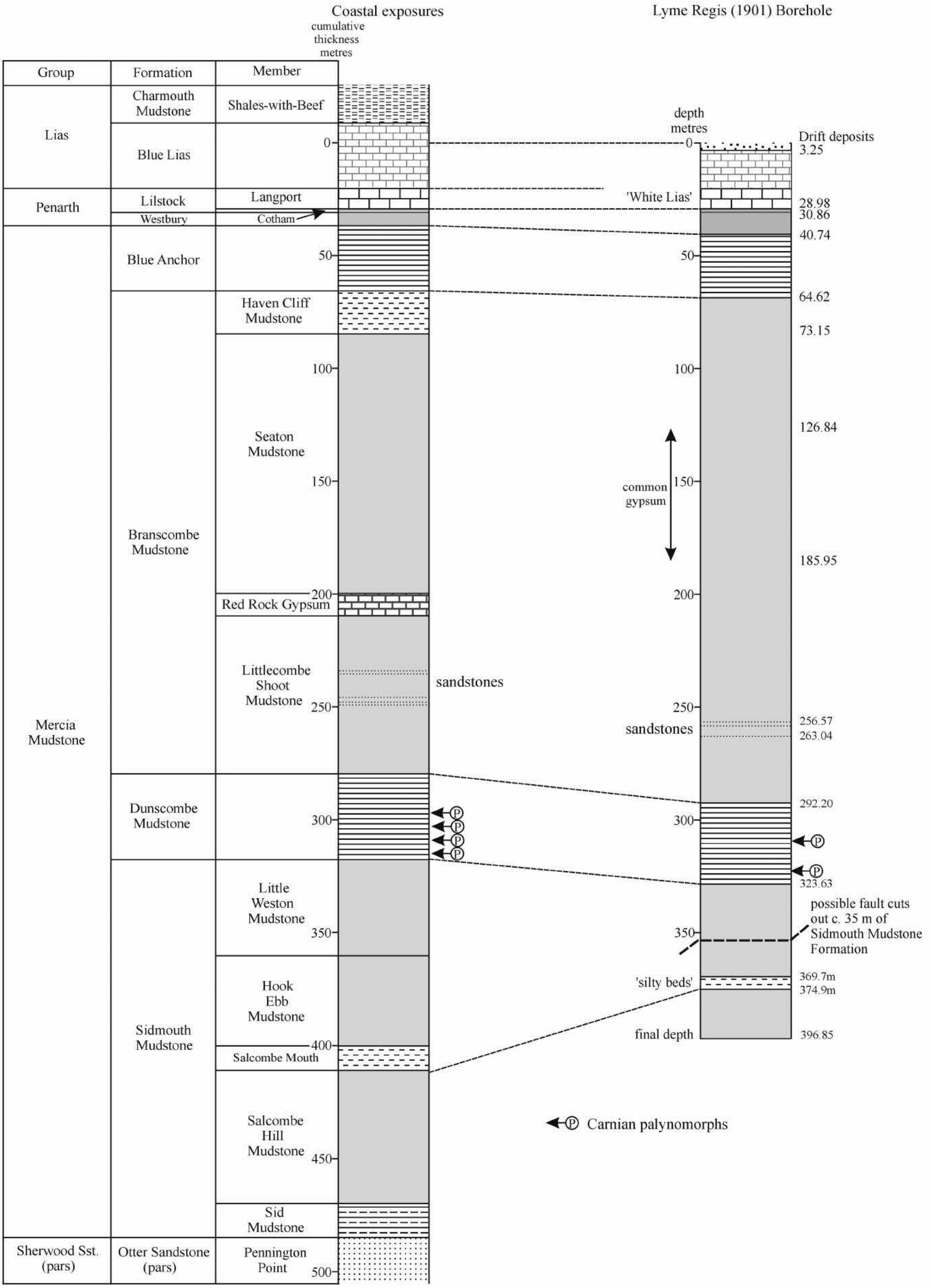
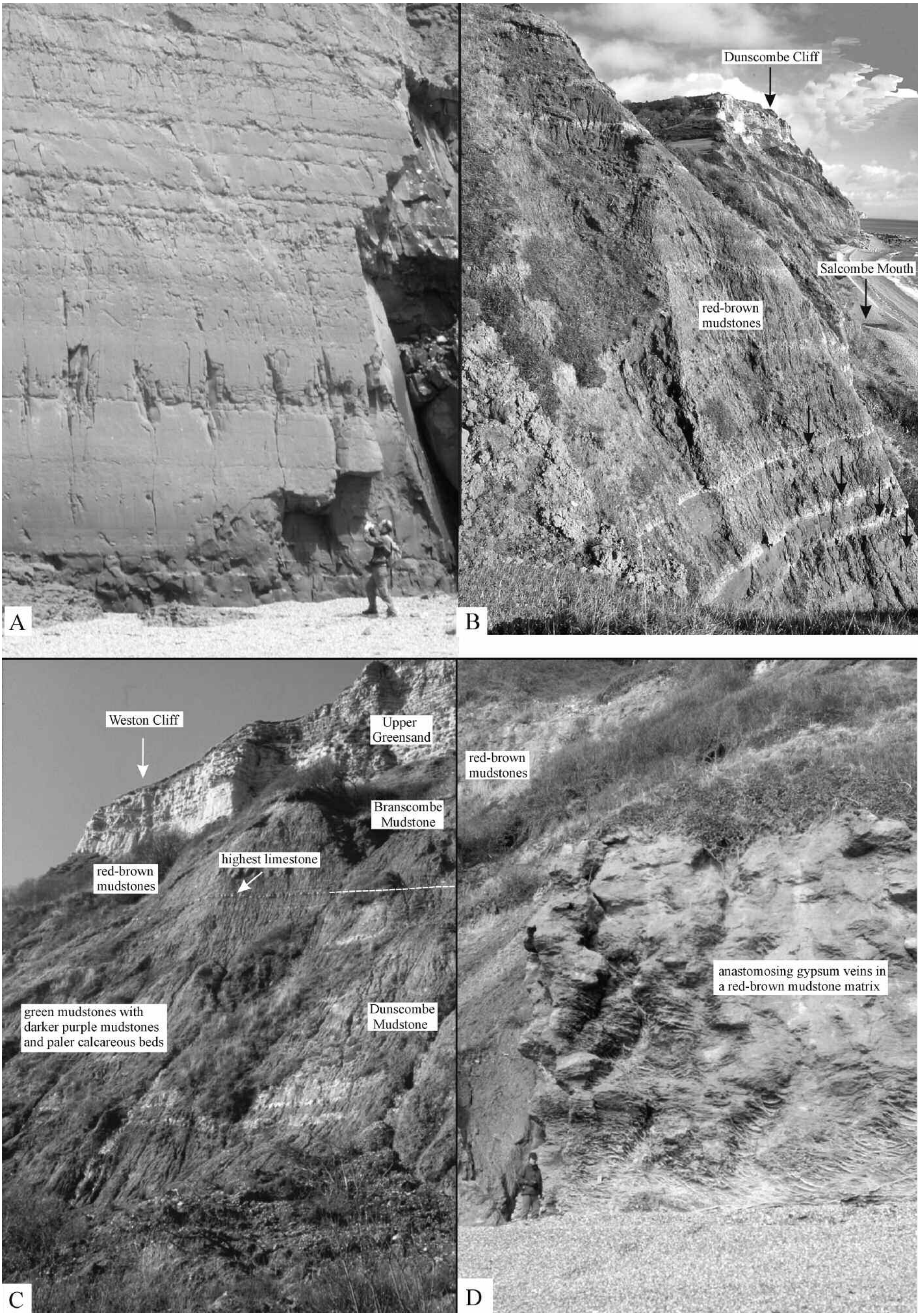


Figure 3. *Correlation of the Triassic-Jurassic succession exposed on the east Devon coast with that proved in the Lyme Regis (1901) Borehole. Coastal succession based on Gallois (2001); borehole succession based on Jukes-Browne (1902) with additions from Warrington and Scrivener (1980) and Warrington (1997).*


A
B
Dunscombe Cliff
Salcombe Mouth
red-brown mudstones
C
Weston Cliff
Upper Greensand
Branscombe Mudstone
highest limestone
red-brown mudstones
green mudstones with darker purple mudstones and paler calcareous beds
Dunscombe Mudstone
D
red-brown mudstones
anastomosing gypsum veins in a red-brown mudstone matrix

The lowest part of the Lim Valley overlies an N-S trending belt of faulting. The faults are exposed on the foreshore at the mouth of the river, and their offshore extension was proved by a seismic-reflection survey (Gallois and Davis, 2001). Their inland continuation is hidden beneath drift deposits, but at least one of the faults is likely to intersect the borehole.

Jukes-Browne (1902) noted that after the borehole had been completed in 1901 it provided a large and constant supply of water with an artesian head of about 6 m. When he visited the site in 1902 the head had been maintained and the water was running to waste. It is not known for how long the supply remained artesian. The geological structure and topography of the site are such that there was a strong possibility that artesian water would be intersected in the White Lias limestones. However, this does not seem to have been the case as the head was not encountered until the borehole had been completed. There is no known analysis of the water, but it is reasonable to suppose that it was not markedly saline as this would have almost certainly led, at that time and at that place, to the development of a medicinal spa.

CONCLUSIONS

Comparison of the Triassic and Jurassic successions recorded in the Lyme Regis (1901) Borehole by Jukes-Browne (1902) with those exposed on the coast between Sidmouth and Lyme Regis suggests that the lithologies and thicknesses are closely similar. The Dunscombe Mudstone Formation in the borehole is condensed in comparison with the succession proved elsewhere in the Wessex Basin. This and the absence of beds of halite suggest that the Lyme Regis (1901) Borehole is sited on or close to the East Devon Structural High (Gallois, 2003).

The total thickness of the Mercia Mudstone Group beneath the borehole site is probably about 450 m, similar to that exposed on the coast. The conclusion by Warrington and Scrivener (1980, p. 31) that the borehole may have terminated as little as 33.50 m above the base of the Mercia Mudstone Group is an underestimate. If there is no loss of Sidmouth Mudstone Formation through faulting in the borehole, then the base of group is about 90 m below the bottom of the borehole. If the 'silty beds' in the borehole are the correlative of the Salcombe Mouth Member, as suggested here, then about 35 m of the Sidmouth Mudstone Formation is cut out by faulting. The base of the formation would then be about 50 m below the bottom of the borehole.

Left Figure 4. A. *Salcombe Hill Cliff, Sidmouth, type section of the Salcombe Hill Member of the Sidmouth Mudstone Formation. The formation and much of the remainder of the Mercia Mudstone Group exposed on the east Devon coast consists of monotonously uniform red-brown mudstones with few bedding features other than lines of gypsum nodules.* ***B.*** *Type section of the Salcombe Mouth Member of the Sidmouth Mudstone Formation at Salcombe Mouth. The member consists of rhythmic alternations of purplish red mudstones and pale-weathering siltstones/very fine-grained sandstones.* ***C.*** *Dunscombe Mudstone Formation exposed below Weston Cliff. Laminated green, purple and grey mudstones with thin interbeds of silty limestone, breccia and red-brown mudstone represent a fluvial interval within the predominantly arid Mercia Mudstone Group. The highest limestone (arrowed) marks the top of the formation. Photograph courtesy of Christopher Jeans.* ***D.*** *Red Rock near Branscombe Mouth, type section of the Red Rock Gypsum Member. The member was proved in the nearby Chard Geothermal, Marshwood and Musbury boreholes, and has been shown from its distinctive geophysical-log signature to have an extensive subcrop in the Wessex Basin.*

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