Aust Cliff and Manor Farm

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Maps

OS Landranger 172	1:50 000 Bristol & Bath
Explorer 167	1:25 000 Thornbury, Dursley & Yate
BGS Sheet 250	1:50 000 Chepstow

Main references

Swift & Martill (1999); Allard *et al*. (2015); Cross *et al*. (2018).

Objectives

The purpose of the excursion is to examine a classic section that documents the major environmental shift from terrestrial to marine rocks caused by the Rhaetian transgression, as well as the Triassic-Jurassic boundary, and to sample the rich fossil faunas, and especially the Rhaetian bone beds.

Risk analysis

Low tides are essential for the excursion to Aust Cliff. Tides rise very rapidly along this section of coast (with a tidal range of about 12 m) and strong currents sweep past the bridge abutment. Visitors should begin the excursion on a falling tide. If caught on the east side of the bridge abutment when the tide rises, visitors should continue east along the coast to the end of the cliff where a path leads back to the motorway service area. In addition, the entire section is a high cliff, and rock falls are frequent, so hard hats must be worn. The Manor Farm section lies inland and is lower, so hard hats are less necessary. Both sites can be slippery and proper footwear is required.

Location

This is a two-part trip, focusing on Aust Cliff itself, but with the addition of the nearby Manor Farm section to provide access to the upper parts of the section.

Aust Cliff is situated at the eastern end of the first Severn Road Bridge (M48) over the Severn Estuary (Fig. 1) at ST 566 898. Good general views of the cliff and rock platform may be obtained from the footpaths on the Severn Road Bridge, especially at low tide. It is possible to gain access to the site from both the eastern and western ends, but the western access is much easier to reach by road and to park cars or coaches. Drive to the

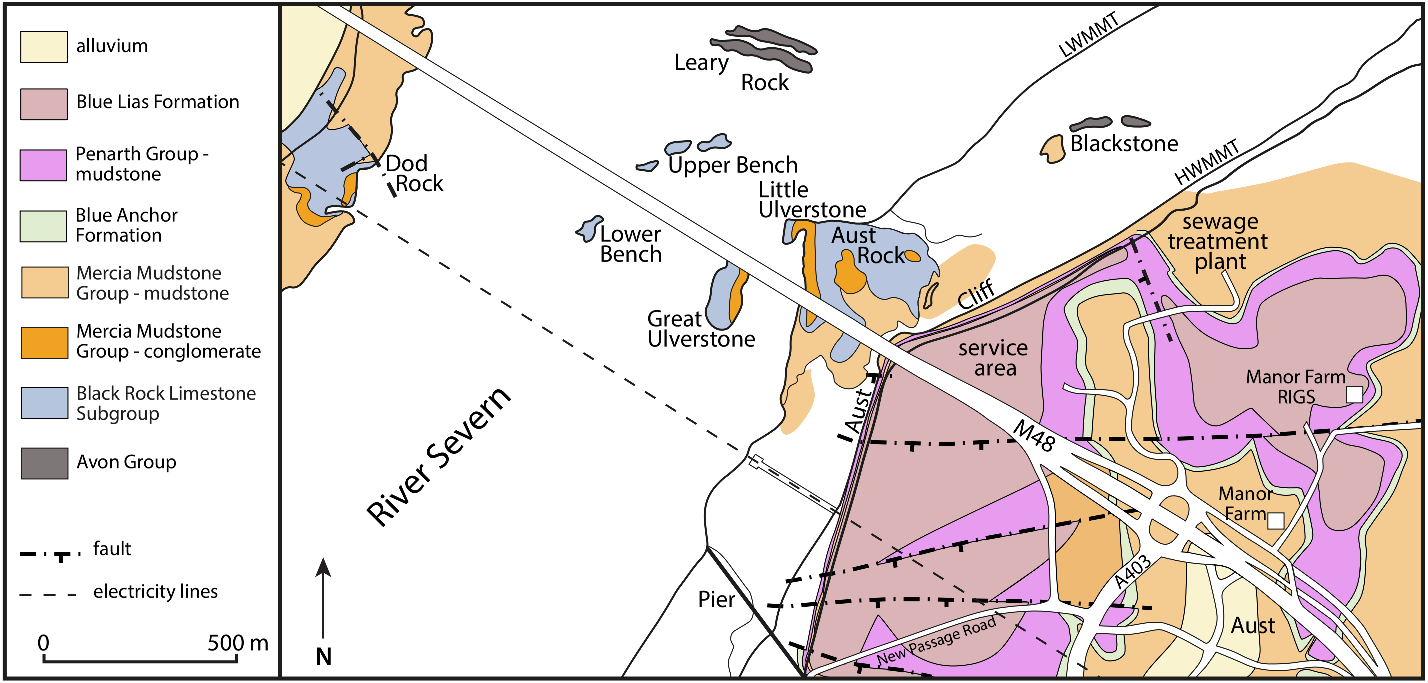

Figure 1. Geology of Aust Cliff and Manor Farm.

Aust junction (junction 21) on the M48 and turn off on the A403 heading south (signs for Avonmouth) but cross the central reservation and turn right almost immediately onto New Passage Road. Drive for 800 m until the road bends right, and park by the right-hand turn to the beach. Walk down this road, which was the old approach to the ferry across the Severn, past the old ticket barriers on the left. Go through the iron gates at the end of the access road (ST 564 889) and walk along the concrete causeway at the base of the cliff. By walking out on to the upper tidal flats of the estuary a more extensive view of the cliff is obtained.

The Manor Farm section (Fig. 1) can be reached from the same roundabout at M48 junction 21, but here turn south-east onto the B4461 (signs for Thornbury) and drive for only 150 m, and turn left down one of the two steep access roads to Manor Farm, and park in the general car park for the businesses located there. Walk back towards the road, and take the farm track to the right, crossing two styles in quick succession, walking diagonally across the field and crossing another style. Then, continue up the hill on the farm track, heading in the same direction until you reach a gate into a wooded area, with a geological interpretation board. This is the entrance to the Manor Farm RIGS site [National Grid Reference ST 574 896].

Outline Geology

The striking Aust Cliff exposure was noted early in the history of geology, and was first described in detail by Buckland & Conybeare (1824). It is famous also as the type locality for the large primitive actinopterygian *Severnichthys acuminatus* (Agassiz), the hybodont shark *Lissodus minimus* (Agassiz) the lungfish *Ceratodus latissimus* Agassiz and *Synectodus rhaeticus* (Duffin). In summary, the section shows:

1. The stratigraphic succession from Triassic Mercia Mudstone Group to Early Jurassic strata in the cliff section.
2. Faulting in a broad anticline.
3. Folding at the base of the Mercia Mudstone Group.
4. Carboniferous Limestone and Dolomitic Conglomerate in the rock platform at the base of the cliff.

The Mesozoic succession exposed in the cliff (Fig. 2) is easily subdivided on the colour of the strata and on fossils. The lower part of the cliff is Triassic Mercia Mudstone Group, comprising two formations, the thick, red-coloured Branscombe Mudstone Formation, forming much of the cliff, followed by Blue Anchor Formation. Macrofossils are generally absent from these beds but occur abundantly in the overlying dark and lighter grey Penarth Group (Rhaetian) sediments above. The prominent limestones and shales at the top of the cliff are Early Jurassic in age (Lias Group).

The oldest rocks in the area are Lower Carboniferous Limestones, which outcrop in the rock platform just upstream from the Severn Bridge. These had been uplifted and folded in the latest Carboniferous to Permian Hercynian (= Variscan) Orogeny, and then eroded down into a Triassic landscape or palaeotopography. In the valleys or wadis of this landscape accumulated the Dolomitic Conglomerate, which is a limestone breccia, the matrix of which now consists largely of dolomite.

Widespread deposition of Mercia Mudstone Group sediments in the Late Triassic buried the limestone topography. The Branscombe Mudstone Formation red dolomitic and calcareous siltstones with gypsum and salt (halite) pseudomorphs were laid down in extensive playa lakes or on intertidal flats or enclosed bays. In the cliff face, note the irregular change in colour from the red Branscombe Mudstone Formation sediments to the

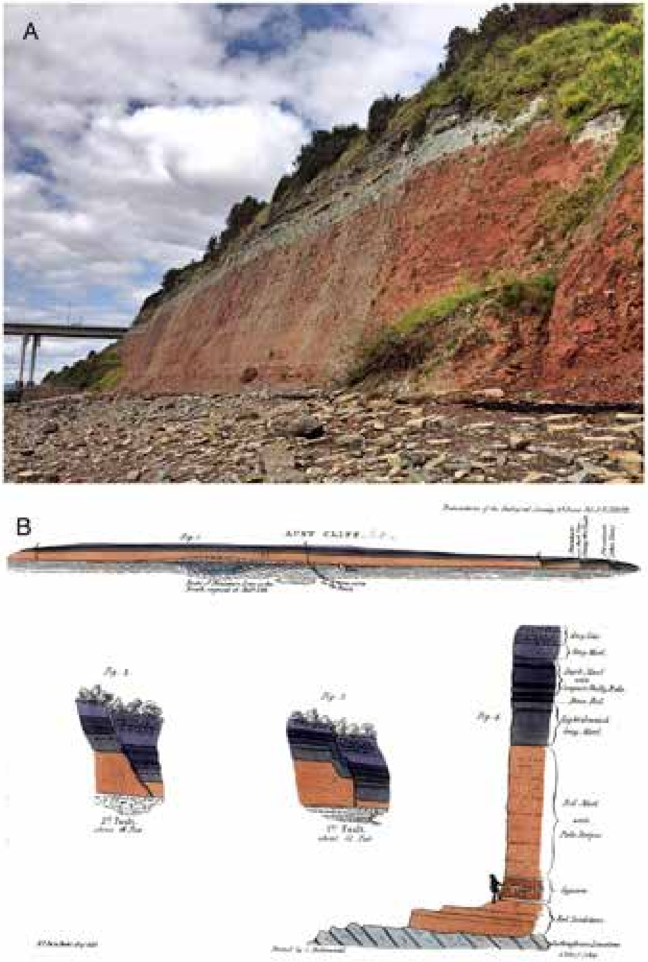

Figure 2. Mesozoic strata exposed at Aust Cliff.

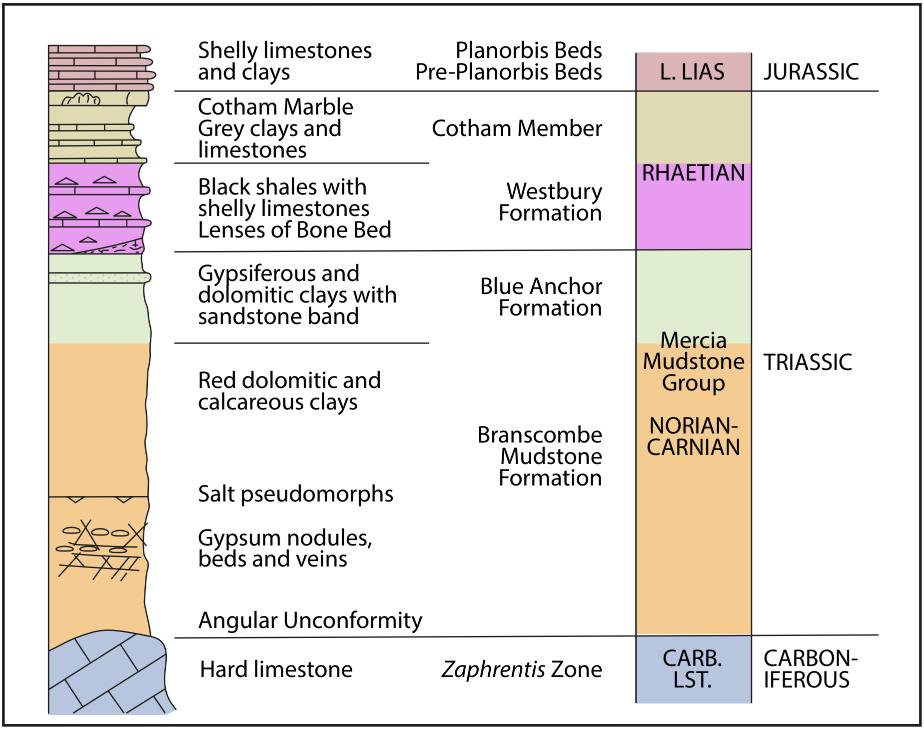

Figure 3. The succession of Triassic to Jurassic rocks exposed in Aust Cliff (based on Hamilton, 1977).

blue-green sediments of the Blue Anchor Formation. The overlying grey Penarth Group (Rhaetian) sediments have distinctive hard limestone bands. The Penarth Group begins with the black or dark grey Westbury Formation mudstones and limestones, and these are overlain by the light grey sediments of the Cotham Member of the Lilstock Formation. The topmost beds of the cliff are usually interbedded hard limestones and soft mudstones of the Lias Group, which spans from latest Triassic through Early Jurassic. These are grey in colour when fresh but weather to light brown.

From this vantage point on the tidal salt marsh, note how the strata rise toward the Severn Bridge, beyond which they decrease in height, clearly showing the anticlinal structure of the cliff (Fig. 3). The SE–NW anticlinal ridge is breached by the River Severn, so that the continuation of the anticline can be seen across the river in Sedbury Cliff. The anticline is developed only in the Triassic and Jurassic sediments as they drape over a flat-topped ridge in the underlying Carboniferous Limestone.

Several faults break the continuity of the strata in the anticline (Fig. 1). These are normal faults, with downthrows to the south (downstream) side. Small promontories occur on the cliff face at the sites of these faults.

The upper parts of the Aust Cliff section, particularly the Penarth and Lias groups, are inaccessible, so these may be seen in close-up at the Manor Farm section. When you enter the Manor Farm site, you can see the excavated rock section that was cleared when a large pit was excavated in 1995 and 1996 to obtain materials to build embankments for the M4 motorway for the second Severn crossing. The present section shows a bench at roughly the contact of the Westbury Formation and the Cotham Member, and the Lias begins just below the soil line, at the top.

Itinerary

Aust Cliff

Start on the foreshore, at the base of the cliff about fifty paces from the entrance gate [ST 564 889]. Much of the cliff is overgrown now, so the sketch of the face as seen in earlier times is reproduced as Fig. 4. Two faults are present, both normal with downthrow to the south. The more northerly fault is plainly visible at present in the upper part of the cliff.

At the base of the cliff on the downthrow side, bluish-grey sediments of the Blue Anchor Formation are exposed. A prominent sandstone, cemented with calcite and in which baryto-celestine may occur, together with beds peppered with small dark crystals of gypsum, can be matched on the north (upstream) side of the fault, where it occurs about half way up the cliff face (Fig. 4). Note the transitional change from the red sediments of the Branscombe Mudstone Formation beds to the Blue Anchor Formation, but the contact between the latter and the overlying dark Westbury Formation is sharp and erosional.

The lowest horizon of the black to dark grey mudstones of the Westbury Formation consists of a highly pyritized sandstone, only a few centimetres thick and often containing colourless tabular crystals and rosettes of selenite ($CaSO_4.2H_20$). The basal Rhaetian Bone Bed occurs at the base of the Westbury Formation, but it is somewhat discontinuous, occurring in lenses of coarse sandstone and conglomerate, rich in vertebrate remains. Fallen blocks, from beyond the end of the concrete causeway, are the best source of specimens, but these can be hard to find as the site is very popular with fossil collectors. (See below for a discussion of the origin of the Bone Bed.)

The basal sandstone passes up into isolated sandstone ripples in the overlying shale. Many of these sandstone ripples, which can be collected in fallen blocks at the foot of the cliff, show abundant trace fossils indicative of a sub-littoral environment. These lowest Westbury Formation sediments pass up into a fissile shale. The lower parts of these shales are fossiliferous, with *Rhaetavicula contorta*, *Chlamys valoniensis*, insect wings, beetle elytrae and small fish scales and teeth. Rosettes of selenite are common, and the joint surfaces are frequently coloured reddish brown with jarosite.

The next prominent bed is the Lower Pecten Bed, a current-concentrated sandy biosparite, with *Chlamys valoniensis*, *Protocardia rhaetica*, and other bivalves, together

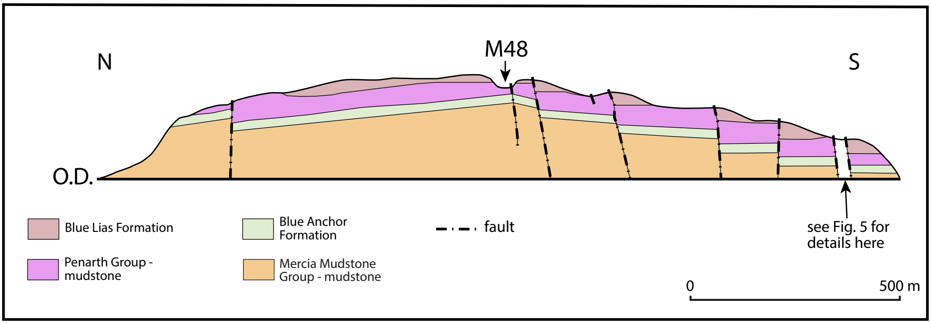

Figure 4. The broad anticlinal structure of Aust Cliff (modified after Buckland & Conybeare, 1824). M48 motorway cut on Severn Bridge approach (based on Hamilton, 1977).

with fish scales and teeth. Generally, the shells have been dissolved away leaving only casts and moulds. Above the Pecten Bed, sand lenticles in the shale pass up into dark blocky shales. These have a sufficiently high hydrocarbon content to burn with a yellow smoky flame when heated fiercely.

The succession of a hard, sandy shelly limestone, the Upper Pecten Bed with abundant *Pleurophorus elongatus* Moore, passing into a dark greenish shale is repeated once again, to form the top of the Westbury Beds.

The succeeding Cotham Member of the Lilstock Formation also includes three argillaceous limestones which each pass up into clays. When fresh, these Cotham Beds are blue-grey in colour but weather to a very pale grey. Fossils are quite scarce in these beds and are different from those in the underlying and overlying beds. The lowest limestone and shales appear to be locally unfossiliferous at Aust, though at other localities nearby derived Westbury fossils and algae occur. The second limestone contains sporadic occurrences of the tiny leaves of the liverwort *Naiadita lanceolata*, together with the ostracod *Euestheria minuta* var. *brodiana* and insect remains. The third limestone also contains ostracods, e.g. *Darwinula* spp.

A fourth limestone occurs at some places but has been removed by slight erosion elsewhere. This uppermost limestone has impersistent mounds of algae, known as Landscape Marble (Hamilton 1961). It is often accompanied by mud-flake breccia, which is termed Crazy Cotham Marble, and this may occur as channel fillings with fragments from the teleost fish *Pholidophorus higginsi*.

The White Lias generally occurs above the Cotham Beds in the Bristol area, but it is not present at Aust. Coarser grained Blue Lias limestones, typically shelly biosparites, rest directly on an eroded surface of the Cotham Beds. The abundant fossil assemblage is suggestive of marine conditions since the lowest Pre-planorbis beds contain *Liostrea hisingeri*, *Plagiostoma giganteum*, *Pleuromya tatei*, *Atreta intusstriata*, *Pseudolimea hettangiensis*, *Oxytoma longicostata*, etc.

The Pre-planorbis Beds are followed by the planorbis Beds containing an abundance of the small Hettangian ammonite, *Psiloceras planorbis*.

Proceed along the base of the cliff, examining fallen blocks for fossils and noting the faults at the promontories of the cliff. The faults are often the sites of springs, caused by the reversal of dip on the downthrow side of the fault (Reynolds, 1946). The carbonate-rich spring waters have deposited tufa. The best area for collecting from fallen blocks is beyond the concrete causeway to the electricity pylon on the estuary; these often include blocks of the Bone Bed, the Lower and Upper Pecten Beds, Cotham limestones and Liassic limestones.

On approaching the Severn Bridge, the lower beds of the Mercia Mudstone Group are exposed, where gypsum nodules and alabaster veins occur at the base of the cliff, both in discontinuous horizontal layers and in near-vertical cracks about 1-metre deep in places. At the foot of the cliff beyond the bridge, cuboidal salt pseudomorphs occur in greyish siltstones. These have formed by the infilling of cavities formed by the solution of halite crystals. A small anticline is visible in the lower part of the cliff, but this is quite local. If tidal conditions are favourable, an anticlinal structure can be traced in Branscombe Mudstone Formation sediments on the rock platform.

Manor Farm

The Manor Farm section (Fig. 5) shows the top portions of the Aust Cliff section, which are inaccessible. The section runs from the top of the Blue Anchor Formation at the base (usually buried under slumped sediment) to the Lias at the top. The account below is

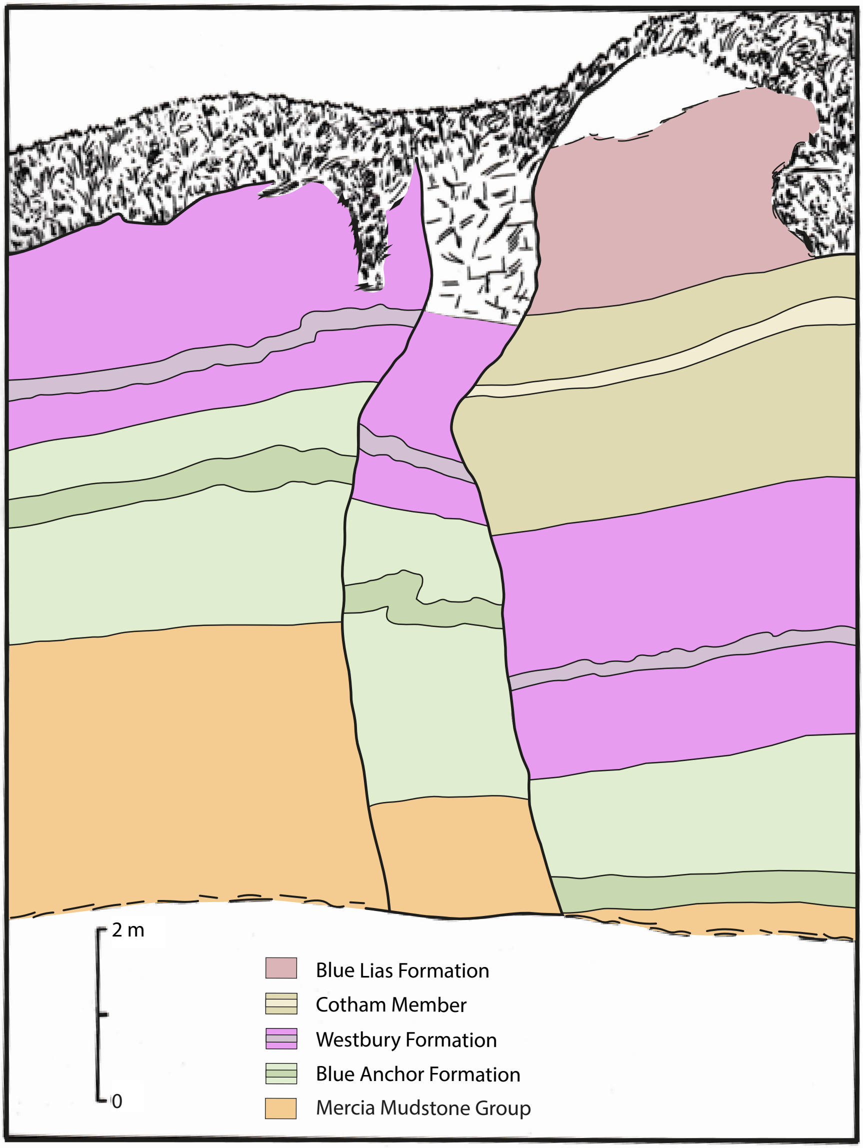

Figure 5. Juxtaposed faults near the southern end of Aust Cliff (Based on Hamilton, 1977).

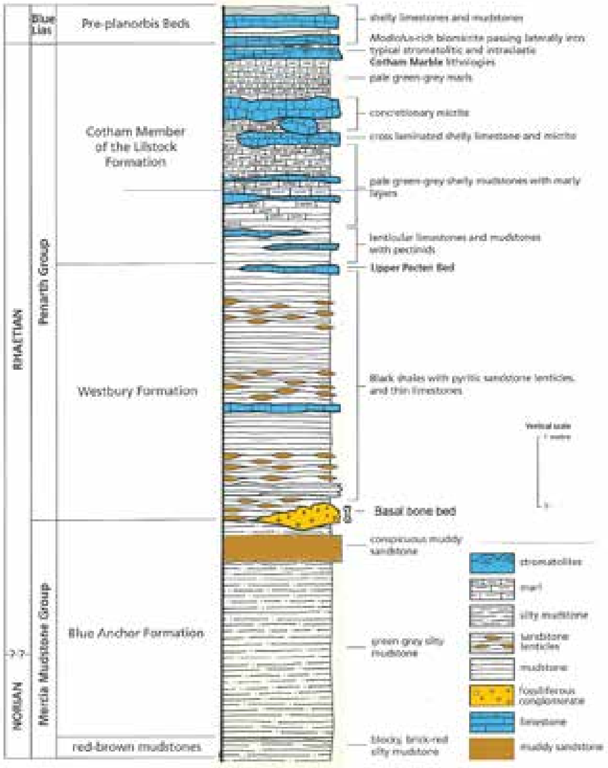

Figure 6. Succession at Manor Farm.

taken from Allard *et al.* (2015), based on an earlier description by Radley & Carpenter (1998).

The Westbury Formation here is some 3.5 m thick, comprising grey-black cyclic shales, thin fossiliferous sandstones, and tabular, muddy bioclastic limestones. At its base, the basal Rhaetian bone bed occurs as discontinuous lenses, up to 20 cm thick, occupying shallow depressions on the eroded top of the Blue Anchor Formation. At some levels, the shales are packed with convex-up, crushed bivalves, including *Rhaetavicula contorta*, and the thin sandstones contain euhedral pyrite crystals, and horizons packed with mouldic, disarticulated, convex-up bivalves, including current-aligned *Pleurophorus elongatus* and scattered vertebrate remains, including fish teeth and rare reptile bones. Other thin sandstones contain trace fossils, including the U-shaped burrow *Arenicolites*, and the bases of bivalve resting traces, *Pelecypodichnus*, possibly formed by infaunal bivalve shells found on neighbouring horizons, including *Eotrapezium*. Near the top of the Westbury Formation there is a laterally persistent unit of muddy, dark-grey, rust-weathering bioclastic limestone, approximately 8 cm thick, which is probably equivalent to the Upper Pecten Bed of Aust Cliff (Reynolds, 1946). The upper surface of this unit displays abundant, disarticulated *Chlamys valoniensis*, sometimes accompanied by *Rhaetavicula contorta*.

The top of the Westbury Formation is marked by a step in the section and passes into the cream-coloured marls and fine-grained limestones of the 3-m-thick Cotham Member of the Lilstock Formation. The lower portion comprises 0.8 m of grey shelly clay with some cemented bands, becoming increasingly marly towards the top. At the base of this unit, abundant and disassociated fish teeth and scales occur, together with the bivalve *Chlamys valoniensis*. Lenses of grey 'pecten limestone' with *C. valoniensis* also occur, the undersides of which, as seen in loose slabs, may display irregular pod-shaped to sinuous casts, representing remains of burrow systems. Higher parts of the Cotham Member comprise pale-coloured marls with some beds of chalky, micritic, tabular to nodular limestone, approximately 1.4 m above the base, equivalent to Reynolds' (1946) 'insect bed', his 'band 100. Loose blocks of this contain scattered casts of *Tutcheria cloacina* and *C. valoniensis*, as well as occasional bones and coprolites.

Examples of the stromatolitic 'landscape marble' were exposed in trial pits at the top of the Cotham Member. At this location the layer was up to 15 cm thick and rested on soft, unfossiliferous khaki-coloured mudstone. Loose blocks of 'crazy' Cotham Marble (intraformational micrite-flake breccia) were found nearby, and probably represent channel fills between the stromatolites (Reynolds, 1946; Hamilton, 1961). In some specimens, the mud-flake breccia is overlain by stromatolitic growths, while in others it is intercalated with splintery, cream-weathering micrite, packed with small, disarticulated *Modiolus* cf. *hillanus*.

The Langport Member ('White Lias') of the Lilstock Formation is absent here, as at Aust Cliff, and the highest strata preserved in the quarry brow and subsoil comprise the distinctive flaggy, brown-grey bioclastic limestones and mudstones of the Pre-planorbis Beds. These limestones are full of disarticulated bivalves, including *Liostrea hisingeri* and *Pteromya tatei*, with rarer *Oxytoma longicostata* and *Modiolus minimus*. Minute echinoid spines stud the surfaces of some slabs. Associated mudstones are also rich in *L. hisingeri*.

Discussion

Having examined the whole section, some further points concerning mainly the environments of deposition will be discussed.

1. Mercia Mudstone Group – red beds and evaporites

The red and green Triassic sediments are fine-grained, of predominantly silt grade and have been laid down in water. The siltstones show calcite, dolomite or even gypsum cements. When sand grains of medium size occur in these sediments, the grains are very well rounded, suggesting aeolian abrasion under desert conditions.

The presence of gypsum, pseudomorphs of halite and the widespread occurrence of dolomite and calcite suggests deposition in hypersaline lake conditions. Curtis (1982) described cyclical sedimentation of these units, characteristic of deposition in a sabkha environment subject to periods of heavy rainfall alternating with extremely arid conditions. The cycles comprise three distinct phases:

1. Blocky red mudstones and variegated mudstones at the base of the cycles contain nodular gypsum. The fine-grained red siltstones were carried in by wind from dry areas, based on evidence of their aeolian rounded grains, and they adhered to wet surfaces across the basin. The gypsum accumulated through later passage of mineral-rich waters and grew in undulating beds that distort the red siltstones below and above.

2. An erosive phase scoured the tops of the variegated mudstones.
3. Laminated, rippled, greenish-coloured silts and clays were deposited during storm events, as sheets of water washed across the land surface. The pseudomorphs after halite were formed as the storm waters evaporated. Halite crystals were dissolved and the voids left in the sediment were filled with silts.

The evaporitic minerals were deposited through a variety of processes. The bedded gypsum was precipitated from hypersaline groundwater, and the associated anhydrite may have been deposited as a primary mineral, or it might represent diagenetic replacement, or be a product of deep burial. Other minerals, including celestite and calcite, may be primary or diagenetic. The striking V-shaped structures near the bridge, where gypsum fills deep, near-vertical cracks, probably represent infills of cracks formed around the edges of large polygons, some of them measuring 1–2 m across, caused by thermal contraction of the red mudstones (Tucker, 1981).

2. Mercia Mudstone Group – Blue Anchor Formation

The Blue Anchor Formation, formerly called the 'Tea Green Marls', is distinguished from the underlying red mudstones by the sharp change to a blue-green-grey colour. This boundary is irregular, with green patches commonly occurring within the red, and less commonly red patches occurring within the green rock. The colour differences are commonly seen in iron-rich sediments such as these, where the red colour comes from ferric oxides (Fe_2O_3) such as haematite and goethite, and the green comes from ferrous oxides (FeO). The two phases of iron oxide are usually interpreted in terms of the oxidation state of the sediments, with more oxygen present in the red siltstones, and with green sediments arising by reduction (removal of oxygen) in the green state. Evidence for this is that red sediments frequently turn green along the sides of faults and joints, where groundwater has been able to flow through, and remove oxygen.

It is debated whether the marked colour switch between the red Branscombe Mudstone Formation and the blue-green Blue Anchor Formation sediments is primary or secondary. The switch seems sharp at the base, suggesting a primary cause. However, an alternative suggestion is that the Blue Anchor Formation sediments may have been originally red when deposited, but that they were reduced by the effects of the Rhaetian Transgression, marked by the overlying Westbury Formation. Oxides in the red sediments could have been reduced to some depth by the low pH and Eh conditions following burial by the overlying Westbury Formation shales. The sea water associated with the Rhaetian Transgression may have soaked down some depth, and the anoxic seabed conditions indicated by the black colour of the sediments and the abundant pyrite, might have drawn out the oxygen. A key weakness of the secondary model is that the red-green contact occurs at a remarkably consistent horizon across the cliff face at Aust, and elsewhere. In other words, the Blue Anchor Formation is well demarcated, with a sharp base, and so likely the colour change has a primary cause.

3. Rhaetian Bone Bed

The well-known bone bed at the base of the Westbury Formation consists of a conglomerate or breccia of sedimentary rocks in a calcite-cemented sandy matrix, together with an abundance of bones, teeth and scales. Abundant vertebrate remains are common in the succeeding shelly limestones of the Westbury Beds and scattered vertebrate remains occur also in the shales, some of the forming additional bone beds, all through the Westbury Formation, and even in the lower beds of the Cotham Member, as seen in the Manor Farm section. Here, we focus on the basal bone bed (BBB) of the Westbury Formation.

The BBB generally sits directly on top of the Blue Anchor Formation, on an irregular, presumably eroded surface. At some locations, this eroded surface acted as a hardground and contains burrows of shrimps and other Rhaetian-aged organisms; sometimes the burrows are full of winnowed bone bed material. The intimate association of the BBB and the underlying Blue Anchor Formation is shown by the fact that at Aust, and some other locations, rounded blocks of Blue Anchor Formation, sometimes up to 10 cm across, have been reworked up into the bone bed. Sometimes these clasts are compressed, all of which suggests they were not transported far and were still soft at the time of erosion and transport. Isolated quartz pebbles are much more abraded, and so have been transported some distance.

The major interest in the bone bed is, of course, the abundance and variety of vertebrate skeletal remains. In addition, coprolites (faecal droppings), especially of aquatic reptiles, are very common; these contain crustacean fragments and abundant fish scales. Though jaw-bones with teeth have been found, the remains are usually disarticulated and frequently show signs of abrasion. The vertebrate remains include fishes and reptiles, and there are two categories of bony remains – larger, abraded chunks of bone and coprolites that may have been transported some distance and can be hard to identify, with smaller, more delicate teeth of sharks and bony fishes trapped between the larger remains, and showing less abrasion and so indicating that these might be animals that lived in the waters above.

Three groups of fishes are present in the fossil remains, sharks, bony fishes and lungfish. The teeth of the sharks *Lissodus* and *Rhomphaiodon* are the most common. The former are symmetrical and elongate, up to 5 mm wide, representing a cutting tooth with a single central smooth peak. *Rhomphaiodon* teeth are smaller and bear distinctive multiple cusps, a larger central one, and two or three cusplets on each branch of the tooth. Both these sharks had powerful fin spines, which may reach up to 30 cm in length. A smaller fin spine, with only a few large denticles, is named Nemacanthus monilifer. There are further, much rarer sharks represented by their teeth (Allard *et al.,* 2015; Cross *et al.,* 2018).

The most abundant bony fish is *Severnichthys* represented by two tooth types formerly called *Saurichthys* and *Birgeria*. The former are elongate and in two portions, a lower, darker section bearing longitudinal ridges, and an upper clear-coloured cap above a definite change in slope of the tooth. The latter are similar but lack the ‘shoulder’ between base and cap, and the cap is relatively longer. Common as well are the superficially similar teeth of *Gyrolepis*, but these are gently curved along their length, and the translucent cap is very short, just at the tip. The fourth bony fish tooth type is *Sargodon*, which has long pointed teeth, but these are rare, and domed crushing teeth at the back, which are quite common. Fish scales are common, most being rhomboidal and showing growth rings, and generally assigned to *Gyrolepis*. Although earlier researchers found abundant teeth of the lungfish *Ceratodus*, thse are now rare finds: the palatal teeth are robust, asymmetric, smooth structures, elongate and with two or three broad points.

The reptiles are mostly remains of ichthyosaurs and plesiosaurs. Remains have often been identified to specific level, but the quality of the material does not justify such precision. The most frequently preserved bones of the fish-shaped ichthyosaurs are discoid vertebral centra, which have two concave surfaces. Both the teeth and vertebrae of plesiosaurs are very common, the vertebrae being distinguished from those of ichthyosaurs by, among other features, being thicker and having two planar surfaces on the centra. Some very large bones were assigned to dinosaurs but may be jaw bones of a large ichthyosaur.

A key feature of the Rhaetian faunas is the preponderance of durophages, specialist feeders on molluscs and other hard-shelled prey. The shark *Lissodus minimus* is the most common taxon (43% of specimens) and it probably had a diet of shelly invertebrates such as gastropods, bivalves, brachiopods, echinoids or arthropods. Some bony fishes such as *Sargodon* and *Lepidotes*, which also had durophagous teeth, also fed on shelly invertebrates. Most of the other Rhaetian sharks have sharp and pointed teeth of varying morphologies, all adapted to piercing and snatching prey such as other fish and invertebrates. *Severnichthys* and *Gyrolepis* were predatory fishes based on their tooth morphology, exhibiting adaptations for snatching other, smaller fishes (Storrs, 1994). Its smaller size made *Gyrolepis* a common prey species for larger fishes. The length of *Severnichthys* has been estimated at around 1m making it the largest fish. Top of the food web were the ichthyosaurs and plesiosaurs.

Many explanations have been made for the concentration of bones and teeth in the Rhaetian BBB. It is clearly marine, based on the fossils (ichthyosaurs, crinoids, echinoids) and it shows signs of rapid deposition and winnowing by wave action and shoreline currents. The basal Rhaetian bone bed traverses much of central and western Europe, and shows substantial local variations in thickness, mean clast size, and the nature of locally derived debris (Macquaker, 1994; Suan *et al*., 2012). In some places it is absent, often because the waters and traction loads swept around minor local topographic highs, such as upstanding ridges of harder Carboniferous sediment. The BBB fossils comprise a mix of locally derived, and more distantly derived materials, judging by the sharpness of smaller teeth and the abraded nature of larger bones. Evidently, the traction loads of heavy phosphatic debris could travel substantial distances and so larger bone fragments became massively abraded, whereas in other locations, fish and reptile debris was carried only a short distance, before being dumped and then winnowed.

Macquaker (1994) suggested that the Aust bone bed represents a storm deposit: a mass of rocks and fossils picked off the shoreline and carried back down into deeper water by a storm surge ebb current or exhumed and redeposited from shallow-water sediments. Although the palaeontological evidence does not give precise dating, it is probable that the marine flooding phase occurred very rapidly and would have had a strong erosive force, probably extending over hundreds of kilometres.

The BBB is not the only Rhaetian bone bed, and several additional horizons with bone concentrations are noted by Allard *et al*. (2015) higher in the Westbuiry Formation and even in the lower part of the Cotham Member. These presumably each have their own story, and there is no evidence that they were reworked from lower horizons, including the basal bone bed, as had been suggested (e.g. Sykes, 1977; Martill, 1999). There is no evidence that the Westbury Formation did not accumulate as generally fine-grade sediment and without intervening erosive episodes that reworked older sediment. Whether any of the higher-occurring bone beds can be correlated over wider areas has yet to be demonstrated. Key evidence that the various Westbury Formation bone beds are not reworked variants of the BBB is that they differ substantially in faunal content and there is no evidence for increasing abrasion, nor of any directional trend in specimen size from coarser to finer up-section. Here, mean clast size diminishes from the basal bone bed to higher bone beds, but abrasion is actually less marked in higher bone beds than the BBB at Aust and Manor Farm.

4. Penarth Group Sedimentology and Fossils

Both the Westbury Formation and Cotham Member are characterized by repeated sequences that start with a sandy or shelly limestone resting on an erosion surface, with a rapid passage upwards into shales with ripple lenticles of sand, a decrease upwards in the amount of sand, as the sand lenticles give way to sand laminae a few grains thick, and an uppermost portion of laminated or blocky mudstones. These fining-upwards cycles indicate a decrease upwards in the energy level of the depositional environment, suggesting possibly regional-scale reductions in the rate of sea-level rise, or basins filling up.

The basal beds are current concentrated sands or more generally shell beds, which in the Westbury Formation are termed the Lower and Upper Pecten Beds. Current activity is shown by the orientation of the shells, which are almost all convex-upwards, and alignment of elongated shells such as *Pleurophorus elongatus*. Though these shelly limestones occur over widespread areas, they wedge laterally, suggesting they may be parts of migrating channel deposits or sub-littoral wave-concentrated deposits. The shells comprising these beds, such as *Rhaetavicula contorta* and *Chlamys valoniensis*, have been transported and are not shell banks. The sand ripple lenticles retain a profusion of trace fossils on their upper and lower sides and these are best collected along the front of the cliff. The ripple lenticles formed under conditions of decreasing currents and availability of sand, such as would occur with an increase in depth. The upper mudstones could represent the deeper water phase of deposition, for the fauna is thin-shelled and fragile.

The fauna of the Cotham Member is quite distinctive from that of the Westbury Formation. The fauna of the Westbury formation has a relatively small number of molluscan species, but these occur in quite large numbers, as is typical of brackish-water assemblages. As well as the aquatic fish and reptiles already noted, ophiuroids (brittle-stars), echinoids (sea urchins), crinoids (sea lilies), and the brachiopod *Orbiculoidia townshendi* are recorded. The presence of these latter two suggests that there was an opening to marine conditions.

In contrast, the main constituents of the Cotham Member faunas are: the liverwort *Naidaita lanceolata* Buckman, with an associated microflora, which was interpreted as representing a lake environment; an abundance at some horizons of the ostracod *Darwinula* spp.; the occurrence of the phyllopod (Arthropoda) *Euestheria minuta* var. *brodiana* Jones; and algal mounds, giving rise to the growth forms of Landscape Marble. These are all consistent with fluctuating lacustrine conditions.

5. Lias Group Sediments

The shallow-water shelly limestone resting on the eroded top of the Cotham Member heralds the marine incursion of the latest Triassic and Early Jurassic. There is a diverse molluscan fauna of marine aspect, which includes echinoids and corals. Truly marine conditions are established by the time the ammonite *Psiloceras planorbis* is present, marking the base of the Jurassic.

Thus, the changes from Triassic terrestrial deposition, through the fluctuating Rhaetian transgression to the Lias marine transgression are recorded in the succession from the base to the top of Aust Cliff and Manor Farm.

Fossil identification

The best guide to all Rhaetian fossils is Swift & Martill (1999). Online resources include classic fossils in the Bath collections, from the Triassic (https://www.brlsi.org/museum-collections/online-museum/fossils-by-geological/37) and Jurassic (https://www.brlsi.org/museum-collections/online-museum/fossils-by-geological/38), and the Jurassic Coast fossil finder (https://jurassiccoast.org/what-is-the-jurassic-coast/all-about-fossils/fossil-finder/fossil-finder-database/).

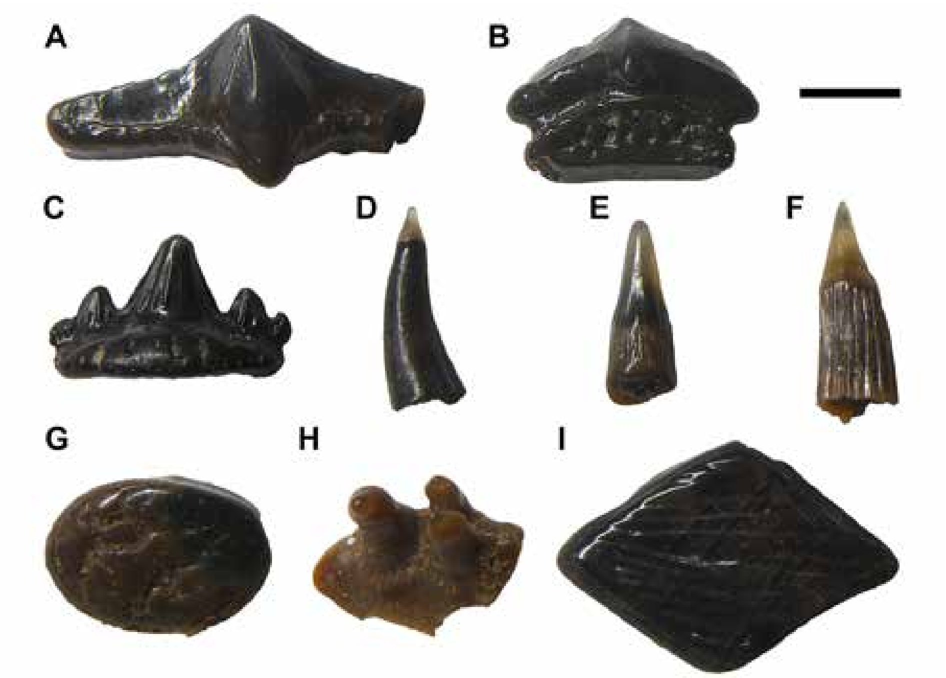

Figure 7. awaiting caption

Minerals

Though not a good collecting site for mineral specimens, the following may sometimes be found in fallen blocks along the cliff:

Baryto-celestine/$(BaSr)SO_4$. Varying amounts of barium and strontium may be present in this sulphate. Occurs very rarely in the Blue Anchor Formation, usually as very pale blue elongate crystals radiating fan-wise on joint planes.

Calcite/$CaCO_3$. Coarse, creamy to white crystals sometimes occur in veins, especially in the Lower Liassic limestones. Dark prismatic calcite often forms at the bottom or top of the Westbury limestones. The elongated crystals are arranged in horizontal bands at right angles to the bedding and are sometimes called ‘beef ‘.

Galena/PbS. Small silvery cubes of this lead sulphide have been noted extremely rarely in the Bone Bed.

Gypsum/$CaSO_4.2H_2O$. This may occur in several forms. Dull, earthy rock gypsum occurs as nodules in the Branscombe Mudstone Formation just downstream from the abutment of the Severn Road Bridge. Here also, pearly, fibrous satin spar, and massive white alabaster can be found. Near the base of the Westbury Formation, small colourless, blade shaped crystals occur in joints. ese are the variety selenite and they generally form small rosettes.

Jarosite/$K_2Fe_6(OH)_{12}(SO_4)_4$. Occurs as a brownish surface incrustation in the Bone Bed and the lower Westbury Formation shales.

Pyrite/FeS_2. Occurs most frequently on the upper and lower surfaces of the Westbury Formation limestones and sand lenticles.

Salt pseudomorphs. These are not truly minerals but are formed by the replacement of salt (halite, NaCl) cubes by sediment as the salt dissolved away. The cuboidal shape of the salt crystal is preserved in the sediment, usually on the underneath side. Salt pseudomorphs may be found occasionally in green bands in the Branscombe Mudstone Formation, just upstream of the abutment of the Severn Road Bridge and further east as the end of the cliff.

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