Gallois, R.W. 2001. *Geoscience in South-west England,* Vol. 10, 195-205.

THE LITHOSTRATIGRAPHY OF THE MERCIA MUDSTONE GROUP (MID TO LATE TRIASSIC) OF THE SOUTH DEVON COAST

R. W. GALLOIS

Gallois, R. W. The stratigraphy of the Mercia Mudstone Group (Mid to Late Triassic) of the south Devon coast. *Geoscience in South-West England,* **10**, 195-205.

An almost complete section through the Mercia Mudstone Group is exposed in the cliffs between Sidmouth and Axmouth on the south Devon coast. This is the only section in North West Europe that exposes such a complete sequence of the mid to late Triassic 'Keuper Marl' facies. The c. 450.m-thick succession dips gently eastwards in a series of long, continuous sections that are separated from one another by minor faults which, with one exception, do not cut out any of the succession. At Seaton about 50 m of strata occur within a complexly faulted zone in which fault-bounded fragments of the succession cannot be readily correlated with the main outcrop. The availability of a continuous core from a nearby borehole has enabled the sequence in the faulted section to be pieced together for the first time, and to provide a complete stratigraphy for the group. The previously un-named lower part of the Mercia Mudstone Group (the beds below the Blue Anchor Formation) exposed in the Devon coastal sections can be divided into three formations and nine members based on gross lithology. The lowest and highest of these formations consist of relatively monotonous red mudstones for which the names Sidmouth Mudstone and Branscombe Mudstone are proposed. The middle formation, for which the name Dunscombe Mudstone is proposed, consists of a 35 m-thick sequence of laminated green, purple and grey mudstones which expands in some inland successions proved in boreholes to over 100 m by the addition of thick beds of salt. 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.
R. W. Gallois, 92 Stoke Valley Rd., Exeter EX4 5ER, E-mail: gallois@geologist.co.uk.

INTRODUCTION

The 'New Red Sandstone' rocks of the south Devon coast are almost wholly exposed in the 45 km of cliffs between Torquay and Axmouth (Figure 1). They were described by early workers (see Woodward and Ussher, 1911 for summary), and there was much discussion concerning the correlation of these terrestrial, poorly fossiliferous red beds with Permian and Triassic sequences elsewhere in Europe. Ussher (1875) divided what is now regarded as the Triassic part of the succession into "Conglomerates and pebble beds" (now the Budleigh Salterton Pebble Beds Formation of Henson, 1971), "Upper Sandstones" (now the Otter Sandstone Formation of Henson, 1971) and "Upper Marls". The "Upper Marls" were subsequently named the Keuper Marls by Irving (1888). They were renamed the Mercia Mudstone Group by Warrington *et al*. (1980) who divided the group into a lower, un-named part and an upper Blue Anchor Formation (formerly the Tea Green and Grey Marls of Richardson, 1906).

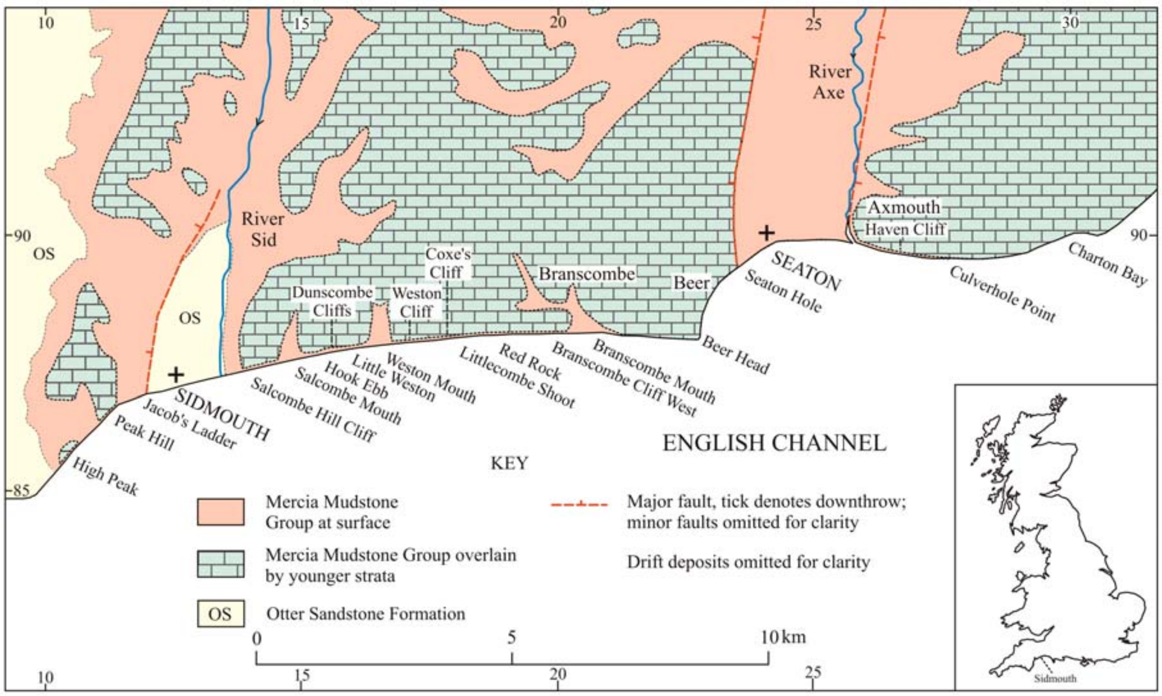

Figure 1. *Geological sketch map of the Mercia Mudstone Group outcrop on the south Devon coast showing the positions of sections referred to in the text.*

Despite the completeness and ready accessibility of the Mercia Mudstone Group succession in the 14 km of cliffs between Sidmouth and Axmouth (Figure 1), the first detailed section was that published by Jeans (1978) as part of a study of the clay assemblages of the 'Keuper Marl' of Europe. Earlier descriptions by De la Beche (1826) and Woodward and Ussher (1911) provided general descriptions of the succession as a whole with additional remarks on particularly distinctive beds.

LITHOSTRATIGRAPHICAL SUCCESSION

The composite section exposed in the cliffs between the outfall of the River Sid [SY 129 873] at Sidmouth and Culverhole Point [SY 274 893] near Axmouth is summarised in

Figure 2. The lower part of the succession is repeated in the cliffs west of Sidmouth, between High Peak [SY 105 860] and Jacob's Ladder [SY 120 869]. A total of c. 450 m of Mercia Mudstone Group sediments are exposed in these sections, but a progressive westerly overstep by the overlying Cretaceous rocks has removed all but the lowest 100 m of the sequence in the most westerly outcrop. Gentle pre-Cretaceous folding, and minor faulting in the Triassic rocks which does not penetrate the Cretaceous rocks, causes small irregularities in the rate of westerly overstep (Figures 3a, 3b).

With the exception of the two units described below, the Mercia Mudstone Group exposed on the south Devon coast consists of a relatively uniform succession of brownish red- and reddish orange-weathering mudstones and siltstones with few visible sedimentary structures. Small-scale rhythms, mostly 0.5 to 0.6 m thick, are picked out by differential weathering at most levels. The most common type shows a darker red (more clay-rich), friable-weathering unit overlain by an orange-brown (more silty) blocky-weathering unit.

The most common subsidiary lithology is thin (mostly up to 0.3 m thick), laterally persistent beds of green mudstone, many of which are laminated and/or partially dolomitised. They commonly weather out as harder, fissile beds in the cliffs. Beds of brownish red, coarse siltstone/very fine-grained sandstone up to 0.3 m thick occur at a few levels: these too weather out as harder beds in the cliffs. Fining-upward beds of fine- or medium-grained sandstone up to 1.4 m thick occur at three stratigraphical levels.

Gypsum is common throughout the sequence, is abundant at some levels, and is rock forming at one level. It most commonly occurs as concentrations of coarsely crystalline geodes and finely crystalline concretions (gypcretes) in the lowest third of the sequence, and mostly as networks of thin veins of fibrous satin-spar in the remainder. Many of the concretionary gypsum horizons occur in association with patchy or pervasive dolomitisation (dolocrusts). These are especially common in the lowest part of the succession.

The two exceptional units referred to above occur in the middle and highest part of the group. Both consist largely of green mudstones with common beds of dolomitic mudstone and less common beds of purple and/or dark grey mudstone, most of which are laminated. The higher unit, 25 to 40 m thick, can be traced throughout southern England and was named the Blue Anchor Formation by Warrington *et al*. (1980) after a type locality on the Somerset coast.

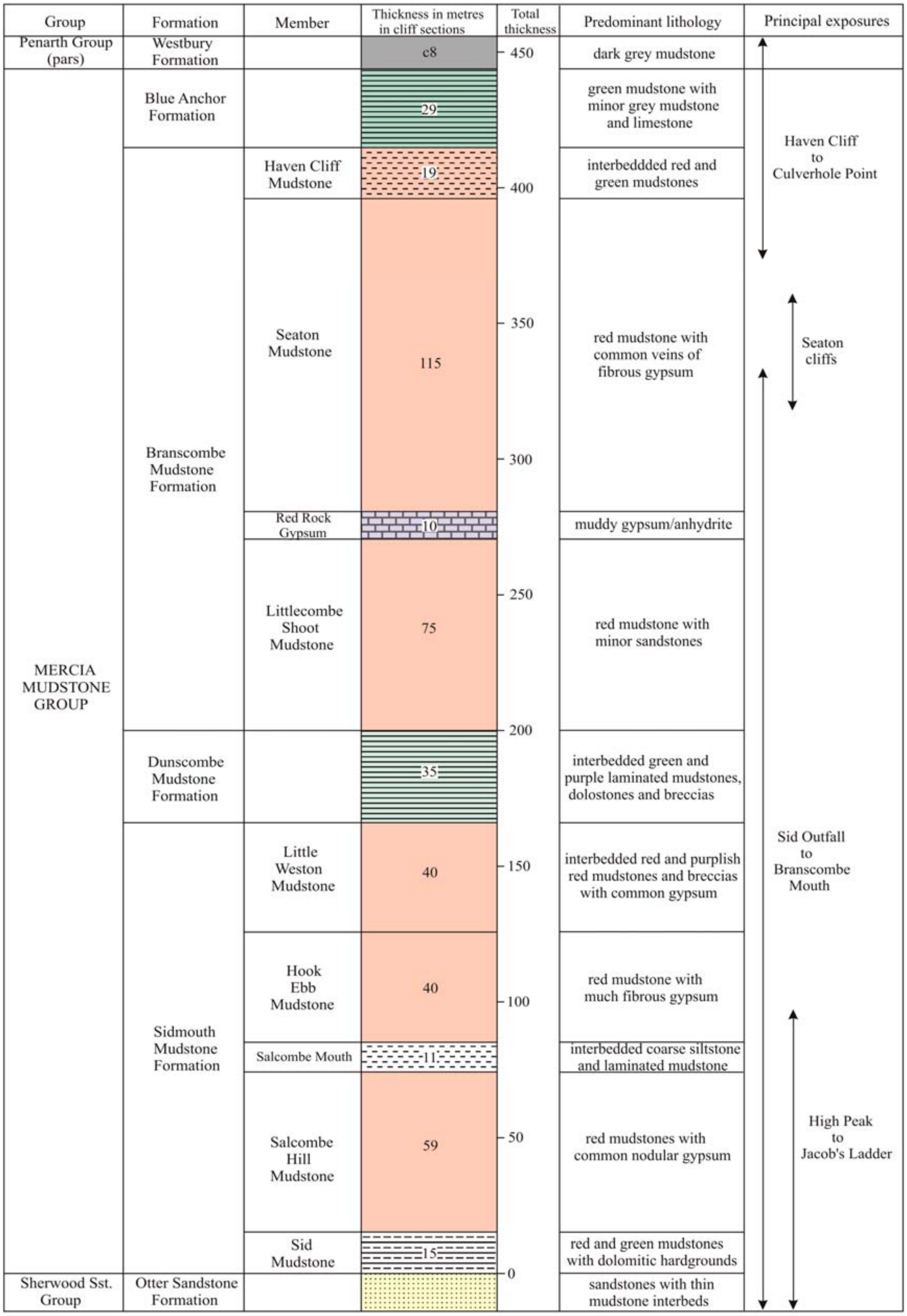

***Figure 2**. Generalised vertical section for the Mercia Mudstone Group succession exposed on the south Devon coast.*

A prominent bed within the lower unit was noted by Woodward and Ussher (1911) as a conspicuous "hard greenish band" exposed in the cliffs on either side of Weston Mouth [SY 163 879]. This was identified by Warrington and Scrivener (1980, fig. 3) as a 20 m-thick sandstone. It was formally named the Weston Mouth Sandstone by Warrington *et al*. (1980), but no description or measured section was provided. The "hard greenish band" forms part of a 35 m-thick succession of laminated mudstones that contain less than 2 % of sand-grade sediment: it is described below under the proposed new name Dunscombe Mudstone Formation.

The sediments exposed on the south Devon coast between the Otter Sandstone Formation and the Dunscombe Mudstone Formation (Figure 2) broadly equate with Jeans' (1978) Mudstone I, and those between the Dunscombe Mudstone and the Blue Anchor Formation with Jeans' (1978) Mudstone III. Both successions are lithologically sufficiently uniform and sufficiently different from the adjacent formations to warrant the status of formations. The new names Sidmouth Mudstone Formation and Branscombe Mudstone Formation are proposed here for the lower and upper formation respectively. In south Devon, these two formations can be divided into five and four members respectively on the basis of combinations of the subsidiary lithological characters described above (Figure 2). These minor variations have a pronounced effect on the bulk geotechnical properties of the rock mass and are, in consequence, reflected in the cliff weathering profiles.

The descriptions of the three formations and their nine constituent members are given below in ascending order. The thicknesses are those exposed in the type sections.

Sidmouth Mudstone Formation

The full thickness of the Sidmouth Mudstone Formation is exposed in its type section in the cliffs between the outfall of the River Sid at Sidmouth and Weston Mouth [SY 129 873 to 164 881] (Figure 3a). The lower half of the formation is also exposed west of Sidmouth between High Peak and Jacob's Ladder [SY 104 854 to 120 869]. The base of the formation is defined as the sharp lithological change from sandstone to mudstone at the top of the Otter Sandstone Formation. In the type section the formation comprises of 165 m of relatively uniform red-brown mudstones and orange-brown muddy siltstones with prominent beds of laminated green mudstone up to 0.3m thick, dolomitic hardgrounds, silty fine-grained sandstones and breccias. Gypsum occurs throughout, both as nodular geodes and fibrous seams. The formation is made up of stacked sequences of small-scale rhythms, mostly 0.5 to 1.5 m thick, that differ from member to member. No stratigraphically diagnostic fossil has been recorded from the formation on the Devon coast. It is thought to span most of the Ladinian Stage on the basis of stratigraphical evidence from the underlying and overlying formations (Warrington *et al*., 1980).

Sid Mudstone Member The type section of the Sid Mudstone Member is the cliff and foreshore outcrops at the foot of the western end of Salcombe Hill Cliff [SY 132 873 to 136 874] where the full succession of the member is exposed. It is also wholly exposed at the foot of the cliffs [SY 110 866 to 116 868] beneath Peak Hill and, less accessibly, in the middle part of the cliffs [SY 104 858 to 105 861] beneath High Peak to the west of Sidmouth. The base of the member is defined as the sharp lithological change from sandstone to mudstone at the top of the highest sandstone of the Otter Sandstone Formation. The uppermost 5 to 8 m of the Otter Sandstone Formation at Sidmouth consists of fine- and medium-grained sandstones that occupy shallow channels that are locally separated by red mudstones. The sandstones are laterally persistent in the Salcombe Hill and Peak Hill cliff sections, even though the highest sandstone is in places less than 0.2 m thick.

The Sid Mudstone Member consists of 15 m of red-brown and reddish orange silty mudstones with common gypsum-rich horizons, many of which are associated with green beds or concentrations of green patches. Calcitised and/or dolomitised hardground surfaces and associated gypcrete nodules occur at two levels.

Salcombe Hill Mudstone Member The full thickness of the Salcombe Hill Mudstone Member is exposed in its type section in the near-vertical cliffs beneath Salcombe Hill where a low easterly dip brings each bed to beach level between the western end of the cliffs [SY 136 874] and Salcombe Mouth [SY 146 876]. It is also wholly exposed beneath High Peak [SY 104 859] and Peak Hill [SY 110 866] to the west of Sidmouth, but in less accessible sections. The base of the member is defined as the sharp lithological change at the top of a hard, laterally persistent dolomitised bed with gypcrete nodules. This bed forms the most easterly of a series of prominent ledges in the Sid Mudstone Member below Salcombe Hill Cliff. The same dolomitised surface and sudden upward change to uniform mudstones is present in the Peak Hill sections.

The Salcombe Hill Mudstone Member consists of 59 m of red-brown mudstones and silty mudstones that show little lateral or vertical variation. Thin beds of siltstone, mostly <0.1 m thick, and partially dolomitised beds occur at several levels, the latter mostly in association with gypsum. Gypsum is common throughout, in the form of small fine-grained concretions and hollow geodes with well-formed crystals. The member contains only one prominent lithological marker interval, a group of thin, laminated, mostly green mudstones in the middle part of the member (34 to 36 m above the base) which give rise to a series of fissile harder beds and a break in slope in the cliffs. Below this, small-scale rhythms (mostly 0.5 to 0.6 m thick) are picked out by weathering as more-friable and more-blocky intervals within the apparently lithologically uniform mudstone sequence. Jeans (1978) recorded two beds with distinctive 'wrinkly' weathering in this lower part of the member in Salcombe Hill Cliff, which presumably reflect subtle textural difference in the mudstones. Similar beds occur in the Peak Hill section, but at slightly different stratigraphical levels. The uniform nature of this part of the member gives rise to rock collapses along very large, single joint faces.

The beds above the laminated marker interval are lithologically indistinguishable from those below. For 300 m westwards from Salcombe Mouth and below Peak Hill, the cliffs are protected from marine erosion by a shingle beach. Gypsum is much less abundant there than in the actively eroding cliffs below Salcombe Hill, but lines of solution holes and green reduction patches that surround many of the gypsum nodules remain and can be used for correlation over short distances.

Salcombe Mouth Member. The member is wholly exposed between the west side of Salcombe Hill [SY 136 875] and Salcombe Mouth [SY 146 877] where the easterly dip brings the member down to beach level. The type section is the lower part of the cliff that runs westwards from Salcombe Mouth [SY 146 877 to 144 877]. A series of gullies allow access to the whole of the member, in which the sedimentary features are especially well exposed after heavy rain. The full thickness of the member is also exposed beneath Peak Hill [SY 104 860], west of Sidmouth. The base of the member is defined as the sudden upward change from silty mudstone to very fine-grained sandstone at the base of the lowest of four fining-upward rhythms.

The member consists of 11.4 m of red, purplish red and orange-brown mudstones and muddy siltstones, with four thin but prominent beds of green coarse siltstone and fine-grained sandstone that make up about 15% of the total succession. These siltstones/sandstones form prominent outcrops in the cliffs below Salcombe Hill and Peak Hill. The basal sandstone forms a laterally persistent, prominent ledge in all sections: the three higher sandstone beds form similar ledges that, together with the massive nature of the intervening silt-rich beds, cause the member to give rise to some of the steepest faces in the cliffs below Salcombe Hill. The junctions of the sandstone/siltstone beds with the underlying mudstones are commonly complexly bioturbated. Below this zone of disturbance, much of the mudstone is well laminated.

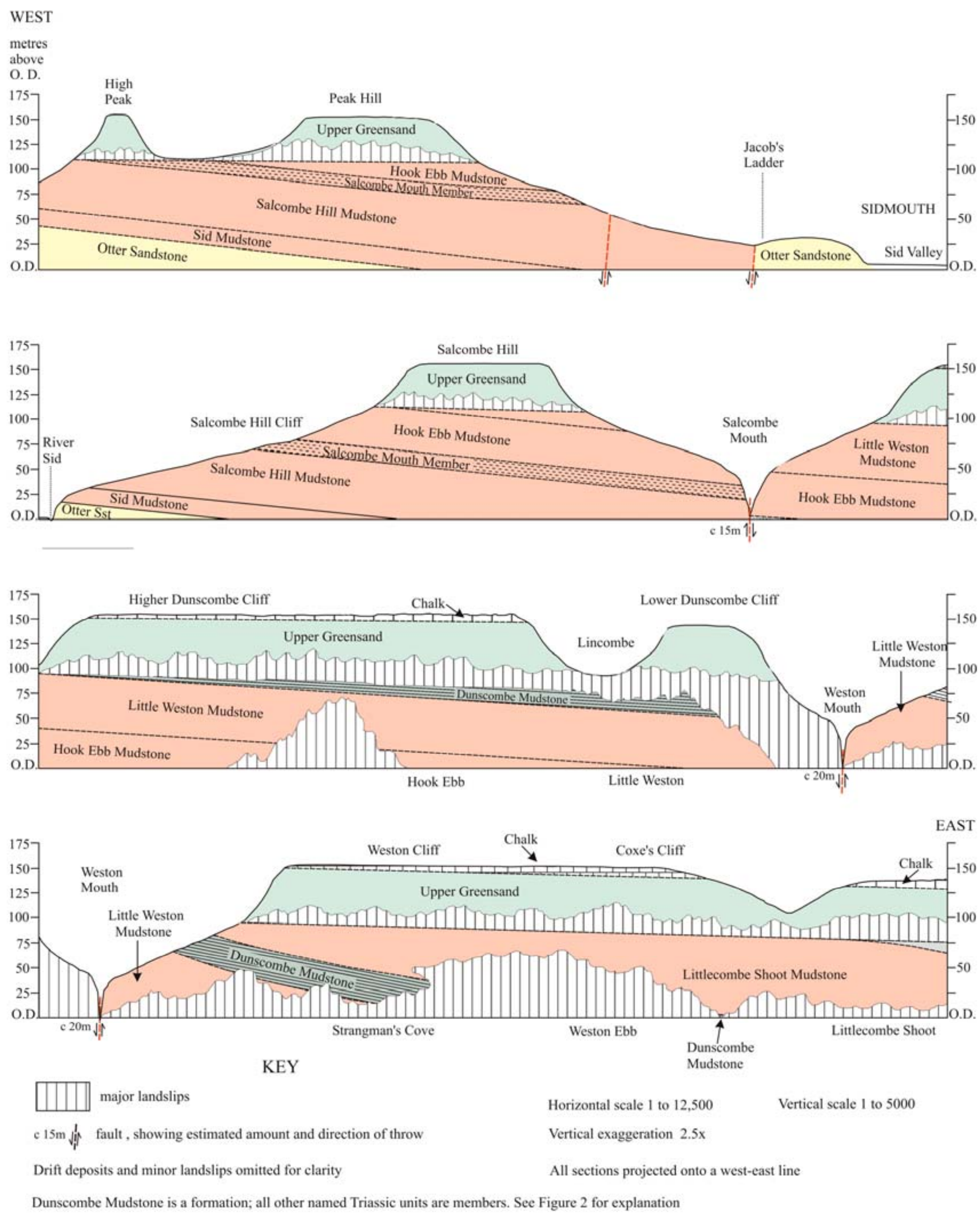

Figure 3a*. Geological sketch sections of the Mercia Mudstone outcrops in the cliffs between High Peak and Littlecombe Shoot.*

Hook Ebb Mudstone Member. The type section of the Hook Ebb Mudstone Member is the cliffs between the east side of Salcombe Mouth [SY 145 875] and Little Weston beach [SY 156 878]. The member is fully exposed between the west side of Salcombe Hill [SY 137 875] and Salcombe Mouth, but much of this part of the section is only accessible by rope. A small fault (c. 15m throw) downthrows the base of the member to stream-bed level at Salcombe Mouth, and between there and Hook Ebb [SY 155 877], the whole of the member is brought down by a low easterly dip to be exposed at the foot of the cliffs at beach level (Figure 3a). West of Sidmouth, the lower part of the member crops out beneath Peak Hill; it is overstepped by Cretaceous rocks between there and High Peak. The base of the member is defined as the sharp lithological change from fine-grained sandstone to mudstone at the top of the highest sandstone of the Salcombe Mouth Member.

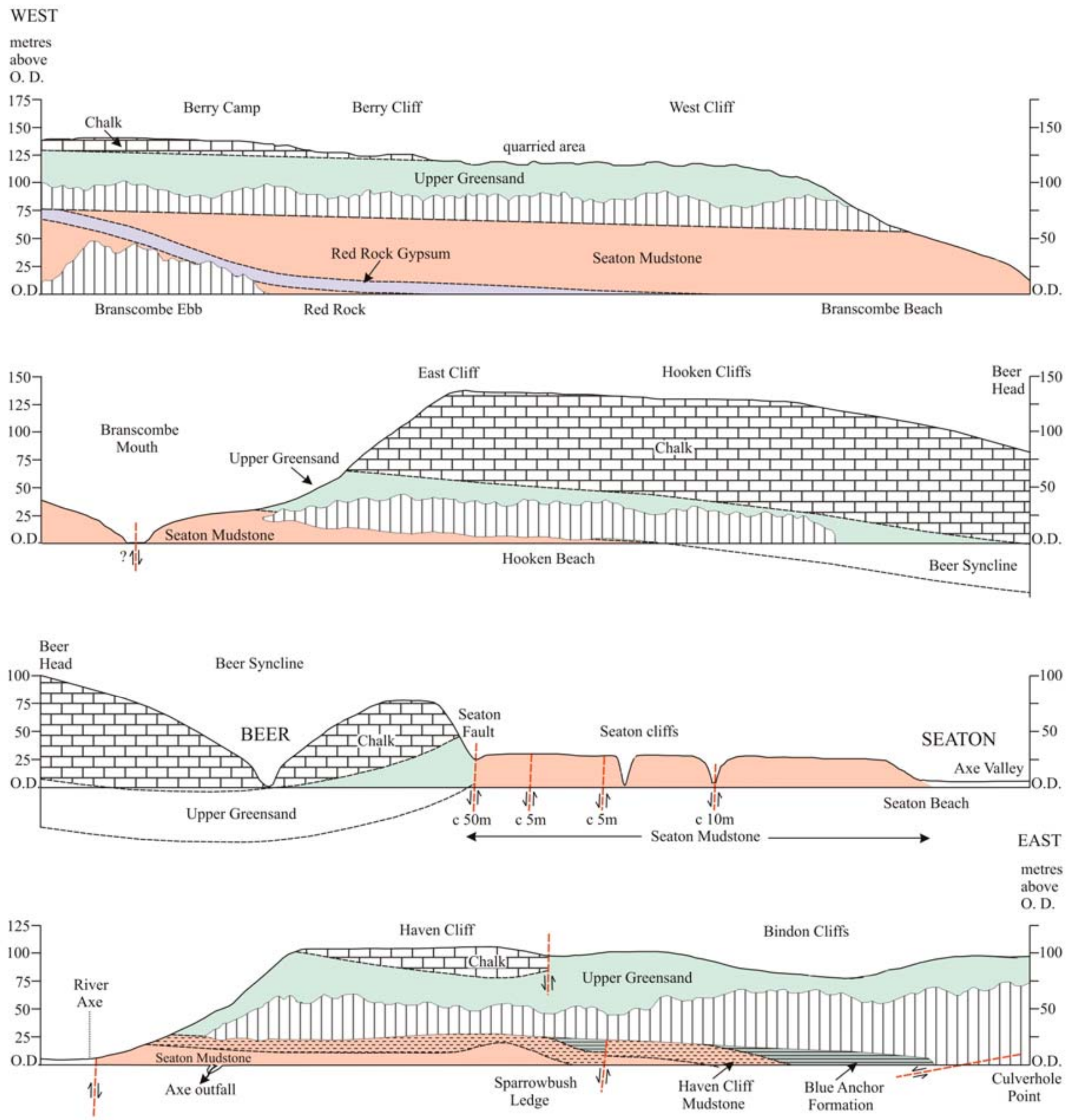

***Figure 3b**. Geological sketch sections of the Mercia Mudstone outcrops in the cliffs between Branscombe Ebb and Culverhole Point.*

The Hook Ebb Mudstone Member consists of 40 m of relatively uniform orange-brown and red-brown mudstones and silty mudstones with little structure other than weakly differentiated, small-scale rhythms. The actively eroding sections adjacent to Hook Ebb provide unweathered sections in all but the lowest part of the member. These expose numerous bedding-parallel and cross-cutting veins of fibrous gypsum up to 0.15 m thick, but gypsum is mostly absent through recent dissolution at Salcombe Mouth where the cliffs are protected from marine erosion by a shingle beach. The gross lithology of the member is similar to that of the Salcombe Hill Mudstone Member, with the exception of the substitution of fibrous gypsum veins for the concretionary gypsum nodules.

Little Weston Mudstone Member. The type section of the Little Weston Mudstone Member is the cliff [SY 157 878 to 159 879] that overlooks Little Weston beach. The lowest third of the member, including the junction with the Hook Ebb Mudstone, is brought down to beach level by the low easterly dip. The best sections in the middle and upper part of the member occur in cliffs below Higher Dunscombe Cliff [SY 154 878]. Between Little Weston beach and Weston Mouth the whole of the member is obscured by landslip and/or debris cones (Figure 3a). The highest beds are again patchily exposed below Weston Cliff [SY 169 879]. The base of the member is defined as the base of an 0.1 m-thick fining-upward, glauconitic sandstone at the base of a laterally persistent group of marker beds that includes two laminated green mudstones and the lowest of several brecciated beds.

The member consists of 40 m of markedly rhythmic red-brown mudstones with common fibrous gypsum seams, common green beds, and subsidiary lithologies, notably purplish red mudstones and gypsum-rich brecciated beds, that are absent from the underlying beds. The number of purplish red mudstones and brecciated beds increases upwards and forms a transition to the overlying Dunscombe Mudstone Formation. Dissolution of the gypsum in the breccias in the higher parts of the cliffs causes collapses with the result that over much of its length the lower and middle parts of the member crop out beneath a debris-covered bench. The striking rhythmicity of the member is well displayed in the type section and in the adjacent cliffs to the west.

Dunscombe Mudstone Formation

The type section of the *Dunscombe Mudstone Formation* is a series of cliff faces below Higher Dunscombe Cliff [SY 152 877 to 156 878] which expose the full thickness of the formation (Figure 3a). The middle and higher parts of the formation are only accessible with care. The formation can be more easily examined in a group of cliffs, degraded steep slopes and slipped masses [SY 168 880 to 171 880] below Weston Cliff. Taken together, these expose the full thickness of the formation including the junctions with the underlying and overlying formations. The easterly dip brings the top of the formation down to beach level below Coxe's Cliff, where the highest few metres and the junction with the overlying Littlecombe Shoot Mudstone Member are exposed in a low cliff [SY 178 879]. The base of the formation is defined as the base of a partially dolomitised breccia which marks a lithological change from the predominantly red-brown mudstone rhythms of the Little Weston Mudstone Member to interbedded green and purple mudstones with thin dolomitic and dark grey mudstones, and common brecciated beds.

The formation is the most lithologically distinctive part of the Mercia Mudstone Group of the south Devon coast. It consists of 35 m of interbedded green, purple and orange-brown mudstones with subordinate beds of dolostone/dolomitic siltstone, dark grey mudstone and several breccia horizons. The breccias in the lower part of the member consist of angular clasts in a mudstone matrix and were probably formed penecontemporaneously by the repeated growth and dissolution of gypsum/anhydrite (autobreccias). Those in the upper part are more coarsely brecciated and are accompanied by pervasive pinkish brown staining indicative of the dissolution of evaporites, probably gypsum and possibly salt, long after deposition (collapse breccias). Fresh cliff falls commonly reveal residual gypsum patches within all the breccias: correlations with inland boreholes suggest that they may pass laterally into thick beds of salt (see below). At outcrop, the breccias are more porous and deeply weathered than the surrounding mudstones and they, and the dark grey mudstones, give rise to seepage lines and small landslips.

Most of the succession is well laminated, in marked contrast to the generally structureless nature of much of the underlying mudstones and almost all the overlying mudstones. The dolomitic beds form prominent, pale weathering markers in the cliffs. The thickest (c 4 m) of these in the exposures below Weston Cliff contains up to 30% of very fine- and fine-grained sand in cross-bedded lenses and in ripples. Jeans (1978, fig. 37) referred to this bed as the "Sandstone Group of the Weston Cycle". One kilometre to the west, beneath Higher Dunscombe Cliff, this bed is only 1.5m thick, but the sand content is about 50%.

When viewed from the beach, a disproportionately large part of the Dunscombe Mudstone Formation appears to consist of green mudstone, a lithology that gives rise to finely friable debris that thinly coats much of the outcrop. Inland, the dolomitic horizons dissolve in the weathered zone and the brecciated horizons and purple-red mudstones break down to form red-brown subsoils that differ little in colour or texture from those of the typical red-brown mudstones of the underlying and overlying 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.

Jeans (1978) recorded *Euestheria*, and *Chondrites* and other trace fossils indicative of deposition in a brackish-water environment in the "Sandstone Group", together with the mineral glauconite sensu lato. Palynomorph assemblages from the formation indicate a Carnian age (Warrington *et al*., 1980).

Branscombe Mudstone Formation

The outcrop of the *Branscombe Mudstone Formation* is divided between three cliff sections that are separated by faults and the Beer syncline (Figures 3a and 3b). Taken together, these three sections form the type section. The lower and middle parts of the formation, including the junction with the Dunscombe Mudstone Formation, are exposed in discontinuous cliffs between Weston Cliff and Branscombe Mouth [SY 168 880 to 207 881]. The highest part of the formation, including the junction with the overlying Blue Anchor Formation, is continuously exposed in the lower cliff below Haven Cliff between the outfall of the River Axe and Culverhole Point [SY 256 898 to 274 893]. All but a few metres of the estimated 40 m of the succession that lies between the highest bed at Branscombe Mouth and the lowest bed at Haven Cliff is exposed in a series of fault-bounded blocks in Seaton Cliffs [SY 235 896 to 244 898]. The base of the formation is defined as the sharp lithological change from pale grey dolomitic mudstone to red mudstone at the hardground surface at the top of the Dunscombe Mudstone Formation.

The Branscombe Mudstone Formation consists of c. 220 m of relatively uniform red-brown mudstones and orange-brown muddy siltstones that are lithologically similar to those of the Sidmouth Mudstone Formation. Gypsum and thin beds of green laminated mudstone occur throughout both formations. In addition, the higher formation contains three beds of fine- and medium-grained sandstone and a 10 m-thick gypsum-rich bed, none of which has an equivalent in the Sidmouth Mudstone Formation. The highest part of the formation has yielded palynomorph assemblages indicative of a Norian age (Warrington *et al*., 1980). It is divided into four members.

Littlecombe Shoot Mudstone Member. The type section is the discontinuous line of cliffs between Weston Cliff [SY 168 880] that exposes the base of the member, and the eastern end of the cliffs above Littlecombe Shoot [SY 190 879] that exposes the junction with the overlying member. The base of the member is defined as the top of a dolomitic mudstone that marks a rapid upward change from the mixed lithologies of the Dunscombe Mudstone Formation to relatively uniform red-brown mudstones.

The Littlecombe Shoot Mudstone Member comprises 75 m of uniform red- and orange-brown mudstones and silty mudstones with three beds of calcareous sandstone, a lower pair (0.15 and 0.6 m thick) and a thicker upper bed (up to 1.4 m thick), that form prominent markers in the cliffs at Littlecombe Shoot. Jukes-Browne (1902) recorded three beds of calcareous sandstone at about this stratigraphical level in the Lyme Regis Borehole [SY 336 930]: they were assigned to the "Weston Mouth Sandstone" by Warrington and Scrivener (1980). Green -mottled beds up to 0.6m thick occur at widely spaced intervals throughout the Littlecombe Shoot Mudstone: three of these contain discontinuous lenses of dark grey mudstone. Gypsum is probably relatively common in this member, but is rarely seen in the deeply weathered cliffs at Littlecombe Shoot which are above the zone of marine erosion.

Red Rock Gypsum Membe. The type section is Red Rock [SY 191 880], a prominent 10 m-high cliff overlain by deeply weathered red-brown mudstone. Smaller cliffs immediately east and west expose parts of the member, together with the underlying and overlying junctions with red-brown mudstones. The base of the member is defined as the sharp lithological change from red-brown mudstone to muddy gypsum.

The member consists of a 10 m-thick succession of a closely knit, anastomosing network of thin (mostly 2 to 10 mm thick) gypsum veins interwoven with stringers of red mud. Solution effects have concentrated the mud fraction at the surface of the outcrops and make it difficult to estimate the overall gypsum content of the bed: it probably exceeds 80%. Some of the nearby exposures in the top 2 to 3 m of the member consist of almost mud-free gypsum.

Seaton Mudstone Member. The Seaton Mudstone Member is the only part of the Mercia Mudstone Group on the south Devon coast that is not fully exposed. The type section for the lower part of the member in West Cliff, Branscombe [SY 200 881 to 206 880] exposes the lower 55 m unconformably overlain by Cretaceous Upper Greensand. It includes the base of the member which is defined as the sharp lithological change from muddy gypsum to red-brown mudstones. Higher parts of the Seaton Mudstone Member are exposed within fault-bounded blocks at Seaton [SY 235 896 to 244 898], and the full thickness of the member was cored in the Chard Borehole [ST 3430 0653] 17 km north of the coastal sections. The latter enables the fragmentary coastal sections to be placed in their correct stratigraphical positions, and show that a total of about 20 m of strata are missing from the coastal exposures. The highest 25 m of the member are fully exposed in the cliffs [SY 255 899 to 267 895] below Haven Cliff, between the outfall of the River Axe and Sparrowbush Ledge.

The Seaton Mudstone Member consists of c. 115 m of relatively uniform red-brown and orange-brown mudstones and silty mudstones with common thin (up to 0.1m thick) veins of fibrous gypsum in the lower part, but with few lithologically distinctive marker beds. At outcrop, the gypsum veins appear to be replaced by thin (1 to 2m thick) flexible sheets of white mineral that were shown by Jeans (1978) to be a mixture of palygorskite, sepiolite and celestite. They appear to be residues derived from, or related to the gypsum, since the white mineral is absent in unweathered borehole cores in the member in which gypsum is preserved.

Haven Cliff Mudstone Member. The Haven Cliff Mudstone Member is wholly exposed in the type section beneath Haven Cliff [SY 260 897 to 268 895] where it forms strikingly colour-banded cliffs The base of the member is defined as the base of a prominent 0.9 m-thick green siltstone beneath which the red-brown mudstones of the Seaton Mudstone Member contain little green mudstone. The member comprises 19 m of interbedded red (c. 60%) and green mudstones in beds mostly 0.2 to 0.4 m thick that were referred to as the "Variegated Marls" by Woodward and Ussher (1911). Their lateral persistence has been proved inland at outcrop in Devon where they give rise to distinctively coloured subsoils that provide a useful stratigraphical marker. A lithologically similar succession to that exposed on the coast, 18 m thick, was proved in the continuous cores of the Chard Borehole.

Blue Anchor Formation

The Blue Anchor Formation is wholly exposed on the south Devon coast between Sparrowbush Ledge [SY 260 897] and Culverhole Point [SY 275 893], and most of the succession is repeated 2.5 km to the east at Charton Bay [SY 298 900]. The south Devon succession is thinner (29 m compared to 36.5 m) than that in the type section at Blue Anchor Cliff, Somerset [ST 0345 4368] (Warrington and Whittaker, 1984). However, the lithologies, and by inference the depositional environments that they represent, are similar in both areas. The base of the formation in Devon is taken at the base of a prominent bed of dolomitic limestone, the lowest in the succession, that marks an overall change from red and green mudstones to green mudstones, and the incoming of dolomitic limestones and beds of dark grey mudstone.

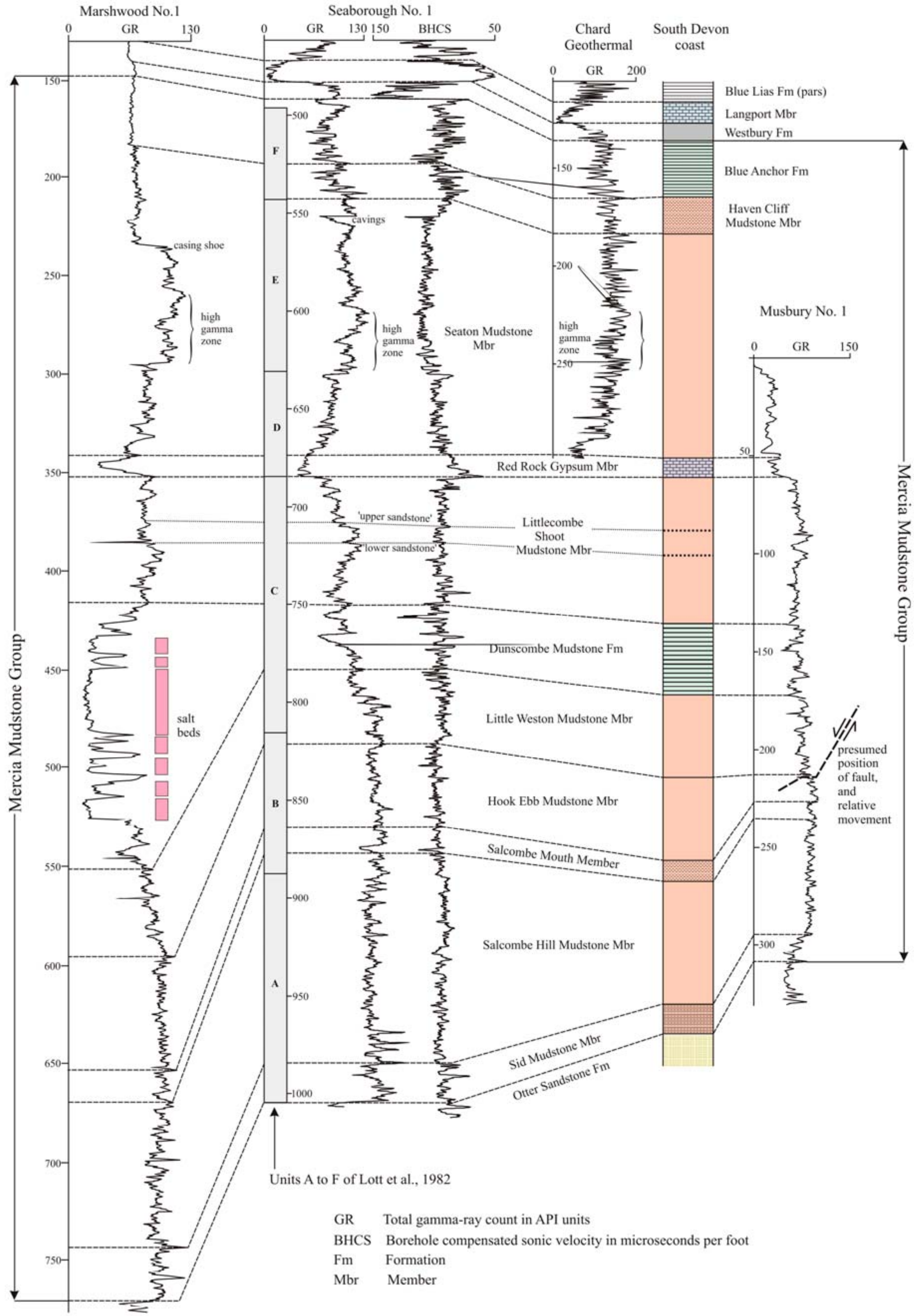

Figure 4. *Examples of geophysical-log correlations between the Mercia Mudstone Group sequences in selected inland boreholes and that exposed on the south Devon coast.*

CORRELATION WITH ADJACENT AREAS

The Mercia Mudstone Group is poorly exposed inland in Devon and south Somerset where it mostly crops out on steep slopes covered by Head deposits derived from the Cretaceous Upper Greensand and Chalk. The group was extensively worked at all stratigraphical levels for agricultural marl up to and including Victorian times, but in a large number of small pits that are now wholly degraded. The lithologically distinctive green, purple and grey mudstones of the Dunscombe Mudstone Formation and the Blue Anchor Formation have been traced inland in stream sections as far north as the Monkton [ST 185 030] and Stockland [ST 265 050] areas respectively. Between there and the Taunton area of Somerset, both formations are largely concealed beneath the Upper Greensand outcrop.

The most southerly drift-free outcrops of the Dunscombe Mudstone Formation in Somerset occur on the south side of Taunton between Lipe Hill [ST 186 215] and Rumwell [ST 187 235]. There, up to 30 m of predominantly green and purple laminated mudstones crop out on the face of a feature capped by about 6m of interbedded mudstones and dolomitic sandstones/siltstones. These last are lithologically similar to the sandy dolostone of the south Devon coast, but appear to occur at a stratigraphically higher level within the Dunscombe Mudstone Formation. They were referred to as the "arenaceous member" by Ruffell and Warrington (1988), who described their sedimentology and palaeontology.

Beds of sandy dolostone and dolomitic sandstone, mostly less than 2m thick, have been locally worked for building stone at two or more stratigraphical levels within the Dunscombe Mudstone Formation to the east of Taunton around North Curry [ST 320 253] and Stoke St Gregory [ST 348 272]. The harder beds cap prominent features and were mapped out during the survey of 1:50,000 Sheet 295 (Edmonds and Williams, 1985), but the boundaries of the green and purple mudstones that enclose them were not. The building stones were referred to by Ussher (1908) as "upper Keuper Sandstones", and were named the North Curry Sandstone Member by Warrington *et al*. (1980) who correlated them with the "Weston Mouth Sandstone" and the Arden Sandstone of the Midlands. At Stoke St Gregory the arenaceous beds pass northwards and then westwards beneath the Somerset Levels and are impersistently and poorly exposed between there and the Bristol Channel (Ruffell, 1991).

The upper part of the Mercia Mudstone Group succession was continuously cored in the Chard Borehole [ST 3430 0653], the complete sequence was proved in the uncored Seaborough No. 1 [ST 4348 0620] and Marshwood No. 1 [ST 3885 9880] boreholes, and large parts of the sequence were proved in the Musbury No. 1 [SY 2670 9510] borehole, all of which were geophysically logged and are within 25 km of the coastal exposures. Taken together, the cores and geophysical logs can be correlated with the coastal sections, and they can be used to make detailed correlations with the sequences in more distant geophysically logged boreholes in Dorset and Somerset.

Lott *et al*. (1982) divided the Mercia Mudstone Group in the Wessex Basin into six units (labelled A to F) based on the geophysical characters of the total gamma-ray (GR) and borehole-compensated sonic (BHCS) logs. These units were of limited stratigraphical value at that time, however, because they were not correlated with rock outcrops nor, for the most part, with borehole cores.

In contrast, the members recognised in the coastal exposures in the present work can be matched with the GR and BHCS signatures of the Mercia Mudstone Group in the Musbury, Seaborough, Chard and Marshwood boreholes (Figure 4). These distinctive signatures can, in turn, be used to recognise the nine members of the coastal sections in more distant boreholes including those at Winterborne Kingston [ST 8470 9796] and Nettlecombe [SY 5052 9544] in Dorset, and Brent Knoll Borehole [ST 3356 5208] (Whittaker and Green, 1983, p. 121) in Somerset using the method described by Lott et al., 1982.

The Red Rock Gypsum has a particularly distinctive low GR-high BHCS signature (mistakenly identified as the "Weston Mouth Sandstone" by Lott *et al*., 1982) that can be correlated with a prominent seismic reflector (the 'Anhydrite Marker') that has been recognised throughout much of southern England (Cripps, MS, 1996).

Comparison of the geophysical logs throughout the region with the lithologies exposed in the coastal sections shows close correlations at every stratigraphical level in the Mercia Mudstone Group except in the Dunscombe Mudstone Formation. The Marshwood, Nettlecombe and Winterborne Kingston boreholes proved thick beds of salt (the 'mid-Dorset Halite' of Warrington *et al*., 1980) within the stratigraphical equivalent of the Dunscombe Mudstone Formation. The 'Somerset Halite' proved in the Brent Knoll and Puriton [ST 3191 4086] boreholes can similarly be shown by geophysical-log correlation to lie within the same formation.

The Mercia Mudstone Group passes northwards in Somerset into complexly interbedded breccias (Dolomitic Conglomerate), sandstones and red mudstones that are banked up against the Carboniferous rocks of the Mendips and Bristol-Cardiff structural highs (Kellaway and Welch, 1993). To the north of Bristol, the Mercia Mudstone Group at outcrop in the Severn Valley and from there northwards into the Midlands is more arenaceous than that exposed on the Devon coast, with lenticular beds of sandstone at several stratigraphical levels. The most prominent of these, the Arden Sandstone, has been mapped out over much of its outcrop and has been used to divide the Mercia Mudstone Group below the Blue Anchor Formation into three formations. In the Tewkesbury district these were named, in ascending order, the Eldersfield Mudstone, the Arden Sandstone Formation and the Twyning Mudstone by Barclay *et al*. (1997).

At outcrop, the Arden Sandstone Formation comprises mostly 1 to 10m of interbedded sandstones, siltstones and mudstones, the more resistant of which have been extensively used for building. At its nearest approach to the Cardiff-Bristol structural high, the formation is less than 2 m thick (Worssam *et al*., 1989). At some localities the sandstones are interbedded with laminated green mudstones (e.g. Old *et al*., 1991) that are lithologically similar to parts of the Dunscombe Mudstone Formation.

Correlation of the Mercia Mudstone Group succession of the Midlands with that of south Devon is not straightforward. The sandstones of the Arden Sandstone Formation contain faunal and floral assemblages and sedimentary features that are similar to those of the Jean's (1978) Weston Cycle Sandstone Group in the lower part of the Dunscombe Mudstone Formation of the south Devon coast. These similarities led Fisher (1985) to suggest that both lithologies resulted from a widespread transgression that introduced 'pseudo-marine' environments to much of north west Europe. In the absence of diagnostic palaeontological or other evidence, it is not yet possible to determine what part of the Dunscombe Mudstone Formation (if any) is the chronostratigraphical correlative of the Arden Sandstone Formation. There are, however, two laterally persistent marker beds in the Midlands that are stratigraphically close to the Arden Sandstone Formation and which may have correlatives south of the Mendips.

The Droitwich Halite Member of the Eldersfield Mudstone Formation is older than the Arden Sandstone Formation (Barclay *et al*, 1997): it has been equated with the 'Somerset' and 'Mid-Dorset' halites (Warrington *et al*., 1980). In Somerset and Dorset the salt-bearing beds lie within the Dunscombe Mudstone Formation. If the deposition of the halites was broadly contemporaneous in both regions, then the Arden Sandstone Formation must be the correlative of the upper part of the Dunscombe Mudstone Formation or younger than it. The second potentially useful marker bed is the Spernall Gypsum, which Barclay *et al*. (1997) reported to lie above the Arden Sandstone Formation in the Worcester district. It could, therefore, be a correlative of the Red Rock Gypsum and the 'Anhydrite Marker' of the Wessex Basin. However, in its type area in the Redditch district, the Spernall Gypsum was reported by Old *et al*. (1991) to lie below the Arden Sandstone and to be the possible correlative of the Droitwich Halite Member. Correlation of the Mercia Mudstone Group succession of the south Devon coast with that of the Midlands will not be possible until the stratigraphical relationships between the Arden Sandstone Formation, Droitwich Halite and Spernall Gypsum have been clarified.

ACKNOWLEDGEMENTS

The author is grateful to all those colleagues and collaborators who helped to bring the work to fruition. In particular to Mark Hounslow for discussions in the field, to Dick Edwards for much assistance in the field and for continuous advice and encouragement, and to Alistair Ruffell for his helpful review of the manuscript.

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.

DE LA BECHE, H. 1826. On the Chalk and sands beneath it (usually termed Greensand) in the vicinity of Lyme Regis, Dorsetshire, and Beer, Devonshire. *Transactions of the Geological Society, London*, **2**, 109-118.

EDMONDS, E. A. and WILLIAMS, B. J. 1985. 1:50,000 Scale Geological Sheet 295 (Taunton). Ordnance Survey for the Institute of Geological Sciences, Southampton.

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.

HENSON, M. R. 1971. *The Permo-Triassic rocks of south Devon.* Unpublished PhD thesis, University of Exeter.

IRVING, A. 1888. The Red-Rock Series of the Devon coastline. *Quarterly Journal of the Geological Society*, *London*, **44**, 149-163.

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.

JUKES-BROWNE, A. J. 1902. On a deep boring at Lyme Regis. *Quarterly Journal of the Geological Society*, *London*, **58**, 279-289.

KELLAWAY, G. A. and WELCH, F. B. A. 1993. *Geology of the Bristol District*. Memoir of the Geological Survey of Great Britain. HMSO, London.

Gallois, R.W. 2001. *Geoscience in South-west England,* Vol. 10, 195-205.

LOTT, G. K., SOBEY, R. A., WARRINGTON, G. and WHITTAKER, A. 1982. The Mercia Mudstone Group (Triassic) in the western Wessex Basin. *Proceedings of the Ussher Society*, **5**, 340-346.

OLD, R. A., HAMBLIN, R. J. O., AMBROSE, K. and WARRINGTON, G. 1991. *Geology of the country around Redditch*. Memoir of the Geological Survey of Great Britain. HMSO, London.

RICHARDSON, L. 1906. On the Rhaetic and contiguous deposits of Devon and Dorset. *Proceedings of the Geologists' Association,* **19**, 401-409.

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.

USSHER, W. A. E. 1875. On the sub-divisions of the Triassic rocks, between the coast of West Somerset and the South Coast of Devon. *Geological Magazine*, **12**, 163-168.

USSHER, W. A. E. 1908. *The geology of the Quantock Hills and of Taunton and Bridgewater*. Memoir of the Geological Survey of Great Britain. HMSO, London.

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., 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.

WARRINGTON, G. and WHITTAKER, A. 1984. The Blue Anchor Formation (late Triassic) in Somerset. *Proceedings of the Ussher Society*, **6**, 100-107.

WHITTAKER, A. and GREEN, G. W. 1983. *Geology of the country around Weston-super-mare*. Memoir of the Geological Survey of Great Britain. HMSO, London.

WOODWARD, H. B. and USSHER, W. A. E. 1911. *Geology of the Country near Sidmouth and Lyme Regis*. Memoir of the Geological Survey of Great Britain. HMSO, London.

WORSSAM, B. C., ELLISON, R. A. and MOORLOCK, B. S. P. 1989. *Geology of the country around Tewkesbury.* Memoir of the Geological Survey of Great Britain. HMSO, London.