Aust Cliff, Avon

[ST 565 895]–[ST 572 901]

Introduction

Aust Cliff on the southern side of the Severn Estuary, is one of the most famous exposures of Triassic rocks in the world. This is partly because it was one of the first to be studied and partly because of its striking location, now squarely beneath a major motorway bridge (see (Figure 4.13)), but mainly because of its record of Late Triassic and earliest Jurassic sedimentary environments and fossils. The vertebrate faunas from the basal Penarth Group bone bed are world famous.

The cliff exposes a section through the upper part of the Mercia Mudstone Group, comprising red marls overlain by the Blue Anchor Formation. The latter is overlain successively by Penarth Group and Lias Group deposits (Figure 4.12). The red marls show gypsum-bearing horizons and infilled desiccation cracks.

The Penarth Group bone bed at Aust is of international significance as a fossil-rich horizon that has been a valuable source of vertebrate materials since early in the 19th century. Fossils recovered from this site include marine reptiles such as ichthyosaurs and plesiosaurs, fishes, and sporadic dinosaur fossils (Wickes, 1904; Storrs, 1993, 1994; Benton and Spencer, 1995; Dineley and Metcalfe, 1999).

The first description of the Aust Cliff exposure was made by Buckland and Conybeare (1824). Since then, the locality has commanded the attention of many geologists, for example Strickland (1841), Wright (1860), Etheridge (1867a,b), Short (1904), Reynolds (1929, 1946), Whittard (1949), Hamilton (1977), Sykes (1977), Curtis (1982), Kellaway and Welch (1993), Storrs (1993, 1994), Benton and Spencer (1995) and Swift (1995).

The site was selected independently for the GCR for five 'Blocks' — both the 'Permian and Triassic red bed' and the former 'Rhaetian' blocks, as well as for the Permian-Triassic Reptilia Block (Benton and Spencer, 1995), the Mesozoic–Tertiary Fishes/Amphibia Block (Dineley and Metcalfe, 1999) and the Palaeoentomology Block.

Description

The Aust Cliff section has been subject to high rates of natural erosion, for example in fractures along joint planes, which has kept the section clear of vegetation (Reynolds, 1906), thus facilitating geological fieldwork. The construction of the first Severn Bridge, especially the stabilization of the cliff and increasing plant cover across the foreshore, have been blamed for decrease in the numbers of fossils reported from the site (Large, 1966; Storrs, 1994). However, this decline may reflect the great popularity of Aust Cliff with amateur and professional collectors.

The Aust Cliff section shows evidence of tectonic deformation. The Mesozoic deposits are draped over Carboniferous Limestone, producing a gentle anticlinal structure (Curtis, 1982), the axis of which is located approximately under the motorway, and runs roughly south-east–north-west. This structure is also seen across the river in Sedbury Cliff. The limbs of the anticline are cut by several normal faults that downthrow to the south. These faults are marked by slight projections from the line of the cliff (Richardson, 1903c; Hamilton, 1977; Curtis, 1982).

Sedimentology

The cliffs on the south side of the Severn Estuary at Aust display long sections through the uppermost Triassic and lowest Jurassic deposits on the limbs of a gentle anticline (Figure 4.13). The section is cut by several normal faults, often marked by slight projections from the face of the cliff

The following description is based on Hamilton (1977), with additional information from Sykes (1977):

Lias Group

planorbis Zone

Pre planorbis Beds

Penarth Group

Lilstock Formation: Cotham Member:

Limestone, in places removed by erosion; including the 'Landscape Marble' and the 'Crazy Cotham Marble'.

Grey shale

Limestone, with ostracods

Grey Shale

Limestone, with occasional fossil plant debris, ostracods and insects

Shale, grey, unfossiliferous

Limestone, unfossiliferous

Westbury Formation:

Dark greenish shale

Upper *Pecten* Bed; dark grey, hard, shelly limestone

Dark shale with sand lenticles in lower part

Lower *Pecten* Bed; dark grey, shelly, sandy biosparite, with quartz pebbles at the base

Black fissile shale with some pellets of Blue Anchor Formation marls, calcareous sandstone pellets and rare vertebrate fossils at the base. Selenite rosettes common.

Shale with isolated sandstone ripples and trace fossils

Basal sandstone

Aust Bone Bed; lenses of grit and conglomerate, with abundant vertebrate fossils

Mercia Mudstone Group

Blue Anchor Formation

Grey-green gypsiferous and dolomitic clays with sandstone

Twyning Mudstone Formation

Red dolomitic and calcareous mudstones and siltstones, with gypsum nodules, alabaster veins and pseudomorphs after halite

Carboniferous Limestone

At the base of the cliff, the red, dominantly argillaceous, sediments of the Twyning Mudstone Formation are exposed; these are cut by a network of white veins and nodules of gypsum. In places, the clays are cemented by calcite. The red mudstones are overlain by the Blue Anchor Formation, the uppermost formation in the Mercia Mudstone Group, composed predominantly of fine-grained mudstones and siltstones, although sandstone bodies are also present (Hamilton, 1977).

Although the reddish-brown, dolomitic and argillaceous Mercia Mudstone Group sediments appear superficially to be homogeneous, a pattern of cyclicity has been described by Curtis (1982) and is best exposed to the north of the road bridge [ST 566 898]; (Figure 4.14)). The base of the cycles is marked by a red mudstone that contains beds of gypsum nodules and vertically orientated gypsum stringers or veins. In places, long v-shaped fissures filled with gypsum extend downwards from horizontal gypsum beds (Figure 4.15)a. The fissures are generally not perfectly vertical, having been distorted and curved by sediment compaction. Gypsum nodules may occur in isolation, or in concentrated patches within the red mudstones, and they are often linked by thin, wavy, sub-horizontal gypsum laminae (Figure 4.15)b. The nodules are surrounded by halos of green sediment. This unit is overlain by further variegated mudstones that contain gypsum veins. The upper ends of the gypsum veins are truncated by an uneven erosion surface, which is succeeded by laminated greenish silts and mudstones. The lower surfaces of the laminations often contain pseudomorphs after halite, and are commonly rippled.

The Blue Anchor Formation consists of predominantly green and grey mudstones, siltstones, and sandstones. There is no lithological difference between the red and green sediments. This formation yields pale blue celestite, often to be found on joint planes. Marine fossils occur sporadically.

Penarth Group

The sequence through the upper part of the Twyning Mudstone Formation and the Blue Anchor Formation of the Mercia Mudstone Group, is overlain disconformably by the Westbury Formation of the Penarth Group. The famous 'Rhaetic' Bone Bed marks the base of the formation (Storrs *et al.,* 1996)

The Westbury Formation sediments are predominantly dark-coloured, carbonaceous, often fissile, shales with some sandstones and bioclastic limestones (Hamilton, 1977; Storrs, 1993, 1994), which form cycles bounded by erosion surfaces (MacQuaker, 1994). Two of the limestones, the Lower *Pecten* Bed and the Upper *Pecten* Bed, both comprise sandy sediment rich in shell debris; the Upper *Pecten* Bed is harder than the Lower (Hamilton, 1977).

Although much of the section at Aust is similar to that seen elsewhere, for example at Blue Anchor and St Audries Bay (see site reports below), the presence of the Rhaetic' Bone Bed sets this locality apart. Unlike other localities where there are several Penarth Group bone beds (Wickes, 1904; Storrs, 1994), at Aust there is only one. The Aust Bone Bed is composed of a breccio-conglomerate with clasts of quartz, potassium-feldspar, phosphate nodules, vertebrate material, a fine-grained shelly matrix and a calcitic and pyrite cement (MacQuaker, 1994; Trueman and Benton, 1997; (Figure 4.4)b. Many of the larger clasts are composed of sediment from the underlying Blue Anchor Formation that show evidence of soft-sediment deformation indicative of reworking before lithification (Hamilton, 1977; Storrs, 1993, 1994). Trueman and Benton (1997) described graded bedding of the apatite and lithic clasts in the bone bed. The apatite is coarser at the base of the bed, while the rip-up clasts of Blue Anchor Formation sediment are coarser at the top of the bed. Trueman and Benton (1997) explained this phenomenon by postulating deposition as an arrested turbulent sediment flow: the dense apatite sank to the bottom of the flow, leaving the larger, less dense lithic clasts to 'float' at the top.

The uppermost unit of the Penarth Group here is the Cotham Member, which is also composed of alternating limestones and shales, but is somewhat paler than the Westbury Formation. The Cotham Member comprises argillaceous limestones that pass upwards into clays (the Langport Member is missing). At the top of the limestone succession is the Cotham Marble, often used as an ornamental stone. The Cotham Marble has two forms: the 'Landscape Marble', with the appearance, in section, of a 'landscape' composed of a hedge, trees and sky, and the 'Crazy Marble' that contains angular flakes of limestone in a fine- to medium-grained matrix (Hamilton, 1961, 1977).

The upper surface of the Cotham Member is eroded and separated from the overlying brown, flaggy Pre-*planorbis* Beds by a disconformity. The base of the Lias Group is marked by a discontinuous conglomerate composed of clasts of limestone from the Langport Member in a dark matrix (Hamilton, 1977; Swift, 1995; Radley and Carpenter, 1999).

Palaeontology

The Penarth Group sediments at Aust have produced abundant and diverse fossil assemblages. The Aust Bone Bed has yielded remains of the sharks *Acrodus, Nemacanthus,* and *Hybodus.*

Bony fishes are represented by jaws of the actinopterygian *Birgeria acuminata* and tooth plates of the lungfish *Ceratodus latissimus.* Reptiles, such as *Plesiosaurus, Ichthyosaurus,* the choristodere *Pachyostropheus,* and a mega-losaurid dinosaur have also been recorded here (Hamilton, 1977; Storrs and Gower, 1993; Storrs, 1994; Benton and Spencer, 1995; Storrs *et al.,* 1996).

The *Pecten* beds in the Westbury Formation have yielded a limited fauna of invertebrate body and trace fossils, including the bivalves *Pleurophorous elongatus, Rhaetavicula contorta* and *Cblamys valoniensis,* ophiuroids, and the inarticulate brachiopod *Orbicula townshendi.* Vertebrate fossils are often found in these limestones, but rarely occur in the intervening shales (Hamilton, 1977).

The Cotham Member preserves a distinct flora and fauna (Hamilton, 1977) consisting of the liverwort *Naiadita lanceolata,* ostracods, and the branchiopod crustacean *Euestheria minuta.*

Interpretation

Mercia Mudstone Group

Many lines of evidence have been put forward to explain the sequence of dolomitic red mudstones in the upper the Mercia Mudstone Group seen in Aust Cliff. The chemistry of the sediment (its dolomitic nature) and the presence of gypsum and pseudomorphs after halite indicate that deposition probably occurred in ephemeral, hypersaline water bodies (Hamilton, 1977) located within an extensive basin (Talbot *et al.,* 1994). Curtis (1982) described cyclical sedimentation, characteristic of deposition in sabkha environments subject to periods of heavy rainfall alternating with extremely arid conditions. The cycles have distinct phases that represent separate events during the deposition of the sediments as follows:

Phase 1: The blocky red mudstone and variegated mudstone at the base of the cycles (Figure 4.14) and (Figure 4.15)a contain bedded nodular gypsum and has an undulating upper surface. The red, fine-grained material accumulated when wind-blown material stuck to the damp sediment surface (produced by a high water table, surface run-off or dew). The growth of gypsum within the profile caused distortion of the surrounding sediments, thus causing the undulating surface.

Phase 2: A phase of erosion scouring the top of the variegated mudstones.

Phase 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 by the subsequent floods, and the voids left in the sediment were haled with coarser-grained material.

The gypsum in the Mercia Mudstone Group was formed by a variety of processes: the bedded nodular gypsum (Figure 4.15)b was precipitated from hypersaline groundwater, and the associated anhydrite may have been deposited as a primary mineral, or it may represent an early diagenetic replacement phase, or be a product of deep burial. Other minerals, for example celestite and calcite, may also be the result of primary sedimentological processes or secondary diagenesis (Curtis, 1982). Wright *et al.* (1988) and Talbot *et al.* (1994) consider the gypsum to be a result of pedogenic processes: the vertically orientated veins mark the position of roots within the soil profile. Alternatively, the vertical V-shaped structures could be gypsum infills of large-scale polygonal structures, a feature sometimes seen in the Triassic red mudstones associated with evaporites, and caused by thermal contraction (Tucker and Tucker, 1981).

The sandstone beds in the Blue Anchor Formation are interpreted as the deposits of flood events that originated in the upland areas surrounding the basin. Generally, the sediments accumulated in the basin through a combination of aeolian and lacustrine processes (Talbot *et al.,* 1994). The colour change from the red mudstones to the blue-green-grey Blue Anchor Formation has a number of possible explanations (Hamilton, 1977). The red coloration is from ferric oxides (haematite and goethite), while the green colour is caused by ferrous oxides, and the red gave rise to the green during the reduction of the ferric oxides. However, it is not clear whether the colour difference is primary, perhaps caused by a switch from primarily continental to primarily marine conditions of deposition, or whether it is diagenetic and secondary.

The Aust Bone Bed

Many theories have been put forward to account for the formation of the Aust Bone Bed, ranging from mass mortality events to reworking of preexisting fossil accumulations. For example, Jukes-Brown (1892) thought that the animals had died catastrophically when they swam into the hypersaline waters of the Mercia Mudstone lakes and lagoons. Wickes (1904), on the other hand, thought that the bone bed represented the location of a massive feeding frenzy of marine animals; the remains of their meals fell to the sea floor as pieces of carcass or as faecal pellets. Physical processes seem more likely. Storm activity was proposed by Short (1904) and MacQuaker (1994) and wave action by Donovan (1955). At Aust, the bone beds may have had tiers of oxygenated and oxygen-deficient sediment, as shown by the trace fossils. The large intraformational clasts are thought to have been produced by reworking during successive flooding events. MacQuaker (1994) concluded that the bone bed represents a transgressive lag deposit that forms a parasequence boundary. The bone bed lithofacies was formed in areas with little clastic input, but significant reworking of older materials; formation began and continued as the sea level rose, and ended with the deposition of argillaceous sediments.

The presence of marine and terrestrial vertebrate remains with a range of taphonomic characteristics (Storrs, 1994) suggests that the vertebrate material was sourced from a wide area and that reworking was a significant process in the formation of the bone bed. Trueman and Benton (1997) suggested that the Aust Bone Bed represents a 'frozen' flow of sediment and fluid. The dense apatite clasts, including the bone material, sank through the soupy mud matrix to the bottom of the flow, while the Blue Anchor Formation clasts remained at the top. Finally, fine-grained clays were deposited as a drape over the surface of the bone-bearing bed. Trueman and Benton (1997) suggested that a very high-energy fluid flow, probably generated by a storm event, was responsible for the reworking of the bone material and producing the rip-up clasts. The evidence provided by the analysis of the REE in the sediments and mineralizing crystals of the bones, and the absence of any other rip-up clasts, indicates that the bones were reworked from beds stratigraphically close to the Blue Anchor Formation (Trueman and Benton, 1997).

As a whole, the Westbury Formation was deposited in relatively shallow water environments (MacQuaker *et al.,* 1985; MacQuaker, 1994) subject to a series of transgressions and regressions. The overlying Westbury Formation was deposited under lagoonal conditions with periods of emergence.

The two varieties of the Cotham Marble formed under very different conditions: the 'Landscape Marble' represents the development of algal mats characteristic of an intertidal environment, while the 'Crazy Marble' was formed when channels or runnels were infilled with brecciated sediment (Hamilton, 1961; Wright and Mayall, 1981). The intertidal or lagoonal environment is supported by the remains of liverworts, which are terrestrial bryophytes (Hamilton, 1977).

At the top of the Aust Cliff section the Lias Group represents deposition in shallow marine waters (Hamilton, 1977).

Comparison with other localities

During the mid 1990s, excavation for construction materials for the Second Severn Crossing created a new section of the Mercia Mudstone and Penarth groups near Aust Cliff. At this new locality, Manor Farm [ST 574 896], sediments of Norian to Rhaetian age described by Radley and Carpenter (1999) were exposed in two large pits in fields behind the Aust Service Station. This locality was easy of access; the strata were exposed in small faces that could be readily climbed, in contrast with the high cliffs at Aust.

The temporary excavations at Manor Farm exposed the highest *c.* 1 m of the Twyning Mudstone Formation at the bottom of the pit, overlain by 3 m of grey-greenish silty mudstones of the Blue Anchor Formation. This is overlain by some 3.5 m of dark shale and limestone alternations of the Westbury Formation that are succeeded by the fine-grained, pale Cotham Member limestones, including the Cotham Marble. As at Aust Cliff, the Langport Member is not recognized; however the Pre-*planorbis* Beds are represented by flaggy brownish limestones (Radley and Carpenter, 1999). Part of this succession remained visible in October 2001 (G. Warrington, pers. comm.).

The Aust Bone Bed was well exposed at Manor Farm, and occupied scour hollows in the top of the Blue Anchor Formation.

Lithologically, it is very similar to that seen at Aust Cliff, and contains clasts of Blue Anchor Formation mudstone, quartz pebbles, and vertebrate remains, including ichthyosaur, plesiosaur, and possible theropod bones, as well as shark fin spines and coprolites. Invertebrate body and trace fossils (Radley and Carpenter, 1999) include the bivalves *Rhaetavicula contorta* and *Pleurophorous elongatus* and the trace fossils *Lockeia siliquaria* and *Archarenicola rhaetica.*

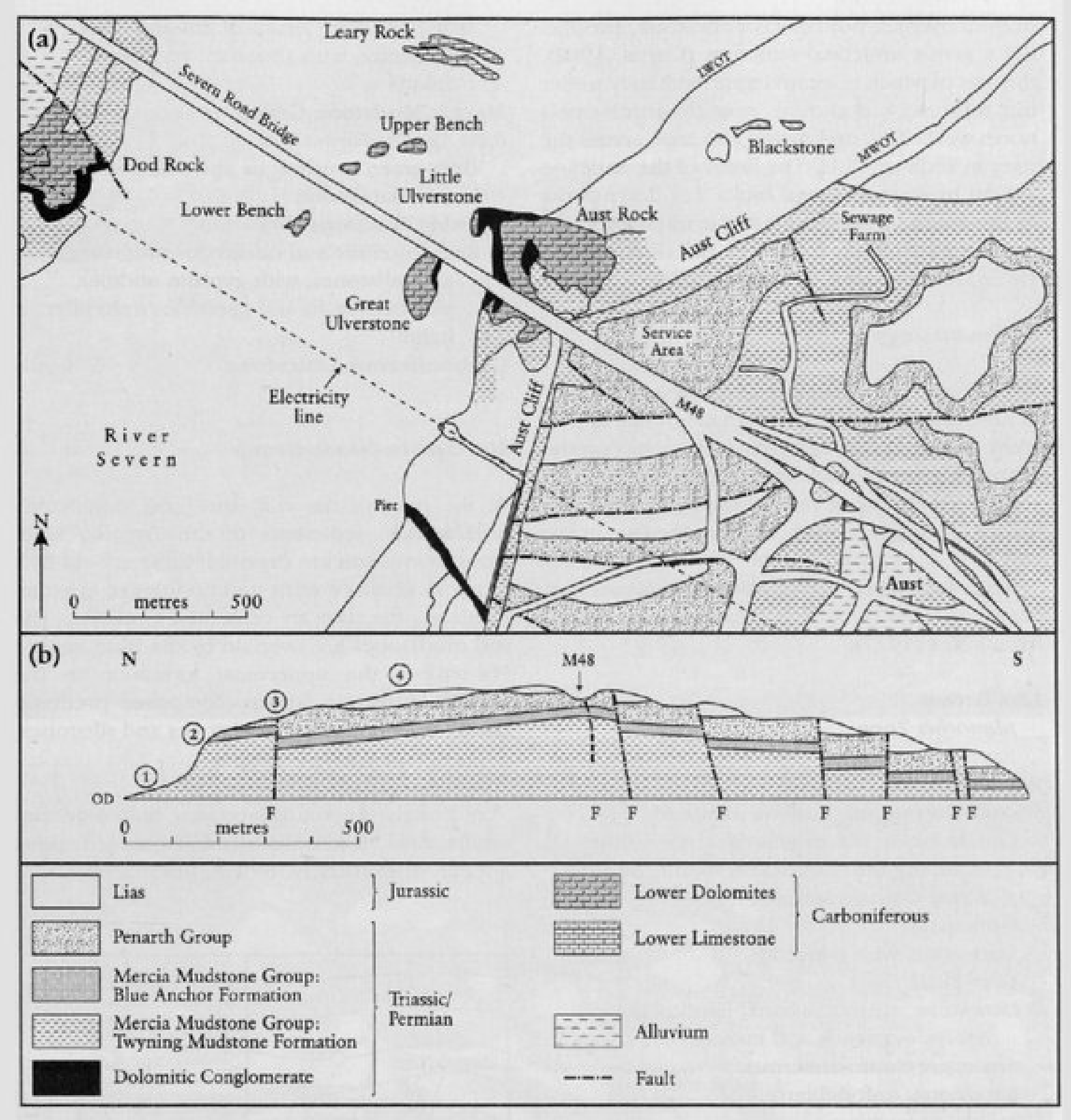
Conclusions

The internationally renowned cliffs at Aust provide one of the best exposures of Upper Triassic sediments in Britain. The lower part of the succession comprises red clays and mudstones of the Twyning Mudstone Formation of the Mercia Mudstone Group. The formation was deposited under dominantly terrestrial conditions in environments similar to modern-day sabkhas and playas.

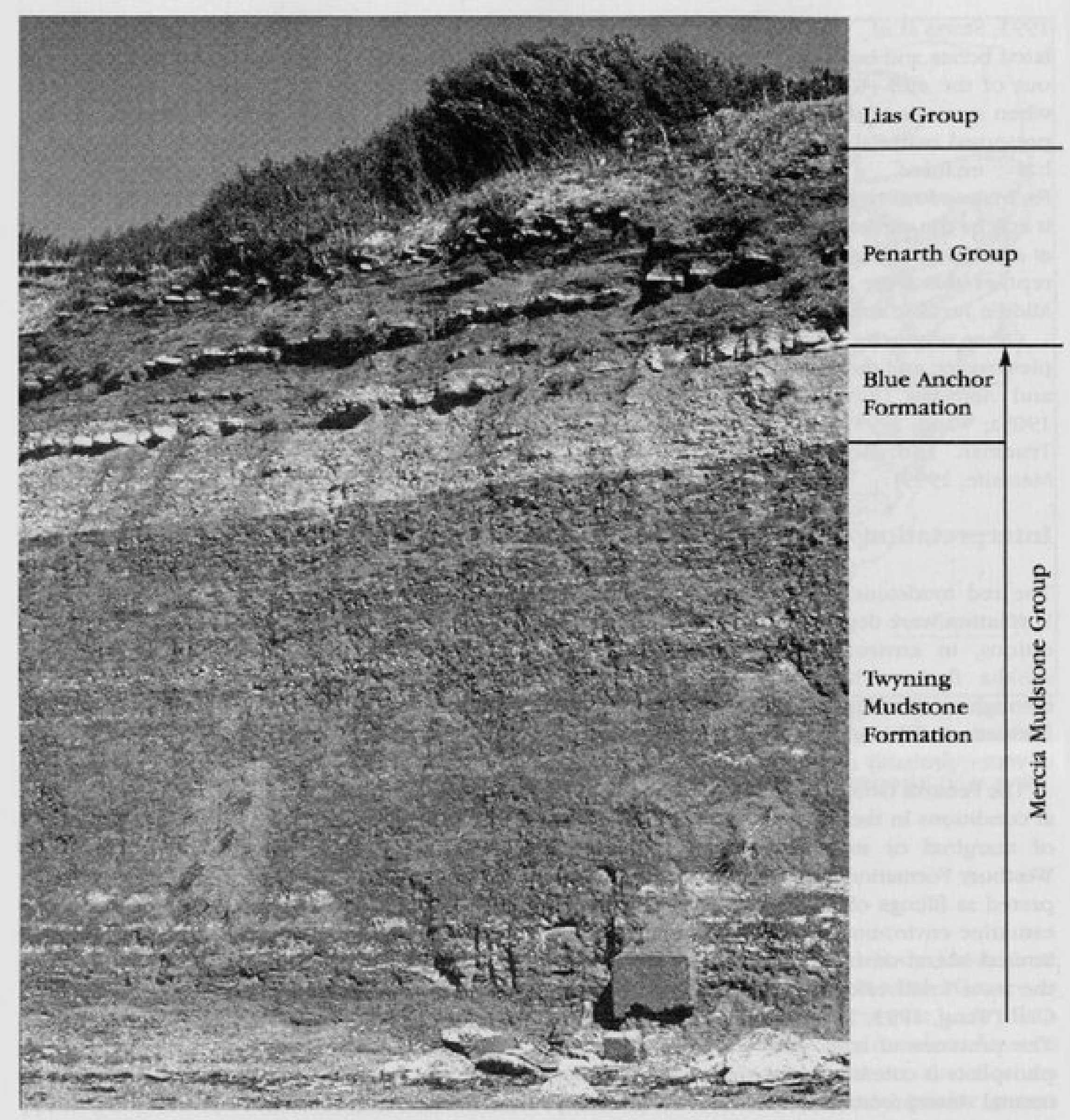
The site is especially important for the fine exposures of the red marls of the Mercia Mudstone Group, with spectacular gypsum beds and enigmatic sub-vertical structures, overlain by the Blue Anchor Formation. Succeeding the Blue Anchor Formation is the Penarth Group, which comprises the marine Westbury and Lilstock formations. The succession is capped by the lowest beds of the Has Group

Aust Cliff is world-famous for the Aust Bone Bed, a discontinuous, coarse-grained, transgressive lag deposit rich in vertebrate fossils that comprise one of the most diverse Late Triassic faunas in Europe.

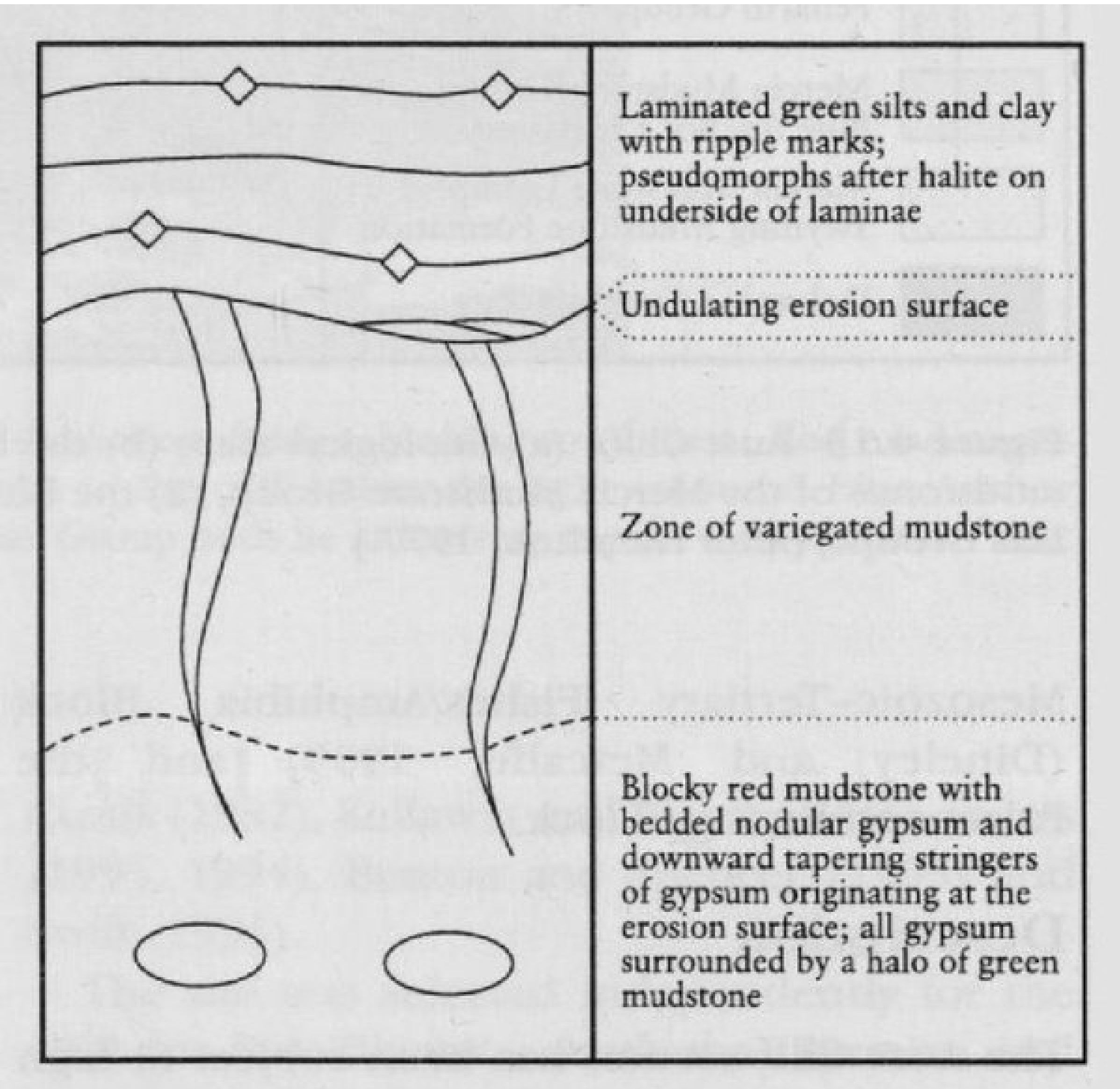
References



(Figure 4.13) Aust Cliff. (a) Geological map; (b) the broad anticlinal structure, and the succession of (1) red mudstones of the Mercia Mudstone Group, (2) the Blue Anchor Formation, (3) the Penarth Group, and (4) the Lias Group. (After Hamilton, 1977.)

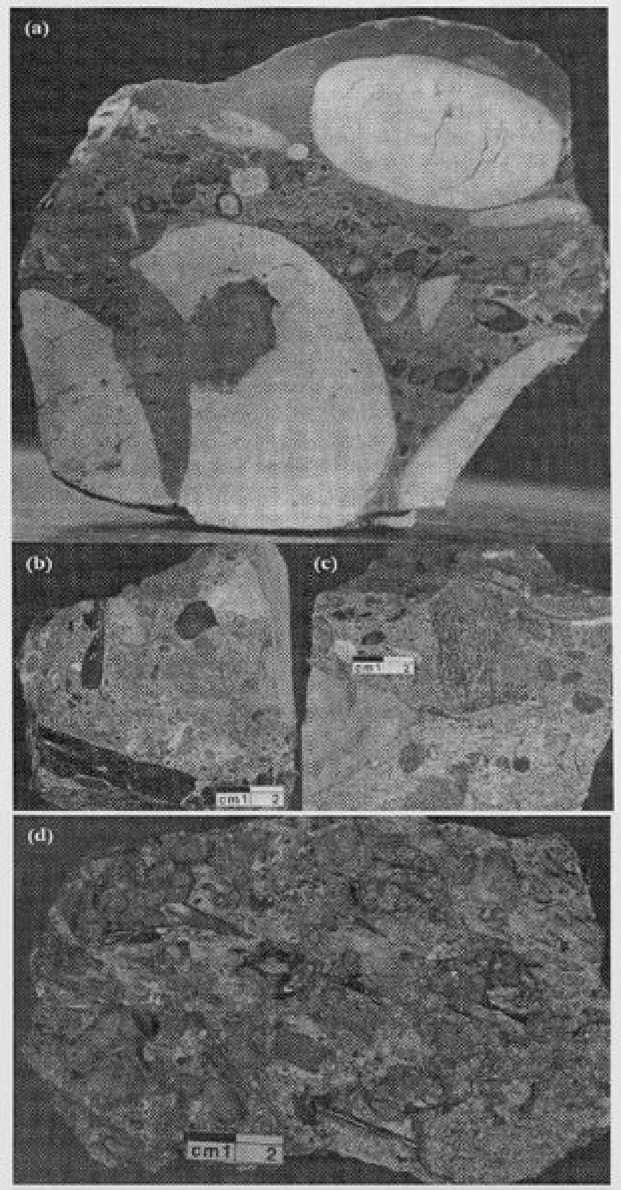


(Figure 4.12) Aust Cliff: view on the north-eastern side of the Severn Bridge, looking south-east. Red mudstones of the Mercia Mudstone Group form the lower two-thirds of the cliff, below the light coloured Blue Anchor Formation, above which lies the Penarth Group. Basal Lias Group beds lie at the very top, in the vegetation line. (Photo: Andrew Swift.)



(Figure 4.14) Idealized sedimentary cycle in the Mercia Mudstone Group at Aust Cliff. (After Curtis, 1982.)

(Figure 4.15) Gypsum deposits in the red mudstones of the Mercia Mudstone Group in the lower portions of the Aust Cliff section. (a) Deep V-shaped fissures filled with gypsum, perhaps forming parts of large-scale polygons. (b) Nodules and veins of gypsum. (Photos: M. J. Benton.)



(Figure 4.4) Cut sections through two basal 'Rhaetic bone beds', (a–c) from Aust Cliff. In cut section (a), about 15 cm wide, the large rounded objects are clasts of Blue Anchor Formation. The smaller, dark objects between are phosphatic nodules, coprolites and rolled bone fragments. In (b), a surface view, the elongated black objects are probably ribs of marine reptiles, and the squarish element could be part of a limb bone. Smaller black objects are fish scales and teeth, and other lighter pieces are nodules. In (c) there is a vertical cut section of a large bone (top, centre). (Photos courtesy C.N. Trueman.) (d) The surface shows numerous well-preserved elongate bones of the small reptile Pachystropheus, showing weak current alignment. Other clasts include coprolites (e.g. immediately above the scale bar), some larger, abraded, bone fragments (far left, middle) and inorganic phosphate nodules. White patches of crystalline pyrite occur in association with the bones; the matrix is 70% disseminated pyrite. (Photo courtesy C.N. Trueman)