Westbury Garden Cliff, Gloucestershire

[SO 719 129]

Introduction

Westbury Garden Cliff (simply 'Garden Cliff' in the GCR Unit records) exposes the Mercia Mudstone Group, Penarth, and Lias groups. This site is especially important for the Penarth Group bone bed that preserves fossils of exceptional quality, as well as for the associated trace fossils that are much richer than at other sites, and give detailed evidence on palaeoenvironment.

The first report on Westbury Garden Cliff was by Conybeare and Phillips (1822). Subsequent accounts include Brodie (1845, 1858), Wright (1860), Etheridge (1865, 1872), Lobley (1875), Richardson (1903a), Sykes (1977), and Green (1992). Descriptions of the palaeontology include Richardson (1903a), Benton and Spencer (1995), Storrs *et al.* (1996) and Dineley and Metcalfe (1999). Trueman and Benton (1997) presented an account of the geochemical taphonomy of the 'Rhaetic Bone Bed' from this section.

Description

Westbury Garden Cliff is on the north bank of the River Severn, some 9 km south-west of Gloucester. The cliff reaches a height of 21 m at the downstream (western) end, and exposes a 1-km-long section of Upper Triassic and Lower Jurassic sediments (Figure 4.10). The beds dip gently south-east and the Mercia Mudstone Group is exposed in the downstream part of the section; the Westbury Formation is seen at the upstream end of the section (Wang, 1993; Storrs *et al.,* 1996). Natural erosion keeps the site free of vegetation, although beds at the top of the cliff are generally inaccessible (Swift, 1995). The base of the cliff is covered by estuarine waters at high tide. Where the Mercia Mudstone Group forms the base of the cliff tidal erosion is generally uniform, and produces a smooth base, which tends to undercut the overlying Westbury Formation, resulting in occasional rockfalls. Where the Penarth Group forms the base of the cliff; exposure is less uniform, as beds such as well-cemented sandstones are more resistant to erosion (Reynolds, 1906; Storrs *et al.,* 1996).

In the literature, the site is referred to as 'Westbury-on-Severn' (Sykes, 1977), 'Garden Cliff' (Etheridge, 1865; Swift, 1995; Storrs *et al.,* 1996), and 'Westbury Garden Cliff' (Trueman and Benton, 1997). The first mention of the 'Westbury Beds' was by Wright (1860) who used it to describe the dark-coloured shales and subordinate sandstones. The unit was formalized as the Westbury Formation by Warrington *et al.* (1980).

Sedimentology

The sedimentary log given here is modified from those of Richardson (1903a) and Sykes (1977, pp. 206–9):

	Thickness (m)
Lias Group	
Limestone, grey and blackish-blue, hard	0.05
Penarth Group	
Lilstock Formation ('Upper Rhaetic' of Richardson, 1903a):	
Brown and grey, calcareous, thinly laminated shales:	0.56
Ia: 'Insect Limestone', limestone, blue-grey to light brown, top 0.02 m fissile	0.06
Ib: limestone, blue-grey to light brown, conchoidal fracture	0.06
IIa: shales, grey, laminated, marly	1.82
IIb: sandstone, pyrite-rich, non-calcareous	0.01
IIc: shales, grey, laminated	0.28

IId: sandstone, calcareous, pyritic, ripples	0.01
IIe: shales, grey, marly, poorly laminated	0.18
Limestone,'*Euestheria*-bed' (Etheridge's bed 14, '*Estheria* Zone')	0.30
Shales, grey, manly, with conchoidal fracture	1.68
Westbury Formation (Tower Rhaetic' of Richardson, 1903a):	
Shales and limestone (Etheridge's bed 12, with Lower and Upper *Pecten* Beds):	
(a) black shales, poorly laminated, selenitic; sandstone (calcareous and pyritic) 0.12m from top	0.86
(b) limestone, sandy in places	0.01
Interbedded calcareous and pyritic sandstone and black laminated shales	1.25
Limestone, hard, blackish-blue, slightly pyritic	0.02
Shales, black, laminated. Grey, micaceous, calcareous sandstone layers near the base and 0.30m below top	0.66
Shales, black, thinly laminated	0.55
Shales, black, imperfectly laminated	0.10
Sandstone, with black shale at middle of bed	0.05
Shale, black, fissile, with some layers of white silt	0.5
Bone bed, 1 to 4 layers, pyritic, bedded, crystalline on the upper surface, with layers of medium-grained sandstone with vertebrate fossils	0.025
Shale, black, fissile, and thin, grey, calcareous siltstones and thin Limestones	0.45
Sandstone (' Upper *Pullastra* Bed'). The upper (finer-grained) part contains minute phosphatic fragments. The lower medium-grained sandstone has more, and proportionally larger, fossils	0.30
Shale, black, fissile and calcareous, with bivalves and some layers of siltstone	0.61
Siltstone ('Lower *Pullastra* Sandstone'); calcareous, micaceous, slightly pyritic, light grey, weathers into two laminae, the lower is a bone bed	0.13
Shale, black and fissile, divided into:	
(a) shale with bivalves and sandy patches, with some bone bed constituents	0.1
(b) shale with some fine-grained sand patches	0.15
(c) shale without sand. Silt patches, flakes and pellets of Blue Anchor Formation mudstone in lowest 0.025 m	0.15
Bone bed: a coarse- and fine-grained sand with large and small fossils including bones and coprolites, and fragments of Blue Anchor Formation mudstones. Discontinuous over short distances	0.05
Mercia Mudstone Group	
Blue Anchor Formation:	
Greenish-grey marls, weathering bluish and yellowish-grey and white; conchoidal fracture	5.49
Twyning Mudstone Formation	

Red marls, with zones of grey and bluish-grey; angular fracture with rarer conchoidal and cuboidal fractures; very thin veins of gypsum	22.25

The Mercia Mudstone Group succession comprises red mudstones and marls of the Twyning Mudstone Formation. These argillaceous lithologies are commonly cut by vertical gypsum veins and in places are laminated or show rippled surfaces. The overlying Blue Anchor Formation is green or grey when freshly exposed but when weathered it acquires a yellowish or bluish tinge (Richardson, 1903a). These beds dip to the south-east at about 2°.

Fossils, especially the remains of fish and coprolites, appear in the Penarth Group. There are two bone-bearing levels, one at the base of the formation, the other some 2 m above the base and 0.4 m above the 'Upper *Pullastra* Bed' (Richardson, 1903a,b; Reynolds and Vaughan, 1904; Storrs *et al.,* 1996). This discontinuous bone-bearing unit varies in thickness and is approximately 0.03 m thick; it is composed of pyrite-rich, shelly silt or sandstone with mud laminations (Figure 4.4)d. Euhedral unabraded pyrite crystals are commonly scattered across the basal surface of the layer, and the matrix consists of approximately 70% disseminated pyrite. Vertebrate remains, coprolites, and nodules occur throughout the bed and quartz grains occur sporadically (Storrs *et al.,* 1996; Trueman and Benton, 1997). The upper and lower surfaces of the bed often show ripples; on the upper surface, argillaceous sediments may infill small channels. Bones are exquisitely preserved on the lower surface of the bed and may show evidence of poorly developed current alignment (Figure 4.11). The bone beds all contain large quantities of vertebrate remains, as well as quartz pebbles, intraformational mud clasts, and pyrite (Richardson, 1903a; Wang, 1993).

Above the bone beds, the Westbury Formation comprises dark shales with sandstones and limestones, which are often especially fossiliferous. In places, the top surfaces of the sandier units are covered with shells and may also preserve trace fossils, seen for example on the upper surface of the 'Upper *Pullastra* Bed' (Wang, 1993).

At the top of the cliff section, the Lilstock Formation comprises alternations of pale shales, grey, brown, or blue-grey limestones and occasional sandstones. Many of the beds show primary sedimentary structures such as laminations and ripples. Of note are the 'Insect Limestone' and *Tuestheria* Bed', both remarkably rich in fossils (Richardson, 1903a).

Palaeontology

Many invertebrate trace and body fossils have been recorded from the Penarth Group in Westbury Garden Cliff Invertebrate body fossils include rare and fragmentary remains of insects and gastropods from beds in the Cotham Member, and several species of bivalve genera such as *Ostrea, Protocardium,* and *Pecten,* many of which are preserved as isolated shells and are commonly pyritized (Wang, 1993), and the inarticulate brachiopod *Lingula* (Richardson, 1903a; Wang, 1993).

Many of the bed boundaries show evidence of bioturbation, and several ichnogenera have been identified. Beds in the lower part of the Westbury Formation show well-defined *Diplocraterion* burrows that have been infilled with the overlying black argillaceous sediment; also present are *Skolithos* traces (Wang, 1993).

The locality has received international attention for the large numbers of well-preserved *Pachystropheus* remains (Storrs and Gower, 1993; Storrs *et al.,* 1996),most of which are isolated bones and bone fragments that weathered out of the cliff (Wickes, 1904) or were found when sections of the cliff collapsed. The well-preserved material from Westbury Garden Cliff has enabled a thorough analysis of *Pachystropheus* to be completed, indicating that it may be the earliest known choristodere (Storrs *et al.,* 1996), a group of extinct, aquatic diapsid reptiles that were previously first known from Middle Jurassic strata.

Other vertebrate fossils include ichthyosaurs, plesiosaurs, and the fishes *Gyrolepis, Ceratodus,* and *Acrodus* (Etheridge, 1865; Richardson, 1903a; Wang, 1993; Benton and Spencer, 1995; Trueman and Benton, 1997; Dineley and Metcalfe, 1999).

Interpretation

The red mudstones of the Twyning Mudstone Formation were deposited under terrestrial conditions, in environments similar to modern sabkha flats. These conditions continued throughout the deposition of the Blue Anchor Formation, although the importance of influxes of water, probably marine, increased.

The Penarth Group marks the end of terrestrial conditions in the area, and the establishment of marginal or marine environments. The Westbury Formation bone beds have been interpreted as fillings of shallow channels within an estuarine environment, a view supported by the limited lateral development of the horizon and the trace fossil assemblage at Westbury Garden Cliff (Wang, 1993; Trueman and Benton, 1997). The presence of large quantities of pyrite and phosphate is consistent with this palaeoenvironmental interpretation. The bones probably accumulated as some form of winnowed channel lag deposit (Trueman and Benton, 1997), or possibly as a shoal or strandline deposit (Storrs *et al.,* 1996).

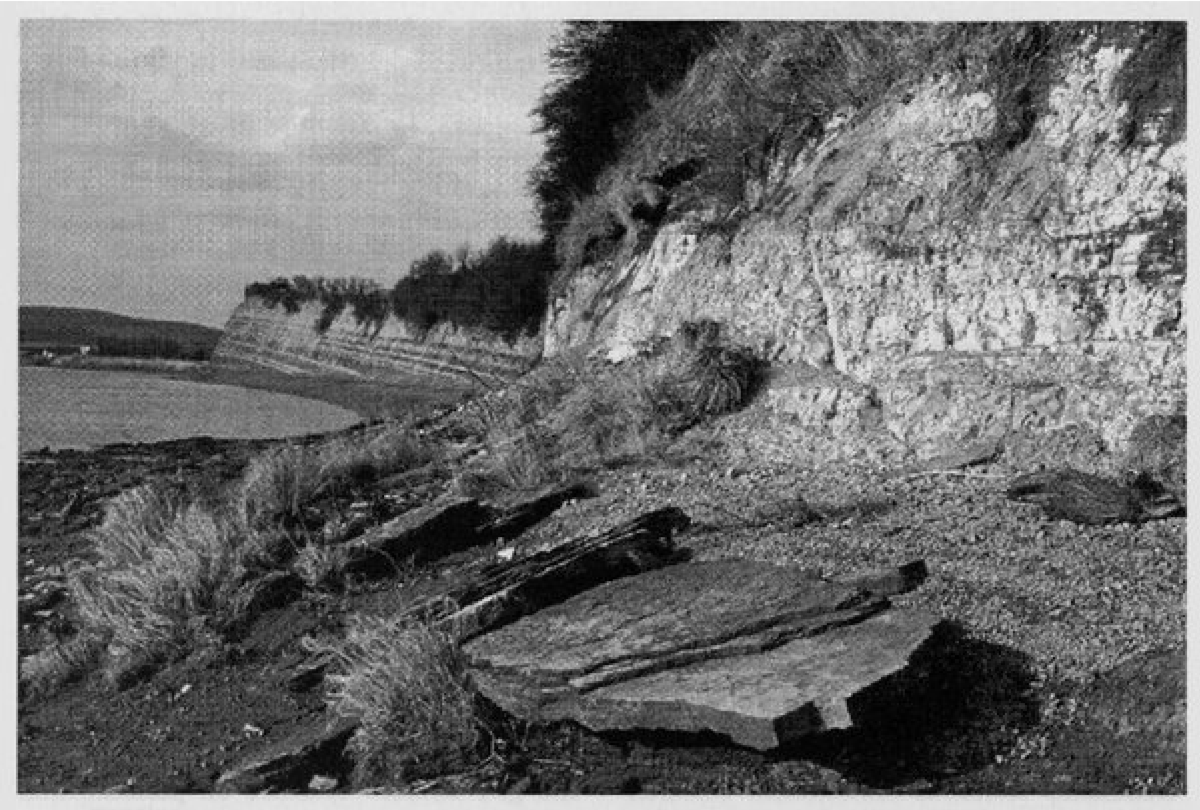
Analysis of the rare earth elements (REE) in the minerals preserving the bones at this site indicate that chemically there is little to separate them from the bones at Aust Cliff (see below), although the REE signatures of the associated sediments are distinct. This suggests that the two bone accumulations experienced similar early diagenetic processes, and that the Aust Cliff material probably originated in a bone bed similar to the one preserved at Westbury, but was then reworked (Trueman and Benton, 1997).

The remainder of the Westbury Formation is dominated by fine-grained sediments, indicative of shallow marine conditions. At the top of the section, the Cotham Member indicates marine conditions, but with evidence for fresh water and for subaerial exposure at some levels.

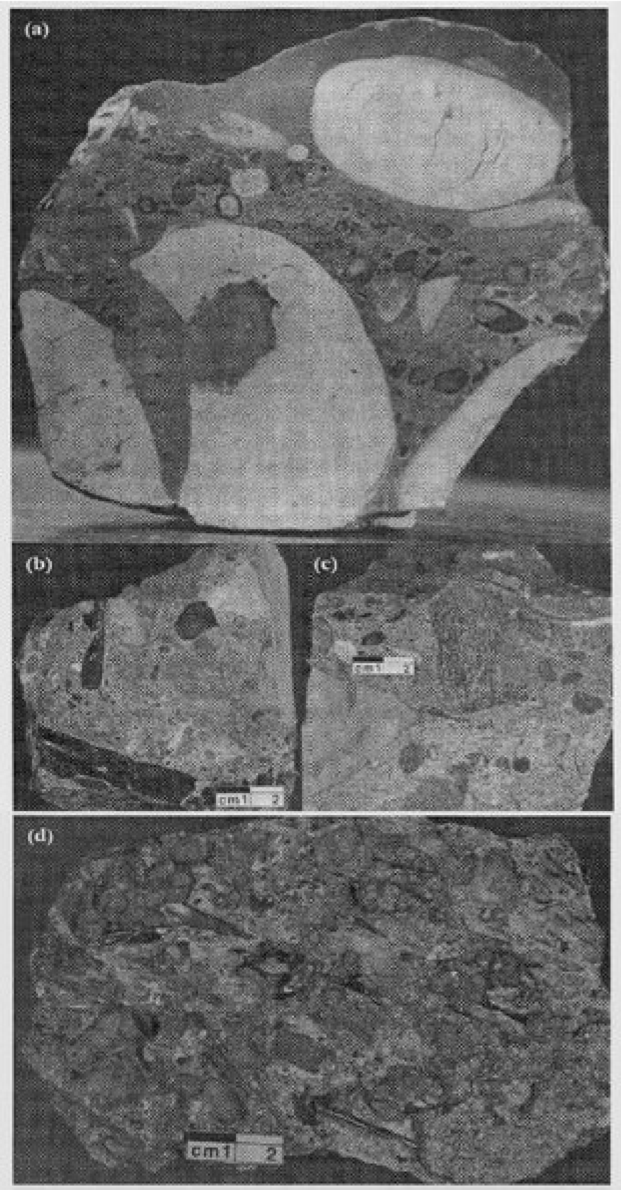
Conclusions

Westbury Garden Cliff provides an important sedimentological record of changing environments from terrestrial, hypersaline sabkha plains (Mercia Mudstone Group) to shallow marine (Penarth Group). Fossils, including invertebrate body and trace fossils, as well as vertebrates such as fishes, ichthyosaurs, and plesiosaurs are commonly preserved in the Penarth Group. Of great significance are the bone-bearing horizons, which have gained international fame as rich sources of vertebrate fossils, especially the choristodere *Pachystropheus.*

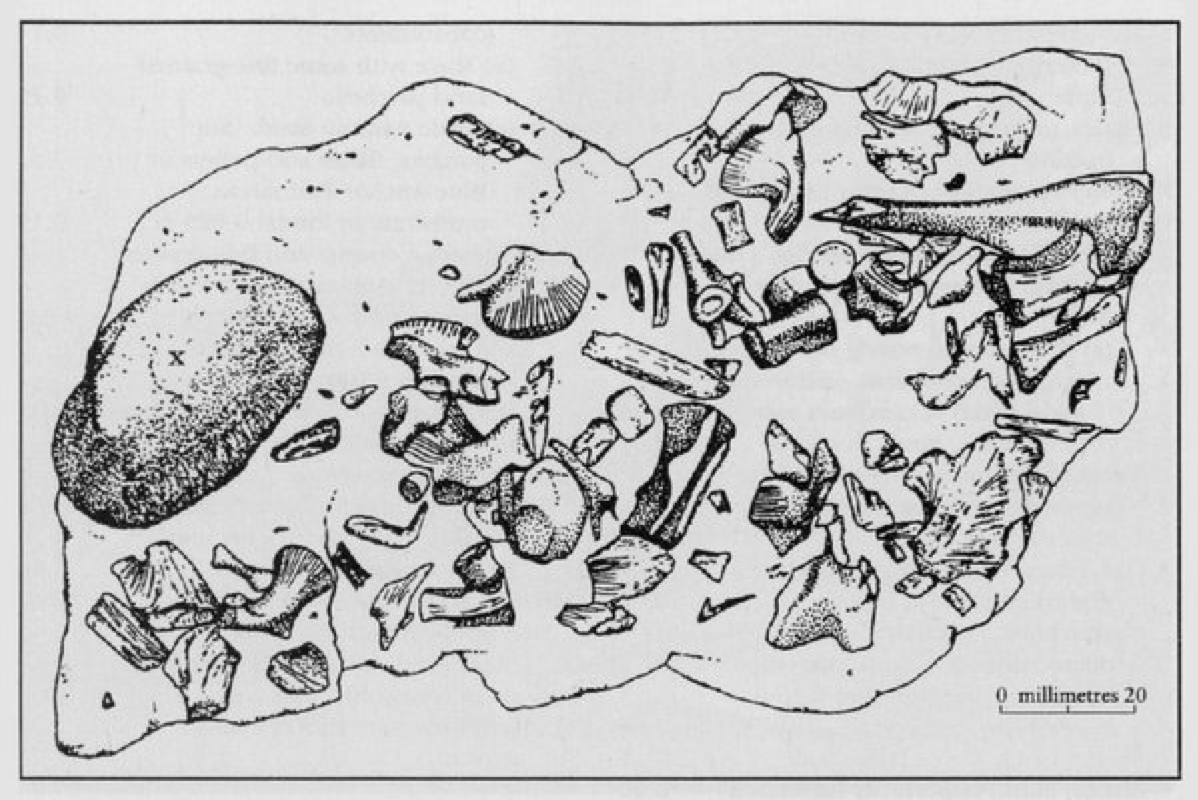
References



(Figure 4.10) Westbury Garden Cliff, looking downstream (westwards) showing loose blocks of phosphate-rich calcareous sandstone from the Westbury Formation Bone Bed on the shore, and Blue Anchor and Westbury formations in the cliff, the latter obscured by vegetation. (Photo: Andrew Swift.)



(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)



(Figure 4.11) A slab of the basal bone bed from the Westbury Formation, Westbury Garden Cliff (Bristol City Museum, Geology Ce17770), containing a scatter of unabraded small bones from the aquatic reptile Pachystropheus, with some evidence of current alignment. A large, abraded plesiosaur epipodial (x) is at the left end. (After Storrs, 1994.)