LATERAL VARIATIONS IN THE TOPMOST PART OF THE BLUE LIAS AND BASAL CHARMOUTH MUDSTONE FORMATIONS (LOWER JURASSIC) ON THE DEVON AND DORSET COAST

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The beds adjacent to the junction of the Lower Jurassic Blue Lias and Charmouth Mudstone formations are intermittently exposed in cliff and foreshore sections over a distance of 8 km on the east Devon and west Dorset coast on either side of Lyme Regis. Comparison of the successions in the highest part of the Blue Lias shows little lateral variation in thickness or lithology, with the exception of minor thickness changes in the two highest limestone beds. In contrast, the basal beds of the Shales-with-Beef Member, the lowest part of the Charmouth Mudstone, are laterally variable. Up to five beds of limestone that are present in the most westerly exposure in Devon are absent at the more easterly exposures in Dorset. This lateral variation does not appear to be related to contemporaneous fault activity. It is largely due to an unconformity at the base of the Shales-with-Beef which cuts out successively more of the basal beds when traced from west to east. The strict application of the definition of the Blue Lias Formation, currently taken at the top of the highest limestone in an interbedded mudstone-limestone succession, would include beds previously classified as Shales-with-Beef in east Devon.

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INTRODUCTION

The highest part of the Blue Lias and the lowest part of the overlying Charmouth Mudstone formations, are intermittently exposed over a distance of 8 km in cliff and foreshore sections between The Slabs [SY 286 894], Devon and Canary Ledges [SY 355 929], Dorset (Figure 1). The succession comprises interbedded fossiliferous marine mudstones and limestones, and contains numerous laterally persistent lithologically and faunally distinctive marker beds (Figure 2) that enable detailed correlations to be made between all the exposures. The Blue Lias exposed along the Devon-Dorset coast consists of a rhythmic succession of thinly interbedded organic-rich mudstones, calcareous mudstones and limestones in which the limestones make up about 40% of the total volume. The overlying Charmouth Mudstone Formation is composed of a similar range of lithologies in a succession that contains less than 3% of limestone by volume.

The organic-rich beds in the Blue Lias Formation are mostly laminated, pyritic and contain little bioturbation or calcareous fauna. In contrast, the calcareous beds and the nodular and tabular limestones that occur within them, are mostly highly bioturbated and richly fossiliferous. The limestones, which occur as tabular beds and lines of concretions, were formed by cementation with calcium carbonate in the carbonate-rich parts of the succession during early diagenesis, prior to compaction (Paul *et al.*, 2008). Many of the boundaries at the bases of the organic-rich deposits are sharp and indicate breaks in sedimentation, although few are of sufficient duration to have been detected in the palaeontological succession. The origin of the rhythms has been much debated. The current consensus is that they are related to climate change induced by Milankovitch orbital cycles (Weedon, 1986). Prominent among the numerous sedimentological and palaeontological studies of the Blue Lias Formation are those of Hallam (1957, 1960a). These and other early studies of the Lias of the Devon-Dorset coast, including specialist accounts of particular aspects of the biostratigraphy and sedimentology, have been reviewed by Callomon and Cope (1995), Hesselbo and Jenkyns (1995) and Simms *et al.* (2004).

In Victorian times, the limestone beds in the upper part of the formation were extensively worked for building stone and cement manufacture in the cliffs and intertidal areas adjacent to Lyme Regis. Woodward (1893) recorded the quarrymen's bed names in the first detailed description of the sections, and these names were used in a slightly modified form by Lang (1914). Lang (1914) allocated odd numbers (beds 1 to 49) to the limestone beds of the upper part of the Blue Lias and even numbers (beds 2 to 48) to the intervening mudstones in the sections at East Cliff [SY 345 924], Lyme Regis. Blue Lias bed numbers referred to in the text are those of Lang (1924) for the lower part (H1 to H52) and Lang (1914) for the upper part (1 to 49). He subsequently (in Lang *et al.*, 1923) continued the numbering system into the Shales-with-Beef (beds 50 to 75). Wright (1860) placed the junction of the Blue Lias and the Lower Lias Clay (now Charmouth Mudstone Formation) at the top of Table Ledge (Bed 53). In the current nomenclature, which defines the base of the Charmouth Mudstone as the top

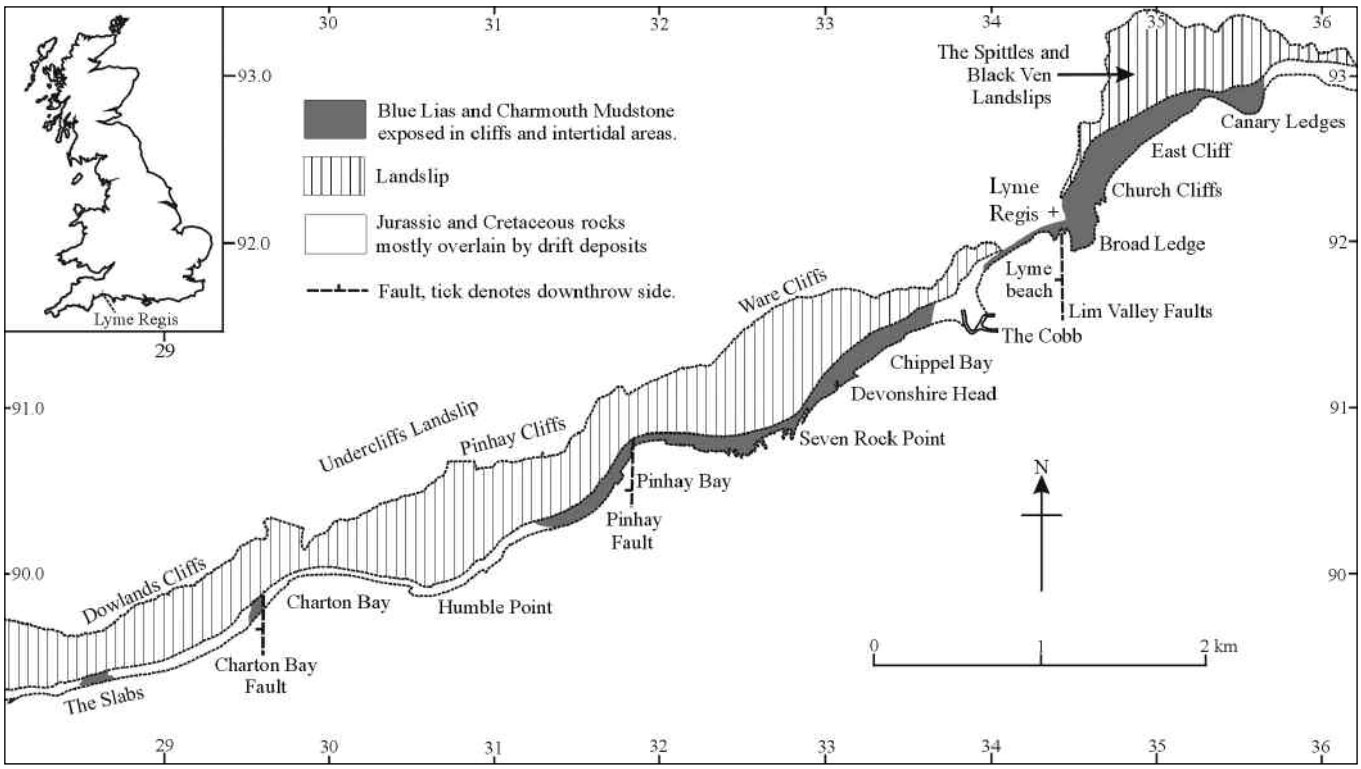

Figure 1. *Geological sketch map of the coast between The Slabs, Devon and Canary Ledges, Lyme Regis, Dorset showing the positions of sections referred to in the text.*

of the youngest limestone in a mudstone-limestone succession that contains numerous limestone beds (Cox *et al.*, 1999), the top of the Blue Lias at Lyme Regis is taken at the top of Grey Ledge (Bed 49).

Comparison of the successions exposed in the beds adjacent to the Blue Lias-Charmouth Mudstone junction on the Devon–Dorset coast showed that almost all the beds in the Blue Lias showed little lateral variation. Hallam (1960a) recorded examples of laminated limestone beds (beds H 30-36 and H 46-52) that can be traced from the south coast of England to the south coast of Wales, a distance of 75 km. In contrast, lateral variations were recorded in the lowest part of the Shales-with-Beef over a distance of a few hundred metres. In the more westerly exposures in Devon, for example that at The Slabs, there are limestone beds that had not previously been recorded in the Shales-with-Beef. These are lithologically similar to those in the Blue Lias and would be included in the Blue Lias using the Cox *et al.* (1999) definition. Four laterally persistent beds proved particularly useful for correlation throughout the outcrop. These are, in ascending stratigraphical order, Best Bed (Bed 41) and Grey Ledge (Bed 49) in the Blue Lias, and Fish Bed (Bed 51) and Table Ledge (Bed 53) in the Shales-with-Beef. A bioturbated erosion surface that caps Grey Ledge in all the sections examined provided an additional, easily recognised marker feature.

Details of the sections

The Slabs

The most westerly recorded occurrence of the Blue Lias on the Devon coast is a folded and faulted exposure of interbedded limestones and mudstones that form a series of seaward dipping ledges known locally as The Slabs [SY 2843 8935 to 2870 8940]. These expose a *c.* 16-m thick succession in the highest part of the Blue Lias and the lowest part of the Shales-with-Beef in exposures on the foreshore and in the intertidal zone (Figure 3). The lowest *c.* 5 m contains six limestone beds that can be matched with the youngest limestones in the Blue Lias succession at Lyme Regis (beds 39 to 49). The overlying mudstones contain eight limestone beds of which only two, Fish Bed (Bed 51) and Table Ledge (Bed 53) can be correlated with confidence with beds in the Shales-with-Beef at Lyme Regis. They have therefore been given the local names Slabs Limestone 1 to 8 for ease of description. At the eastern end of the foreshore, the Cretaceous Upper Greensand rests with angular unconformity on a bored surface that transgresses across Bed 49 and Slabs Limestone 1 over a distance of a few metres. The middle and western parts of the exposure are overlain by landslip deposits.

The Blue Lias succession exposed at The Slabs (beds 41-49) is lithologically similar to that at this stratigraphical level exposed elsewhere along the Devon and Dorset coasts. The succession is rhythmic with each rhythm having a sharp base overlain by laminated organic-rich mudstones which pass up into dark grey and then pale grey mudstones through the addition of calcium carbonate. Trace fossils are common and diverse at some levels, and are especially obvious at lithological boundaries where burrow fills of pale grey mudstone occur in a darker grey host sediment and vice versa. The lithological difference between burrow fills and host sediment is evidence of primary differences in the composition of the sediments (Hallam, 1957; Moghadam and Paul, 2000; Martin, 2004). In some rhythms the more calcareous beds are secondarily cemented to form a hard impure micrite. The paler grey beds and the limestones are mostly bioturbated and fossiliferous, in marked contrast to the organic-rich mudstones (Paul *et al.*, 2008).

The succession, in ascending stratigraphical order, can be summarised as follows. The top surface and *c.* 0.15 m of Bed 39 are exposed over a wide area. It contains a diverse fauna that includes dissociated ossicles and pluricolumnals of *Isocrinus*, large *Plagiostoma* (up to 0.17 m parallel to the hinge), *Amberleya* and *Bathrotomaria*, rare *Calcirhynchia* and common *Cenoceras*, two of which are orientated with the axis of coiling parallel to bedding and some with epifaunal oysters. Two small pieces of wood and one ammonite were also recorded. The trace-fossil assemblage includes pale-grey-filled *Planolites* with 1- to 2-cm diameter tubes, pale-grey-filled

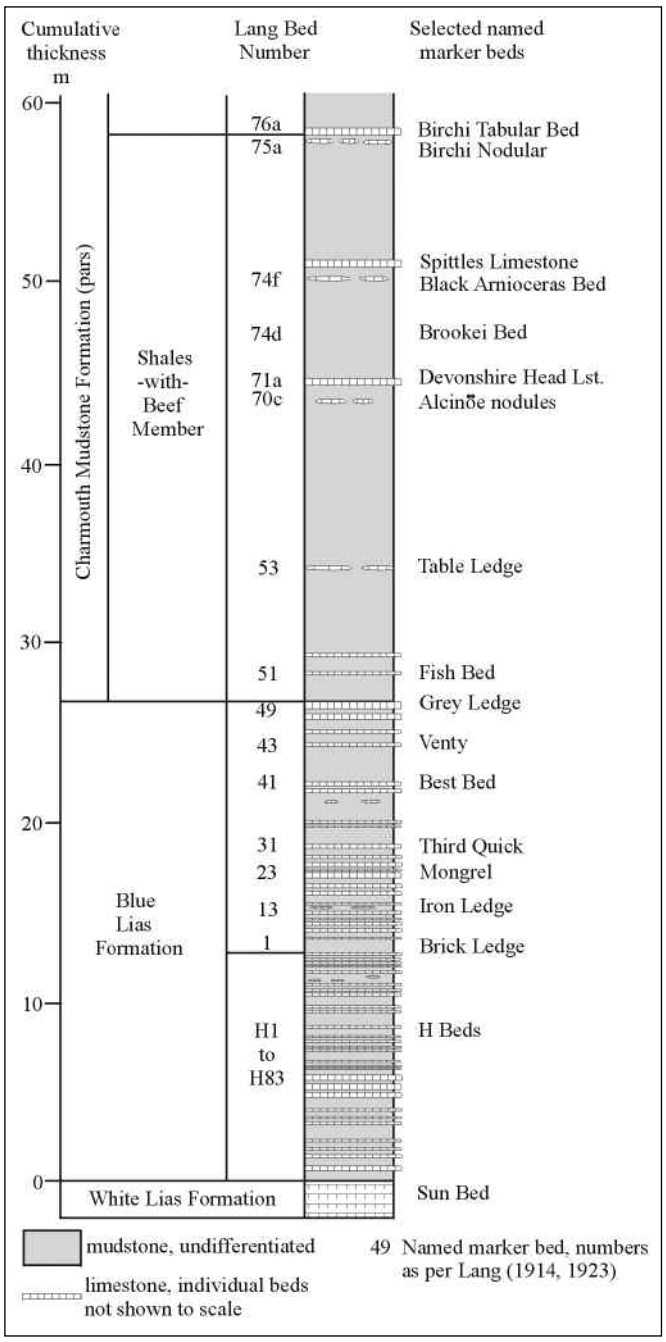

Figure 2. *Generalised vertical section for the Blue Lias Formation and the lower part of the Charmouth Mudstone Formation (Shales-with-Beef Member) of the Devon-Dorset coast.*

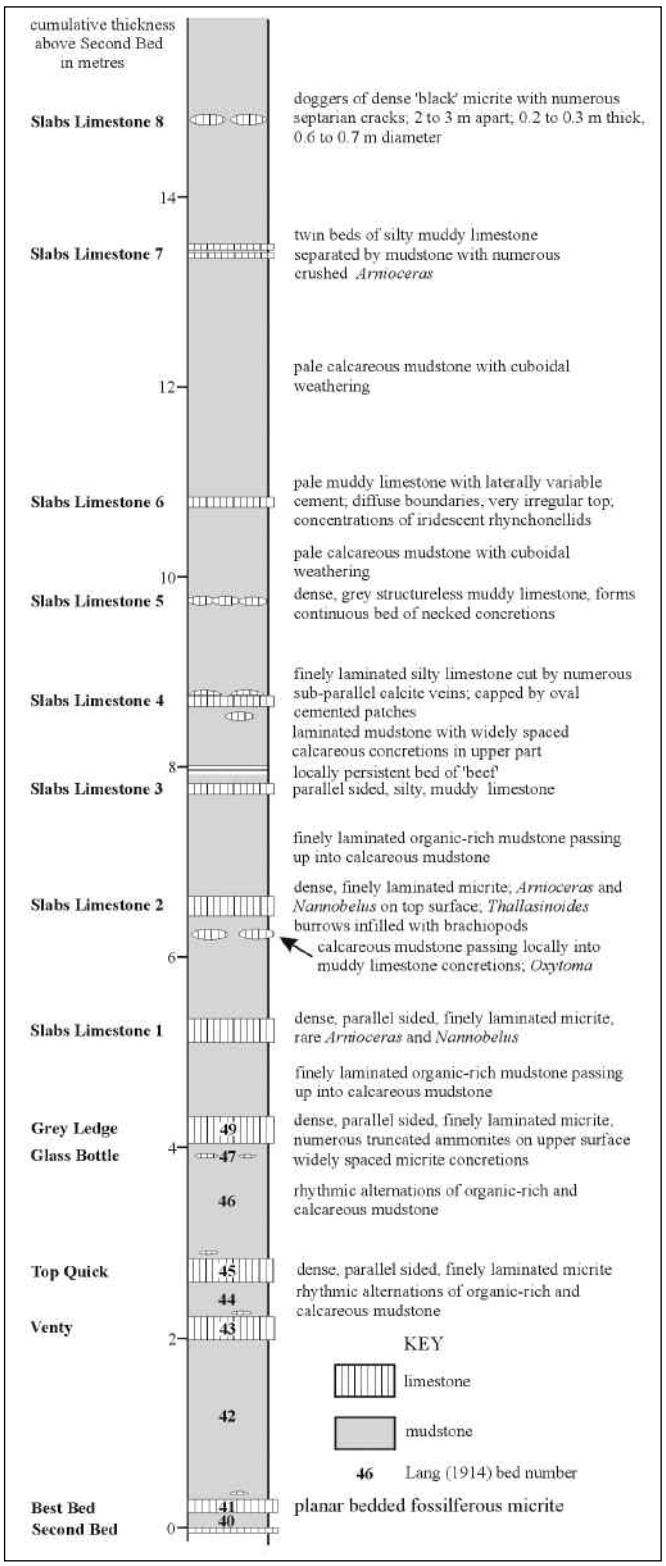

Figure 3. *Generalised vertical section for the succession exposed at The Slabs. See Figure 4 for outcrop map.*

Rhizocorallium with 1 cm wide branches, pale grey *Chondrites* with 2-mm diameter burrows, and dark-grey-filled *Rhizocorallium* reworked by pale-grey-filled *Chondrites* on the upper surface of the bed. The complex vertical burrow *Kulindichnus* (Hallam, 1960b) also occurs. Bed 40 consists of a lower 50-mm thick and an upper 90-mm thick bed of pale grey calcareous mudstone separated by a 15-mm thick bed of laminated organic-rich mudstone with thin sheets of beef.

Bed 41 is one of the most distinctive beds in the Blue Lias. It has planar upper and lower surfaces and is locally crowded with small (mostly <5 cm diameter), spar-filled ammonites chaotically orientated with respect to bedding. Other fauna includes *Spiriferina, Cenoceras*, a low-spired pleurotomariid gastropod plus *Amberleya* and a small high-spired gastropod (? *Procerithium*), an articulated bivalve and local patches of crinoid debris, some filling *Thalassinoides* burrows up to 60 mm across. Pyritized ammonites occur in the top surface, which also contains dark-grey-filled *Rhizocorallium*. Dark-grey-filled *Arenicolites* burrows *c.* 10 mm in diameter penetrate the bed locally. Widely spaced concretions occur on the top surface crowded with crinoid debris in the base, and with smooth, regular-echinoid spines and *Calcirhynchia* in the top.

Bed 42 (1.44 m thick) includes seven rhythms which start with a laminated organic-rich mudstone of variable thickness that rests with sharp contact on pale grey calcareous mudstone. Pale-grey-filled *Arenicolites* and *Planolites* occur in the bases of

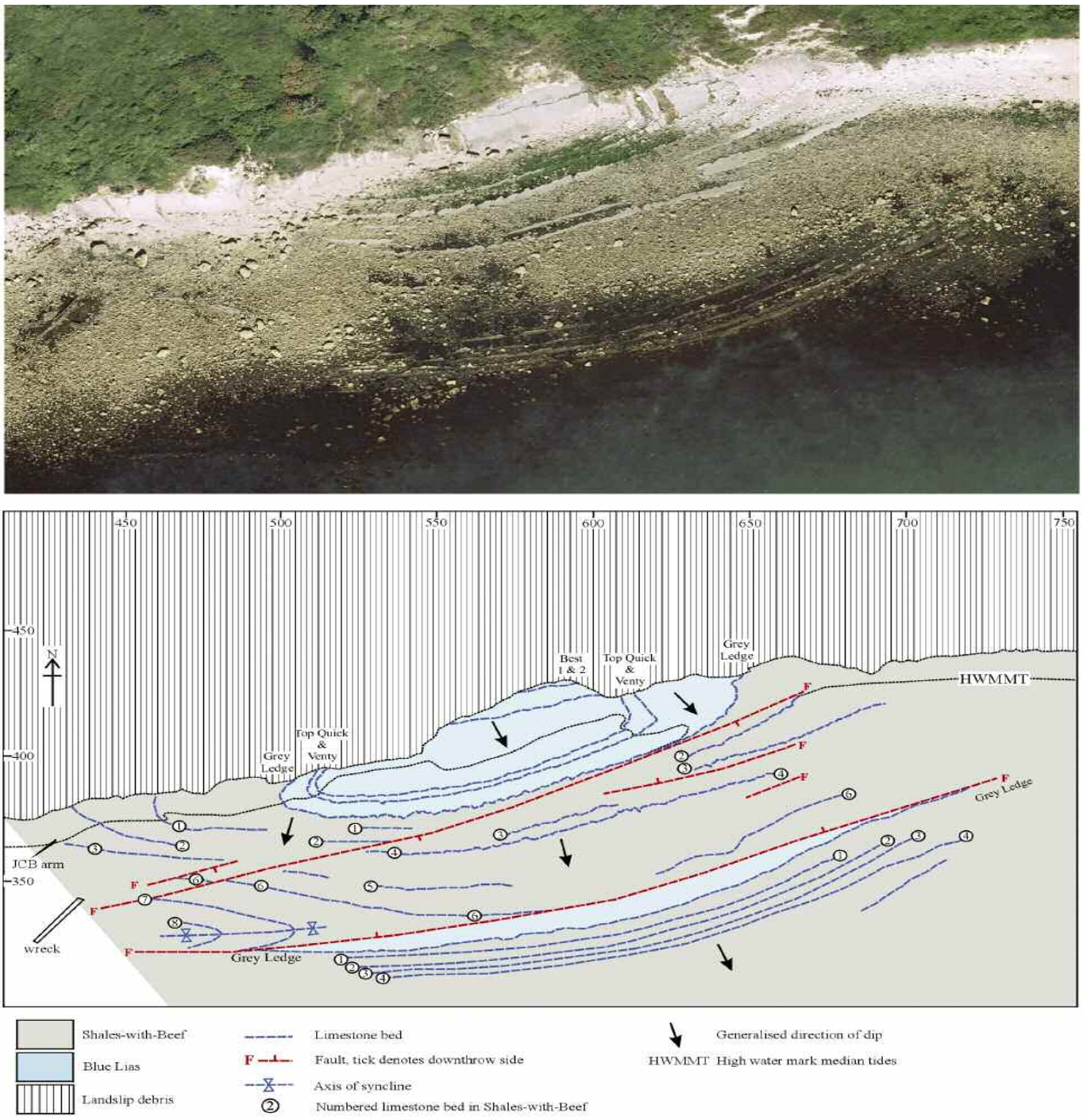

Figure 4. *Blue Lias and Shales-with Beef exposures at The Slabs, Devon. Ortho-corrected air photograph taken at about median low tide, September 2006. Image reproduced courtesy Channel Coastal Observatory (*www.channelcoast.org*). Geological sketch map of the intertidal area based on field surveys. See Figure 3 for the succession.*

rhythms, and dark-grey-filled *Planolites* and *Diplocraterion* penetrate the top of the calcareous mudstone in rhythm 2. Locally rhythm 4 contains calcareous concretions with echinoid spines. A small ammonite and brachiopods were recorded in rhythm 6, and shell chips in rhythm 7.

Bed 43 (0.18 m thick) is planar bedded with a fauna that includes *Plagiostoma*, *Calcirhynchia*, an oyster and nautiloids. Trace fossils include very common dark-grey-filled burrows and large (up to 6-cm diameter) *Kulindichnus* with complex fills.

Bed 44 (0.30 m thick) contains three rhythms in which pale-filled *Arenicolites* penetrate the lower two laminated mudstones. Bed 45 (0.3 m thick) is planar-bedded and contains several *Gryphaea*, ammonites (at least one of which is orientated vertical to bedding), *Calcirhynchia* and wood fragments. Dark-grey-filled, complex *Rhizocorallium*, including spiral and branched examples, occur in the top surface. Some are reworked by 1-mm diameter, pale-grey-filled *Chondrites*.

Bed 46 (0.90 m thick) contains four rhythms in which calcareous concretions with rare ammonites are locally present in calcareous mudstones in the lowest rhythm. Small (4- to 5-mm diameter) dark-grey-filled *Arenicolites* and *Diplocraterion* occur on the top of the calcareous mudstones and concretions in the lowest rhythm together with 1-cm diameter *Arenicolites* and *Diplocraterion* in the lowest part of the rhythm. *Oxytoma* is present in the middle two rhythms. Bed 47, a continuous bed at Lyme Regis, is represented by widely spaced concretions

(up to 0.1 m thick) that are penetrated by the trace fossil *Arenicolites*. Bed 48 is a single bed of pale grey calcareous mudstone. Bed 49 (0.26 to 0.33 m thick) has an uneven base and a relatively flat top that represents an erosion surface. Numerous *Arenicolites* burrows infilled with dark grey and pale grey mudstone extend down from the erosion surface, locally in such profusion as to resemble the Cambrian 'Pipe Rock' of NW Scotland (Figure 6c). The top surface of the limestone contains abundant ammonites up to 0.70 m in diameter, mostly *Arietites* indicative of the Lyra Subzone (Page, 2002), some of which bear epifaunal oysters. Others are planed off by the erosion surface. *Cenoceras* between 0.20- and 0.35-m diameter are relatively common and *Calcirhynchia* is common. A single *Nannobelus* recorded on the top surface of the limestone stands proud of the surface and may have come from the overlying bed. This is the lowest recorded stratigraphical occurrence of belemnites in the Lias of the Devon-Dorset coast.

The basal few centimetres of the overlying bed comprise of organic-rich, laminated, fissile-weathering mudstone with abundant sand-grade carbonate particles (shell fragments?) and many crushed *Arnioceras* indicative of the Scipionianum Subzone (Page, 2002). This bed is locally calcareously cemented to the top of Bed 49 to form a single limestone bed. *Chondrites* burrows (2 mm and 3 to 4 mm diameter) infilled with pale grey mudstone penetrate this bed together with pale-filled *Arenicolites* tubes up to 6 mm in diameter. A 1.1 m long piece of wood was observed at the western end of the exposure. At the eastern end, large *Thalassinoides* with burrows 50 mm across are crowded with *Calcirhynchia*: these were not recorded elsewhere in this bed. Irregular calcite-filled tubes (?fish coprolites) occur at the eastern end of the exposure. The basal bed is overlain by up to 0.8 m of darker and paler mudstones that probably form four rhythms. A single belemnite (*Nannobelus*) was collected 0.5 m below the top in the pale mudstone of the 3rd rhythm, and lenses of fine-grained fossil debris occur in laminated mudstone at the base of the 4th rhythm. Thin sheets of beef are relatively common in the laminated mudstones.

Slabs Limestone 1 (0.25 to 0.27 m thick) is a densely cemented, planar-bedded, laminated micrite. An outcrop area of *c*. 250 m^2 of bedding surface yielded three ?*Arnioceras* 3.5-6.5 cm in diameter and one *Nannobelus*. Trace fossils are extremely rare. The overlying mudstone unit (*c*. 0.9 m thick) includes two rhythms of laminated organic-rich mudstone and calcareous mudstone. A more prominent concentration of beef layers, 40 mm thick, occurs 0.24 m above the base. The upper rhythm contains widely spaced, dark grey limestone concretions, up to 0.13 m thick, within a bed of the laminated organic-rich mudstone. The overlying mudstone (0.23 m thick) appears to represent a single rhythm composed of the same lithology. A single *Oxytoma* was recorded within it.

Slabs Limestone 2 (0.20 to 0.28 m thick) is laminated and planar bedded. Numerous small (up to 90 mm but mostly 50 mm in diameter) crushed ?*Arnioceras*, many with epifaunal oysters, are present on the top surface. Other fauna includes pale grey *Oxytoma, Nannobelus* and, at the western of the exposure, masses of *Calcirhynchia* infilling large (50 mm across) *Thalassinoides* burrows. Trace fossils include dark-grey-filled *Planolites* 15 mm across and reworked by 1-mm diameter *Chondrites*, pale-grey-lined, dark-grey-filled *Palaeophycus* (? lined *Planolites*, <10 mm across) and pale-filled *Thalassinoides* with burrows 30 mm across with both T- and Y-shaped junctions. At least one brachiopod-filled *Thalassinoides* has a dark grey fill. Limestone 2 is overlain by *c*. 0. 55 m of laminated organic-rich mudstones. The lowest 0.10 m contains granules of shell and possible mudstone, and forms two distinct beds. This is followed by *c*. 0.35 m of laminated black shales, then a further 60 mm of black shale with granules, with 20-30 mm laminated black shale above that. The basal bed contains common pale-shelled *Oxytoma*, and two *Nannobelus* were seen. Its top surface is crowded with 2-3 mm diameter pyrite clusters. Two more *Oxytoma* were seen in the upper granular level.

Slabs Limestone 3 (0.7 to.0.9 m thick) is a planar-bedded, structureless micrite that appears to be unfossiliferous except for indeterminate (?oyster) shell chips on its upper surface. It is overlain by poorly exposed laminated mudstone.

Slabs Limestone 4 (*c*. 0.1 m thick) is planar-bedded and strikingly laminated (Figure 6d). The presence of numerous closely spaced mm-scale vertical calcite veins and round and ovoid concretions up to 1.5 m across on its upper surface make this one of the most lithologically distinctive beds in the succession. When traced eastwards to Pinhay Bay and Lyme Regis this bed can be seen to be the Fish Bed (Bed 51). Fossils include *Oxytoma*, small crushed ammonites up to 25 mm in diameter, a possible brachiopod valve and bone fragment, and abundant mm-sized shell chips. The lower part of the overlying poorly exposed bed consists of laminated organic-rich mudstone. At the western end of the exposure an additional four limestones form reefs in the lower part of the intertidal area (Figure 3), separated by poorly exposed mudstones.

Slabs Limestone 5 (up to 0.20 m thick) comprises laterally impersistent lenses of structureless micrite with irregular top and bottom surfaces. A large fragment of a bivalve, ?*Procerithium*, a possible fish scale, and a single, sinuous trace fossil (*Planolites*) were the only fossils recorded.

Slabs Limestone 6 (0.10 to 0.22 m thick) is a pale grey weathering muddy limestone with a laterally variable carbonate content that gives rise to uneven basal and top surfaces. The presence of nests of small, smooth ?*Piarorhynchia* within a succession of pale grey weathering, structureless calcareous mudstones with at least 8 thin (1-2 mm thick) beds of beef indicates correlation with Table Ledge (Bed 53) of more easterly sections.

Slabs Limestone 7 (0.25 to 0.30 m thick) consists of two layers of structureless micrite separated by mudstone with crushed *Arnioceras* up to 40 mm in diameter.

Slabs Limestone 8 consists of closely spaced septarian concretions of dense crystalline micrite up to 0.3 m thick and 0.7 m in diameter that are exposed in a shallow syncline at the western end of the outcrop.

At the eastern end of the upper foreshore the top of Slabs Limestone 1 is an iron-stained, bored and oyster-encrusted hardground overlain with angular unconformity by a gritty, sandy mudstone at the base of the Upper Greensand (Figure 6e and f). The hardground surface, which represents a mid-Cretaceous (Albian) sea floor, cuts across the limestone and the underlying mudstone in a planar fashion with no evidence of differential erosion. The unconformity is part of the regional overstep that brings Cretaceous rocks to rest on progressively older rocks when traced westwards along the Devon and Dorset coasts (Hancock, 1969). At Culverhole [SY 272 894], 600 m west of The Slabs, the unconformity rests on a burrowed and bored surface of late Triassic White Lias Formation (Gallois and Goldring, 2007).

Pinhay Bay

The whole of the Blue Lias and the lower part of the Shales-with-Beef are exposed in cliff and foreshore sections in Pinhay Bay. The beds adjacent to the Blue Lias-Shales-with-Beef boundary are exposed in low cliffs on the western side of the bay, and almost continuously between there and the Pinhay Fault [SY 3119 9031 to]. The succession is continuously exposed between the fault and Seven Rock Point [SY 3176 9071 to 326 909], but is difficult to access. The Blue Lias succession between beds 41 and 49 is similar to that exposed at The Slabs, with small differences in the thicknesses in the individual beds and the spacings between them. In the more westerly exposures, Grey Ledge comprises widely spaced limestone concretions crowded with dark-grey-filled *Arenicolites* and with large *Arietites* on their upper surface. East of the fault, it passes laterally into closely spaced concretions and tabular beds. The overlying mudstone (0.3 m thick), with a pyrite-rich horizon at the base, is overlain by an 0.35 to 0.4 m thick, planar-bedded and laminated limestone that forms a prominent

marker bed throughout the Pinhay Bay sections (Figure 6a). The lithology and faunal assemblage is closely similar to that of Slabs Limestone 2. It contains small, crushed ammonites and many small, crushed *Arnioceras* with epifaunal oysters, pale-grey-shelled *Oxytoma* and *Nannobelus* occur on its upper surface. Flat-sided slabs of this bed up to 3 m across are common on the foreshore where they contain *Thalassinoides* burrows crowded with *Calcirhynchia*. We suggest the name Picnic Ledge for this distinctive bed. Higher in the succession, the characteristically laminated Fish Bed is intermittently exposed west of the fault and is continuously exposed, albeit high in an inaccessible cliff, east of the fault. Table Ledge forms a prominent pale weathering marker bed in the cliffs east of the fault.

Seven Rock Point

The highest part of the Blue Lias and the lowest part of the Shales-with-Beef are exposed in a low cliff [SY 3275 9097] at Seven Rock Point. Grey Ledge (0.20-0.36 m thick) shows the characteristic dark-grey-filled *Arenicolites* and *Diplocraterion* burrows and truncated ammonites. It is separated from Slabs Limestone 2 (Picnic Ledge, 0.10 to 0.20 m thick) by 60 to 100 mm of fissile weathering mudstone, at the base of which is a pyrite-rich horizon. As elsewhere, the limestone is laminated, has a planar top, and contains *Calcirhynchia, Oxytoma* and, more commonly in the lower half, crushed and uncrushed ammonites. Fallen blocks contain *Nannobelus* immediately below, within and on top of the limestone, the base of which is formed by a pavement of crushed ammonites and *Oxytoma* valves.

Above Picnic Ledge are 1.4 m of mostly laminated organic-rich mudstones with several beef horizons and two beds of structureless, planar-bedded micrite. The first of these is the presumed correlative of Slabs Limestone 3 (0.10 to 0.12 m thick) and the second (0.08 m thick) the correlative of a horizon of widely spaced limestone concretions at The Slabs (Figure 5). The higher limestone is separated by 0.6 m of laminated mudstone from the distinctively laminated silty limestone of Fish Bed (almost continuous lenses up to 0.01 m thick).

Devonshire Head

The topmost part of the Blue Lias and the lower part of the Shales-with-Beef are wholly exposed in the continuous cliff [SY 328 910 to 332 914] below Devonshire Head between Seven Rock Point and Monmouth Beach, but can only be accessed at a few localities. All the limestone beds can be observed from the beach and many are present in large numbers as fallen blocks. Those in the upper part of the Blue Lias are laterally persistent throughout the section. The erosion surface at the top of Bed 49 is well developed with sheets of truncated large *Arietities* underlying the surface. Throughout most of this section the erosion surface is overlain by a laminated organic-rich mudstone crowded with small *Arnioceras* that is cemented to the top of the underlying limestone. When traced north eastwards along the section, Picnic Ledge, the most prominent

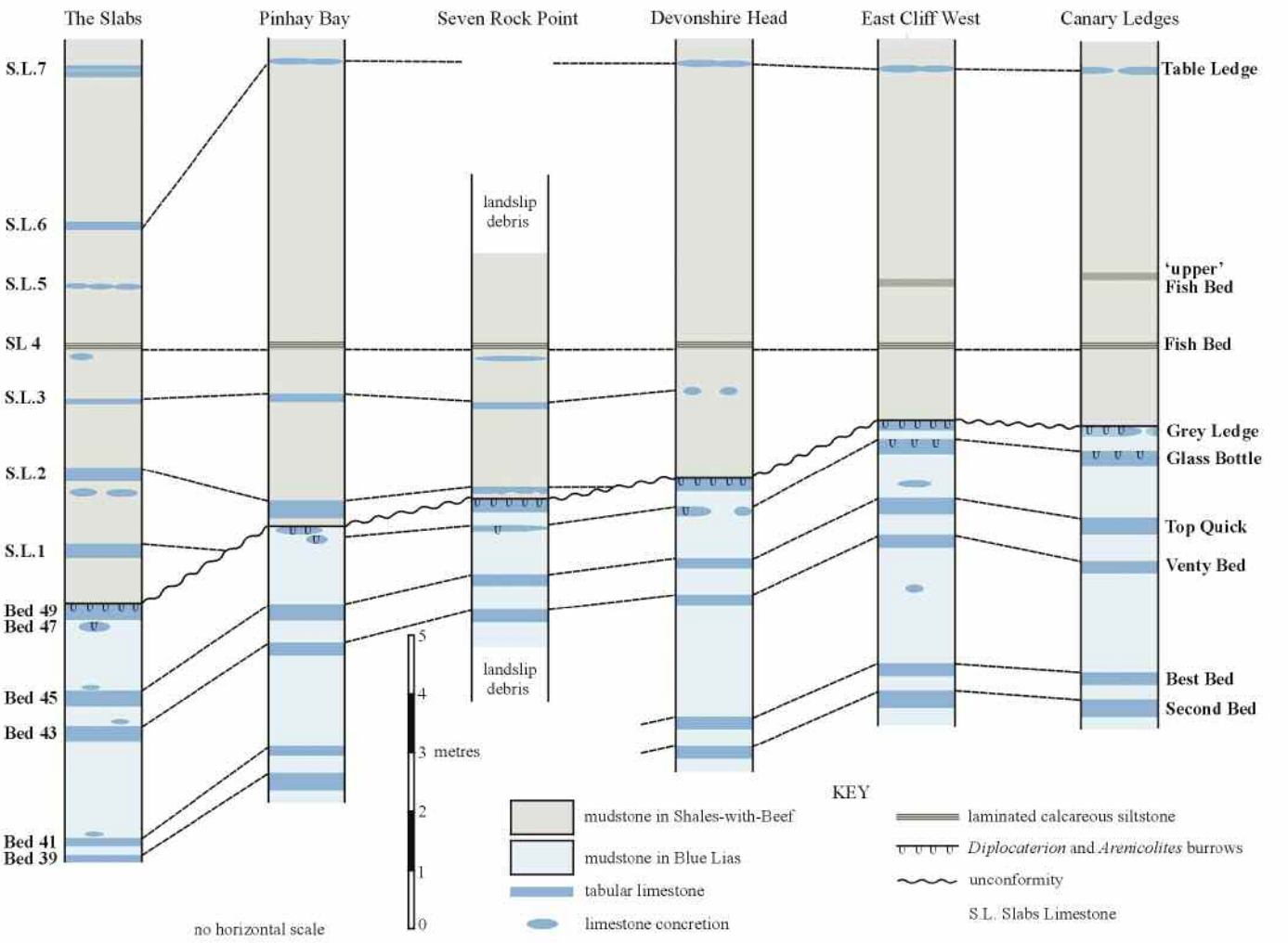

Figure 5. *Lateral variations in the highest part of the Blue Lias and the lowest part of the Shales-with-Beef between the most westerly (The Slabs) and most easterly (Canary Ledges) exposures on the Devon-Dorset coast.*

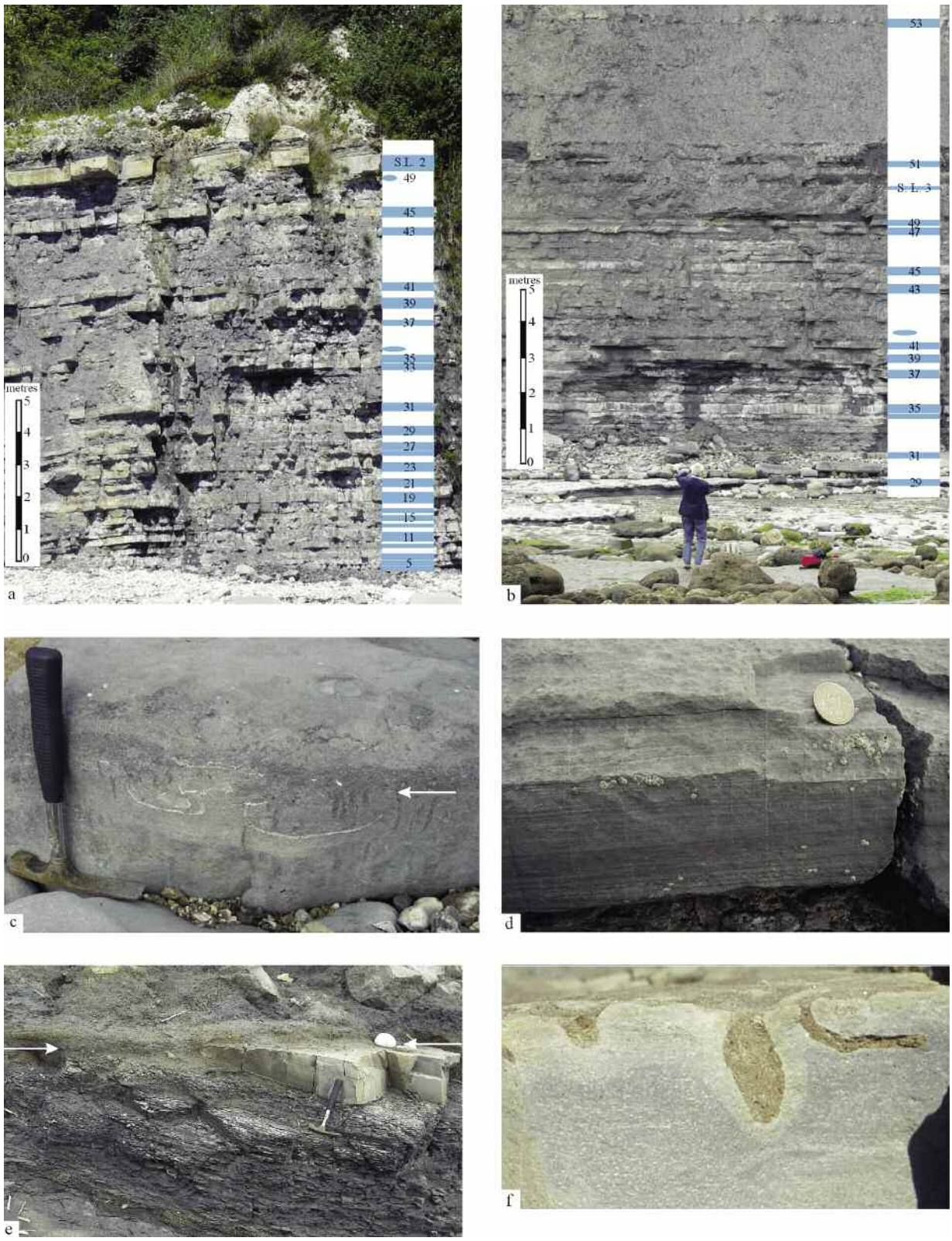

Figure 6. *Selected examples of Blue Lias and Shales-with-Beef lithologies. (**a**) The upper part of the Blue Lias and basal beds of the Shales-with-Beef, cliff section [SY 3151 9044], west side of Pinhay Bay. Bed numbers after Lang (1914). Bed 47 (Glass Bottle) is absent in this section but is locally present in the adjacent cliffs as widely spaced (5 to 10 m apart) limestone concretions. Bed 49 (Grey Ledge) is represented here and in the adjacent sections by similar concretions that are mostly 3 to 6 m apart. Slabs Limestone 2 (Picnic Ledge) is the most prominent bed in the succession. (**b**) The upper part of the Blue Lias and basal beds of the Shales-with-Beef, cliff [SY 3295 9118] below Devonshire Head. Beds 47 and 49 are present as laterally continuous beds here and throughout the Lyme Regis area. Higher in the succession, Bed 51 (Fish Bed) and Bed 53 (Table Ledge) form laterally continuous beds throughout the section the Devon-Dorset coastal sections. Slabs Limestone 2 is absent. (**c**) Unconformity surface (arrowed) in Bed 49 (Grey Ledge) Arenicolites and Diplocraterion burrows descend from the surface and ammonites are planed off by it. The overlying bed of organic-rich mudstone with crushed Arnioceras is here cemented to the underlying limestone. Fallen block below Devonshire Head. (**d**) Bed 51 (Fish Bed) silty limestone with characteristic lamination. The Slabs. (**e**) A planar unconformity (arrowed) at the base of the Cretaceous Upper Greensand Formation cuts across beds 48 and 49. Eastern end of The Slabs [SY 3295 9118]. (**f**) Bored unconformity surface on Bed 49. Locality as (e).*

limestone at this stratigraphical level in the cliffs at Pinhay Bay and as far as Seven Rock Point, becomes progressively thinner until it dies out *c*. 100 m north east of the point.

Lyme Regis Beach

The topmost part of the Blue Lias and the basal Shales-with-Beef crop out in the intertidal area [SY 340 919] at Lyme Regis. The Venty, Top Quick, Glass Bottle and Grey Ledge limestones form prominent ledges, the last named with numerous ammonites and dark-grey-filled *Arenicolites*, within and adjacent to the Lim Valley fault zone. Stratigraphically above this, five weak reefs cross the intertidal area. The first three of these are formed by thin beds of 'beef', the fourth and longest [SY 3405 9186 to 3417 9177] is formed by Fish Bed, and the fifth [SY 3397 9178 to 3404 9176] by Table Ledge. Continuously cored site-investigation boreholes drilled on the adjacent sea front proved a tabular silty limestone between Fish Bed and Table Ledge (the 'upper' Fish Bed of Gallois, 2008, figure 6), but this does not crop out on the beach. It is lithologically similar to the Fish Bed but lacks the prominent lamination that distinguishes Fish Bed from all the other beds in the succession.

Church Cliffs and East Cliff

The beds adjacent to the boundary of the Blue Lias and Shales-with-Beef were formerly well exposed in Church Cliffs [SY 345 924 to 346 925], but are now largely obscured by sea-defence works and landslip (Gallois, 2005). Church Cliffs pass eastwards into East Cliff [SY 346 925 to 349 928] where this part of the succession is well exposed, but only accessible at its eastern end where an easterly dip brings the beds down to beach level. A section above the sea wall in Church Cliff exposes beds 43 to 49. All four limestones and the intervening mudstones are bioturbated by dark-grey-filled *Planolites* burrows, some reworked by 1 mm pale-filled *Chondrites*, and *Arenicolites*. As elsewhere, *Arenicolites* burrows are common in beds 47 and 49. The latter is thinner (0.1 to 0.2 m thick) than at Lyme Regis and westwards from there, and when traced eastwards in East Cliff becomes discontinuous.

East Cliff exposes the upper half of the Blue Lias (beds 1 to 49) overlain by the lower part of the Shales-with-Beef. Fish Bed and Table Ledge form prominent, laterally continuous marker beds throughout the section. Beds 43 to 53 (Table Ledge) are exposed at the eastern end of East Cliff [SY 349 928] where beds 47 and 49 are both burrowed by *Arenicolites*. Bed 49 is lenticular (up to 0.2 m thick) and locally discontinuous, possibly infilling scour hollows. Above this Fish Bed, the 'upper' Fish Bed and Table Ledge, and the intervening mostly laminated bituminous mudstones are exposed in a deeply weathered section.

Canary Ledges

Bed 49 forms a prominent reef in the intertidal area adjacent to East Cliff (Lang, 1914; Gallois, 2005) and can be traced eastwards from there to similar exposures at Canary Ledges [SY 351 927]. The top surface carries large eroded ammonites and dark-grey-filled *Arenicolites* burrows descend from it. Belemnites that stand proud of the top surface are assumed to relate to the overlying mudstone. The basal beds of the Shales-with-Beef consist of laminated mudstones and more resistant beds with pavements covered with *Oxytoma*. Fish Bed (*c*. 0.1 m thick) occurs *c*.1 m above Bed 49 with the 'upper' Fish Bed, an apparently structureless silty limestone (*c*. 0.1 m thick) *c*.1 m above it. Farther east, the succession from Bed 46 to Fish Bed crops out in the nose of the Newfoundland Syncline [SY 352 928] and within the adjacent Black Ven Fault Zone (Gallois, 2008, figure 4). These are the most easterly exposures of the Blue Lias on the Dorset coast.

Summary and conclusions

Comparison of the sections in the youngest part of the Blue Lias and the oldest part of the Shales-with-Beef on the Devon and Dorset coast has shown more lateral variation than has previously been recorded. The top part of the Blue Lias remains relatively unchanged laterally throughout the 8 km of exposures. Limestone beds 39, 41, 43, 45, 47 and 49 and the mudstones that separate them show lateral variations in thickness, but few lithological differences. The most marked variations are in Bed 47 (Glass Bottle) and Bed 49 (Grey Ledge) which appear to have a reciprocal relationship whereby Glass Bottle expands from a bed of discontinuous concretions in the west to a continuous tabular bed of limestone in the east, and Grey Ledge undergoes a similar change from west to east. The junction of the Blue Lias and Shales-with-Beef at Lyme Regis is taken at a prominent erosion surface that rests on Bed 49 in all of the sections recorded. Numerous *Arenicolites* and *Diplocraterion* burrows descend from the erosion surface and large ammonites at the top of Bed 49 are planed off by it. In the lower part of the Shales-with-Beef, the lithologically distinctive Fish Bed and Table Ledge form marker beds in all the cliff sections. In contrast to the lateral uniformity of the Blue Lias, the lowest part of the Shales-with Beef expands westwards to include beds that are not present at Lyme Regis.

At The Slabs, the beds between Fish Bed and the erosion surface comprise over 4 m of mudstones that contain three tabular beds of limestone and two horizons of limestone concretions. The tabular beds (Slabs Limestones 1 to 3) are lithologically similar to the limestones in the Blue Lias and could be included in that formation. One of them (Slabs Limestone 2) forms the most prominent bed in the cliffs between The Slabs and Seven Rock Point. At East Cliff and Canary Ledges, Fish Bed is separated from the unconformity by less than 1 m of mudstone with no intervening limestone.

Comparison of the lateral variations visible in the extensive cliff sections suggests that they are not directly related to penecontemporaneous faulting. The successions on either side of the Pinhay and Lim Valley faults can be matched in detail, and the more rapid lateral changes occur away from the faults. Similarly, the Charton Bay Fault did not have a marked influence on sedimentation. The unconformity therefore appears to represent a longer break in sedimentation in the east than it does in the west. If so, then the lowest *c*. 3 m of beds below Fish Bed at The Slabs are older than the oldest Shales-with-Beef (Bed 50) at East Cliff, Lyme Regis. The ammonite succession at this stratigraphical level is currently too poorly known to test this hypothesis.

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