Chapter 4 British Penarth Group sites

Introduction

The Penarth Group, formerly the 'Rhaetic', represents a dramatic change in sedimentation style throughout the British Isles and much of western and central Europe at the end of the Triassic Period. The mainly continental, red and yellow mudstones and sandstones of the Germanic Keuper, and of the Mercia Mudstone Group, come to an abrupt halt, and are succeeded by grey, marine mudstones, limestones, and sporadic, thin, bone beds. This change has long been interpreted as reflecting a major marine transgression that apparently flooded much of north-west and central Europe a few million years before the end of the Triassic Period.

A number of GCR sites that show the highest part of the Mercia Mudstone Group, including red beds, also contain strata of the succeeding Penarth Group (see (Figure 3.1)). Their inclusion in the present volume is justified on the grounds that it provides an appropriate conclusion to the account of British Triassic continental sedimentation.

Stratigraphy

The term 'Penarth Group' was introduced by Warrington *et al.* (1980) as a formal lithostratigraphical name for the rocks formerly called 'Rhaetic' in Britain, where it comprises the formations between the Mercia Mudstone Group and the base of the Lias Group. These formations are the Westbury Formation and the succeeding Lilstock Formation. The latter is formally subdivided into the Cotham and overlying Langport members. The relationships of these units to the older informal stratigraphy of the 'Rhaetic' is summarized in (Figure 4.1), and two typical Penarth Group successions are shown in (Figure 4.2), contrasting the styles of sedimentation in Somerset and Devon, and illustrating the current and former lithostratigraphical terminology.

The term 'Rhaetic' was based on the German 'Rhät' or 'Rhätkeuper', derived from the first identification of these rocks in the Rhaetic Alps in the 1820s and 1830s. The 'Rhaetic', as a localized rock unit in north-western Europe, was equated with the Rhaetian Stage, a chronostratigraphical unit that was defined biostratigraphically and identifiable worldwide. Like the other Triassic stages, the Rhaetian Stage was based on the marine Triassic sequence of the Alps, with its type section at Kendelbachgraben, St Wolfgang, Austria. Formerly, the Rhaetian stage was commonly included within the Jurassic System (e.g. Arkell, 1933), although it has been definitively and uniformly accepted as the last stage of the Triassic System since 1962.

Tozer (1967) presented detailed ammonite evidence for dating of the Triassic stages, and proposed a global stratotype section for the base of the Rhaetian Stage at Brown Hill, Peace River, north-east British Columbia, Canada.

The Westbury Formation overlies the Blue Anchor Formation, the uppermost unit of the Mercia Mudstone Group, usually unconformably. In many places, a thin, laterally imper-sistent bone bed, the famous 'Rhaetic bone bed', occurs at the base of the Westbury Formation. The remainder of the formation consists of dark grey mudstones or shales with subordinate thin limestones and sandstones. The formation was formerly termed the 'Westbury Beds' or 'Black Shales', and it corresponds approximately to the *contorta* Zone or Lower Rhaetic of various authors. The type area for the formation is the coastal section at Penarth and immediately north of Lavernock Point, South Glamorgan.

The overlying Lilstock Formation is bounded below by the Westbury Formation, and above by the base of the 'Paper Shale' of Richardson (1911). The lower part of this formation, the Cotham Member, is equivalent to the 'Cotham Beds', and the overlying Langport Member is equivalent to the remaining units below the 'Paper Shale'. The Langport Member shows considerable facies variation, with thick limestones (White Lias') in South Devon and Mid-Somerset, passing laterally into a thin limestone representative in West Somerset and South Wales and parts of the Midlands (Swift, 1995).

The Pre-*planorbis* beds and the Triassic–Jurassic boundary

The position of the Triassic–Jurassic boundary has been a subject of debate for many years (see, for example, Pearson, 1970; Orbell, 1973; Morbey, 1975; Poole, 1979; Hallam, 1990, 1994; Hodges, 1994; Warrington *et al.,* 1994).

Up to 1980, the base of the Jurassic System in Britain was traditionally taken to be the base of the Lias Group, the succession of generally grey-coloured mudstones and limestones so characteristic of the Lower Jurassic Series throughout much of Europe. This interpretation placed the boundary at the base of the lithologically defined 'Blue Lias', in particular placing the Pre-*planorbis* Beds (see (Figure 4.1)) in the Jurassic System. However, this characterization of the base of the system in Britain was purely lithological, and a formal, biostratigraphical definition was required.

Since 1980, the base of the Jurassic System has been placed at the first appearance of the ammonite genus *Psiloceras,* and the species *P. planorbis* in particular, which thereby marks the base of the Hettangian Stage (Cope *et al.,* 1980; Warrington *et al.,* 1980). This view was not uniformly accepted (see, for example, Hallam, 1981), but international agreement now indicates that the Pre-*planorbis* beds of the Blue Lias are of Triassic, not Jurassic, age (Warrington *et al.,* 1994; Warrington and Ivimey-Cook, 1990).

Sedimentology

The Rhaetian transgression

The Penarth Group reflects the widespread establishment of marine environments following a transgression that spread northwards through central and north-western Europe into Britain (Figure 4.3). At the same time, there was major rifting and volcanism in southern Europe, North Africa, and eastern North America, as proto-North Atlantic rifting opened up linear structures parallel to the current coastline of eastern North America, from North Carolina to Nova Scotia where thick lacustrine sediments of the Newark Supergroup accumulated.

The marine rocks of the Penarth Group succeed the greyish and greenish, dolomitic mudstones of the Blue Anchor Formation, formerly the 'Tea Green Marls' and 'Grey Marls', the highest formation in the Mercia Mudstone Group. Geochemical and palaeontological evidence of marine conditions are seen in the upper Mercia Mudstone Group (Warrington and Ivimey-Cook, 1995). These marine influences in the upper Norian in the UK were followed by full-scale marine conditions in Rhaetian times.

The Penarth Group sediments mark the marine transgression proper. The top of the Blue Anchor Formation is often intensely burrowed, and clasts of Blue Anchor Formation mudstones commonly occur in the basal Westbury Formation. The unconformable base of the Penarth Group is also marked here and there by bone-rich arenaceous units, the 'Rhaetic bone beds', and these are overlain by beds containing marine fossils such as oysters, pectinid bivalves, and echinoids (Ivimey-Cook, 1974).

The timing of the transgression is unclear in Britain. It appears to have occurred rapidly, perhaps sweeping from the south to the north, but there is no independent evidence of dating. Kent (1970) suggested that the whole of the Midlands was inundated almost simultaneously. After the initial flooding, dark shales of the Westbury Formation accumulated. This facies is typical of the English Penarth Group, and is also seen throughout the region of the transgression, from the Alps to the Baltic (Kent, 1970). The black shales throughout this whole area contain a limited fauna, predominantly the bivalve *Rhaetavicula contorta,* hence the former name of the unit, the '*contorta* Zone'. *Rhaetavicula* is a specialized epifaunal bivalve that was presumably adapted to unfavourable conditions, particularly anoxic bottom waters, evidenced by the black colour of the shales and by associated pyrite.

The Westbury Formation bone beds

There are bone beds at several horizons in the Westbury Formation, not just at its base. In all cases the bones are heavily phosphatized and may be in superb and apparently unworn condition, or extensively rolled and abraded (MacQuaker, 1994, 1999; Storrs, 1994; Trueman and Benton, 1997; Martin., 1999). The contrast in styles of preservation is best brought out by a comparison of material from the bone beds at Westbury Garden Cliff, on the north bank of the River Severn, and Aust Cliff, on the south (Trueman and Benton, 1997; see (Figure 4.4)).

The horizon of the bone bed at Westbury Garden Cliff is hard to determine because of poor exposure. It occurs in a 20–30-mm-thick shelly sandstone, with mud laminations, and abundant pyrite crystals. Apatite fragments (heavily phosphatized bones, teeth, fish scales, phosphatic nodules, coprolites) occur uniformly throughout the bed, with no evidence of grading, and other clasts are quartz fragments, but there are no rip-up clasts of the underlying Blue Anchor Formation. The limited lateral extent of this bone bed suggests that it may represent a shallow channel in an estuarine environment. This is confirmed by the trace fossil assemblage (Wang, 1993) and the anoxic sediments with extensive pyritization and phosphate genesis. The bone bed may be a winnowed accumulation of bone debris in the channel base.

The Aust Cliff bone bed is a discontinuous deposit, varying in thickness from 0–300 mm. It rests on an uneven surface eroded on the Blue Anchor Formation, and has a fine grey carbonate matrix that comprises around 50% of the deposit. The matrix contains numerous clasts of four types: apatite clasts (bones, teeth, copro-lites, phosphatic nodules), rip-up clasts of the underlying Blue Anchor Formation, and lithic clasts of both quartz and Carboniferous limestone. Of these, the first two are predominant. The apatite clasts grade normally, while the rip-up clasts are reverse-graded, presumably the result of the arrest of a turbulent sediment-rich flow. The dense apatite fragments sank through an unconsolidated matrix of carbonate mud, and the less dense mud fragments were suspended within this matrix after flow stopped. The final stages of deposition consisted of settling of fine clays from suspension, leaving a mud drape over the top surface of the bed. The Aust Cliff bone bed arose from a high-energy, storm-driven fluid flow, reworking an area rich in apatite debris, with occasional quartz and limestone lithic fragments.

The Westbury Garden Cliff and Aust Cliff bone beds show physical and chemical evidence of transport. Fossil material in the Westbury Garden Cliff bone bed comprises mainly small platy elements (*Gyrolepis* scales), distributed in thin layers on single laminae, and delicate unabraded remains of the small aquatic reptile *Pachystropheus.* The Aust Cliff bone bed, on the other hand, consists of a mixture of spherical, cylindrical, and platy elements, and most of these clasts are medium or large in size and well rounded. The physical evidence of apatite clasts shows that the Westbury Garden Cliff bone bed was deposited by low-energy currents that had picked up the bones and scales nearby, while the Aust Cliff bone bed consists of bony debris carried some distance by high-energy currents.

Local mapping shows that the two bone beds are of nearly identical age, and the fossil taxa represented in both suggest that the source area for the bone material that was reworked into the Aust deposit was probably similar to that which produced the Westbury Garden Cliff deposit.

The bones and matrix at Aust Cliff contain disseminated euhedral pyrite crystals, and there is abundant phosphate, in the bones and teeth themselves and in numerous phosphatized coprolites and phosphatic nodules. The pyrite and phosphate indicate that the source of the Aust Cliff bone bed materials was a low-energy anoxic environment, since neither mineral could be produced in the high-energy storm beds that are seen at that locality. The physical indicators of transport are confirmed by the geochemistry of the two bone beds (Trueman and Benton, 1997): rare earth elements show that the bones and matrix in the Westbury Garden Cliff bone bed came from the same source, while the Aust Cliff bones came from a source different from their enclosing sediment.

In both cases, bones, spines, teeth, and scales have been swept in by storm activity of some kind. The remains represent aquatic, and presumably marine, vertebrates for the most part (fishes, ichthyosaurs, plesiosaurs, choristoderes), but there are some unequivocal dinosaur bones. Hence, the bone beds indicate a shallow marine setting, confirmed by the associated trace fossils and shelly fossils. Perhaps the transgressing sea swept over the playas and sabkha plains of the Mercia Mudstone Group, engulfing the remains of dinosaurs and other terrestrial fauna, and mixing them with those of fishes and marine reptiles living in the newly expanding sea.

The genesis of the classic bone beds is still debated. Martill (1999) reviewed the five main models for the generation of the basal bone bed:

1. Mass mortality: the idea, proposed first by Buckland (1829), that the accumulation of bones is simply the result of a dramatic mortality event, perhaps caused by anoxia or dramatic salinity changes associated with the transgression. There may be some truth in this idea, but physical processes (numbers 2–5, below) must have had a critical role.

2. Winnowing: the idea that the accumulation of bones was produced by repeated episodes of erosion of the sea floor, and removal of fine debris (Sykes, 1977). This is probably at least a contributory factor, but it does not explain the presence of terrestrial elements.
3. Condensation model: reduced rates of sedimentation would allow bones to make up a greater proportion of the deposit than usual, a model suggested by Richardson (1901) and Wickes (1904). There is no evidence, however, that the bone beds are anything other than short-term accumulations.
4. Diagenetic concentration: bones are concentrated by the selective dissolution of aragonitic and calcitic material. Some bone beds contain shells, so this model cannot apply in those cases, but others contain only lithic and phosphatic debris, and the carbonates may have been removed chemically.
5. Transgressive lag model: the transgressing Rhaetian sea eroded and picked up clasts from existing sediments, and deposited them later as a lag (MacQuaker, 1994). This model is certainly supported by the presence of lithic clasts from the Blue Anchor Formation in the basal Rhaetic bone beds. However, no likely source bed for the abundant vertebrate bones and coprolites has yet been identified (it may have been completely eroded away).

The Lilstock Formation

The black shales of the upper part of the Westbury Formation are overlain by grey-green and grey marls of the Cotham Member of the Lilstock Formation. At most localities, the Cotham Member marls contain small fossil crustaceans (*Euestheria*), which are comparable to modern forms from lakes in Africa. However, marine conditions evidently persisted, since dinoflagellate cysts occur abundantly in the member in Britain, and other marine biota, including bivalves, are also present (Mayan, 1983).

The environment in southern England was probably an extensive inhospitable hypersaline tidal flat. Such conditions are indicated by a range of sedimentary structures in the Cotham Member sediments. In places, domal stromatolites have been reported (Hamilton, 1961), formed by the growth of cyanobacteria and calcareous sediments, and indicating desiccating saline conditions. Locally, these form the famous landscape Cotham Marble in the Bristol district. Desiccation cracks cut these stromatolites in places. Deformed bedding in this member may reflect disturbance by earthquake activity locally, possibly associated with faulting.

The Langport Member consists mainly of limestones with dark shales, and indicates a renewal of fully marine conditions (Wignall, 2001). In Devon, the Langport Member, formerly known as the 'White Lias', is a dean, micritic limestone up to 8 m thick. The top bed was called the 'Sun Bed' because of supposed desiccation cracks on its upper surface (Hallam, 1960). On the south coast of Devon, the base of the overlying Blue Lias Formation (Lias Group) is marked by a sharp contact between the Sun Bed and an overlying laminated, organic-rich shale, traditionally called the 'Paper Shale'. In Somerset, an additional thin shale unit called the Watchet Member', occurs between the White Lias and the Paper Shale, and it may be contemporary with the thicker White Lias of Devon (Wignall, 2001).

Wignall (2001) offered a revised sedimentological account of the Langport Member of the south Devon coast in which he identifies five phases of facies history: the topmost White Lias (Sun Bed) represents a micritic hardground that was lithified and bored, and then eroded locally, probably in a shallow sea, to produce a spectacular intraformational conglomerate, which was in turn lithified. The surface was exposed sub-aerially and fissures and pits were formed. This short-term regression was then followed by a full-scale transgression marked by the base of the Blue Lias.

The Penarth Group sediments document an apparently rapid marine transgression at the base of the Westbury Formation, followed by shallowing and local exposure as hypersaline tidal flats during Cotham Member times, and a further inundation in the Langport Member times. The sea apparently deepened into Jurassic times.

Palaeontology

Penarth Group fossils include a range of predominantly marine forms including foraminifera, corals, annelids, gastropods, bivalves, crustaceans, echinoderms, brachiopods, conodonts, and fishes (sharks, chimaeras, bony fishes, coelacanth) (Swift and Martill, 1999), and organic-walled microplankton (dinoflagellate cysts and acritarchs; Warrington, 1981), but

also including continental organisms (plants, insects, lungfish and dinosaurs).

Fossil fish remains include abundant isolated teeth, dermal denticles, and fine spines ('ichthyodorulites') of sharks: *Polyacrodus, Lissodus,* '*Hybodus*', *Nemacanthus, Palaeospinax, Synechodus,* and *Vallisia* (Storrs, 1994; Cuny and Benton, 1999). Rare tooth plates of chimaeroids include the genera *Myriacanthus* and *Agkistracanthus* (Storrs, 1994). Bony fishes are represented by teeth, scales, and isolated bones of the actinopterygians *Gyrolepis, Birgeria, Severnichthys,* a coelacanth, and tooth plates of the lungfish *Ceratodus* (Storrs, 1994). Amphibians were reported, based on massive teeth with labyrinthine infoldings, and heavy jawbones, but these have been found to belong to the bony fish *Severnichthys* (Savage and Large, 1966; Storrs, 1994).

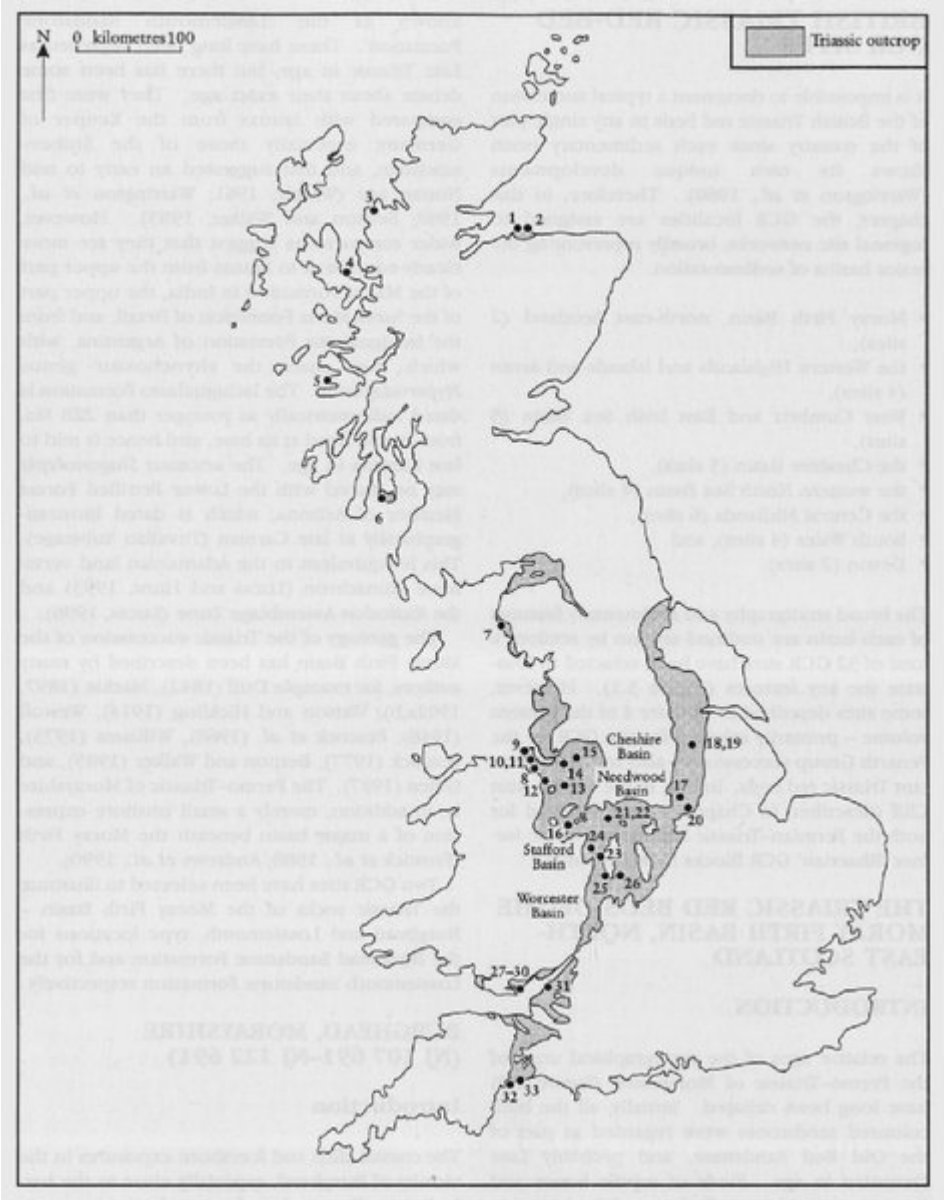
Penarth Group tetrapods (reviewed by Storrs, 1993, 1994, 1999) are represented mostly by isolated teeth, vertebral centra, limb bones, and occasional ribs. Such fossils may be referable to a broad group, or even to a genus, but it is hard to be more precise. Storrs (1999) noted the following fossil marine reptiles from the Penarth Group, primarily from the basal bone bed: ichthyosaurs (isolated teeth and vertebral cen-tra; humerus of *Leptonectes*), plesiosaurs (isolated teeth and vertebrae, paddle elements), placodonts (armour plates of *Psephoderma*), and the *choristodere Pachystropheus rhaeticus* (limb bones and vertebrae), a small, superficially crocodile-like animal. Isolated remains of terrestrial reptiles reported from a number of bone-bed sites include the dinosaurs *Camelotia* (femur, claw, and vertebra) and (?) *Megalosaurus* (a lower jaw), and the phytosaur '*Paleosaurus*'(a tooth). In addition, isolated teeth of mammal-like reptiles and mammals have been noted (the cynodont *Tricuspes* and the haramiyids *Haramiya* and *Hypsiprymnopsis*). These scattered elements of terrestrial animals were presumably washed from landmasses some distance away, and incorporated into the essentially marine bone beds.

Penarth Group sites

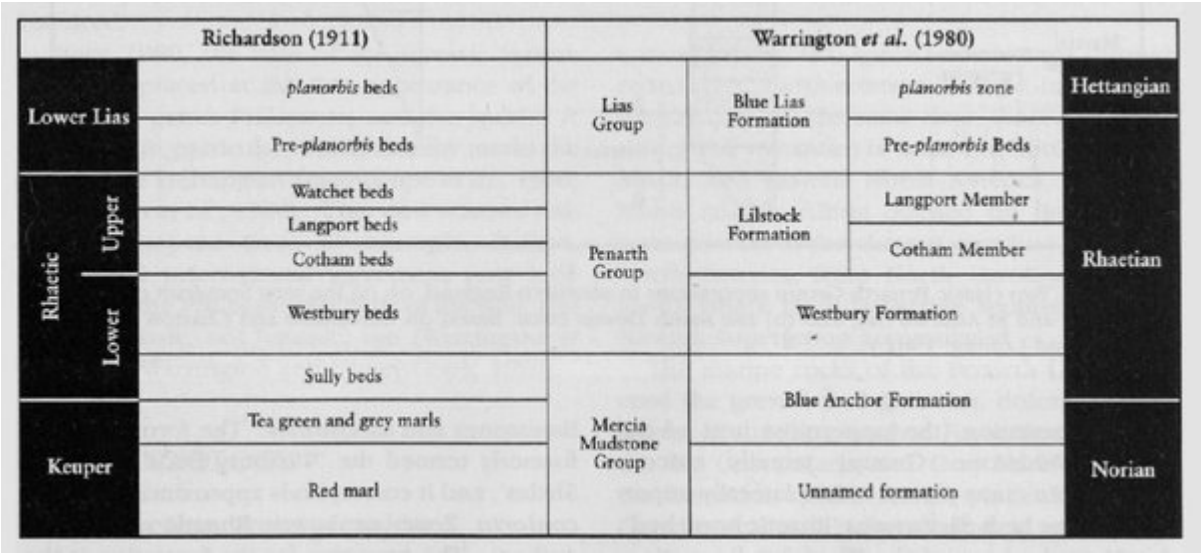
Penarth Group sediments have been described from a large number of sites, especially in the south-west of England and South Wales, but also from occurrences in Gloucestershire, Hereford and Worcester, Warwickshire, Staffordshire, Cheshire, Leicestershire, Nottinghamshire, Lincolnshire, Yorkshire and Cumbria. The group was also identified in Scotland (Morayshire, Hebrides, Arran) and in Northern Ireland, as well as from boreholes in the North Sea, the Irish Sea, the Western Approaches, and in south-east England.

Thirteen GCR sites on the north and south shores of the River Severn and its Estuary, around the Mendips, and on the Dorset coast have been selected (Figure 4.5). More northerly localities do not show additional or better features. The sites include the type Penarth Group sections of Lavernock to Penarth, Stormy Down, and the famous bone-bed sites of Westbury Garden Cliff and Aust, on opposite sides of the Severn. Other sites in South Gloucestershire, north Somerset, and east Devon illustrate the range of sedimentary facies.

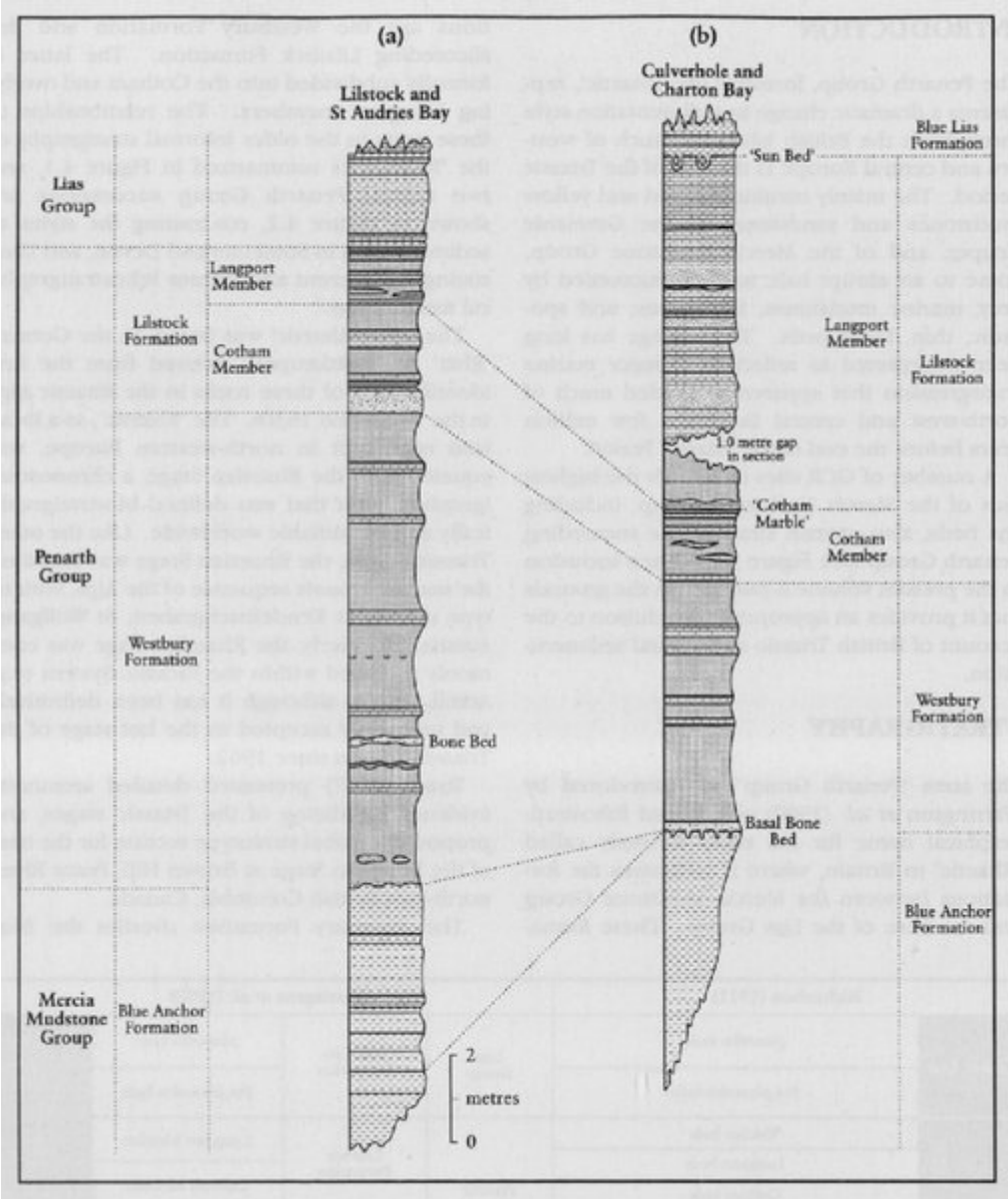
References



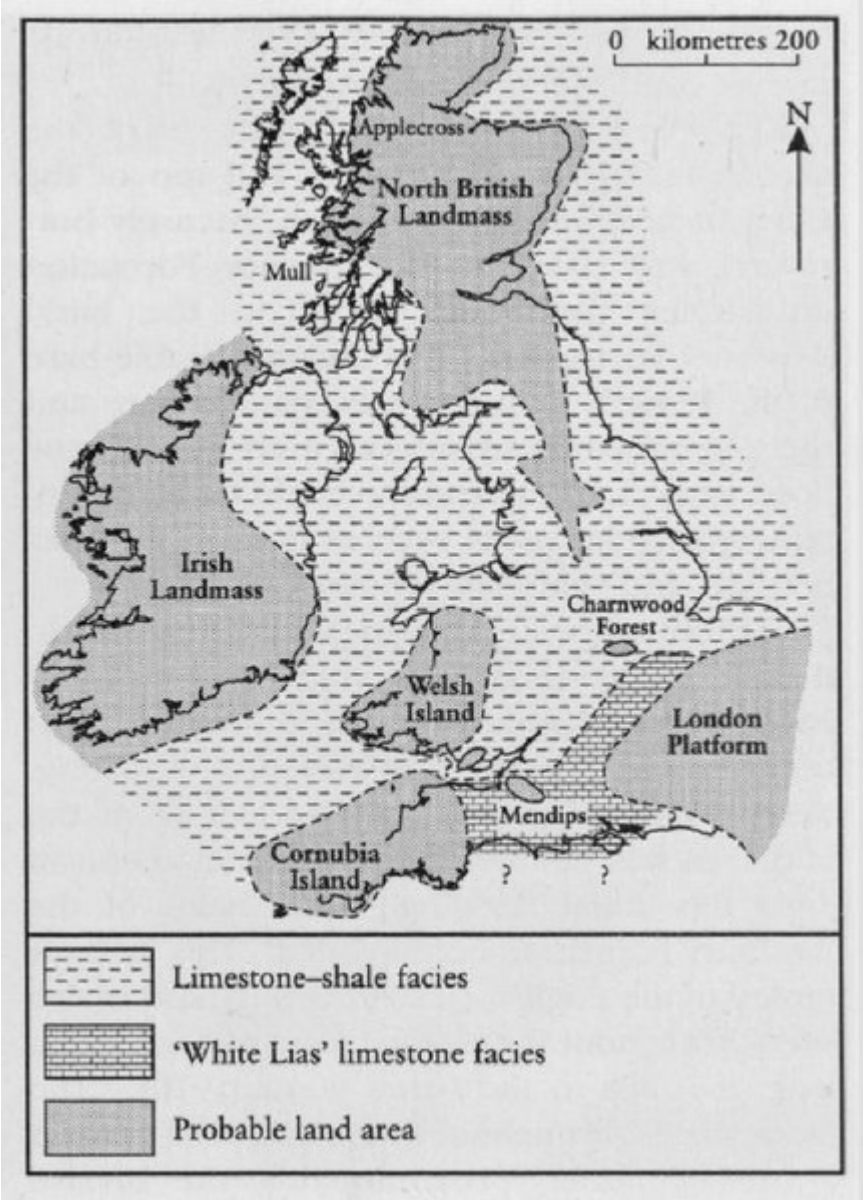
(Figure 3.1) Map showing the distribution of Triassic rocks in Great Britain. GCR Triassic red-bed sites are indicated: (1) Burghead; (2) Lossiemouth; (3) Gruinard Bay; (4) Eyre Burn; (5) Gribun; (6) King's Cave to Drumadoon; (7) Fleswick to St Bees; (8) Burton Point; (9) Hilbre Island; (10) Thurstaston; (11) The Dungeon; (12) Dee Cliffs; (13) Bickerton Hill; (14) Frodsham; (15) Red Brow; (16) Grinshill; (17) Nottingham Castle; (18) Styrrup Quarry; (19) Scrooby Top Quarry; (20) Colwick; (21) Hulme Quarry; (22) Brocton; (23) Wollaston Ridge; (24) Claverley Road Cutting; (25) Burcot; (26) Shrewley; (27) Sutton Flats; (28) Barry Island; (29) Hayes Point to Bendrick Rock; (30) Sully Island; (31) Aust Cliff (see Chapter 4); (32) Budleigh Salterton; (33) Ladram Bay to Sidmouth. The Triassic red-bed/Penarth Group sites described in Chapter 4 are shown on <a href="gcr24_04_05.html (Figure 4.5).</figcaption>



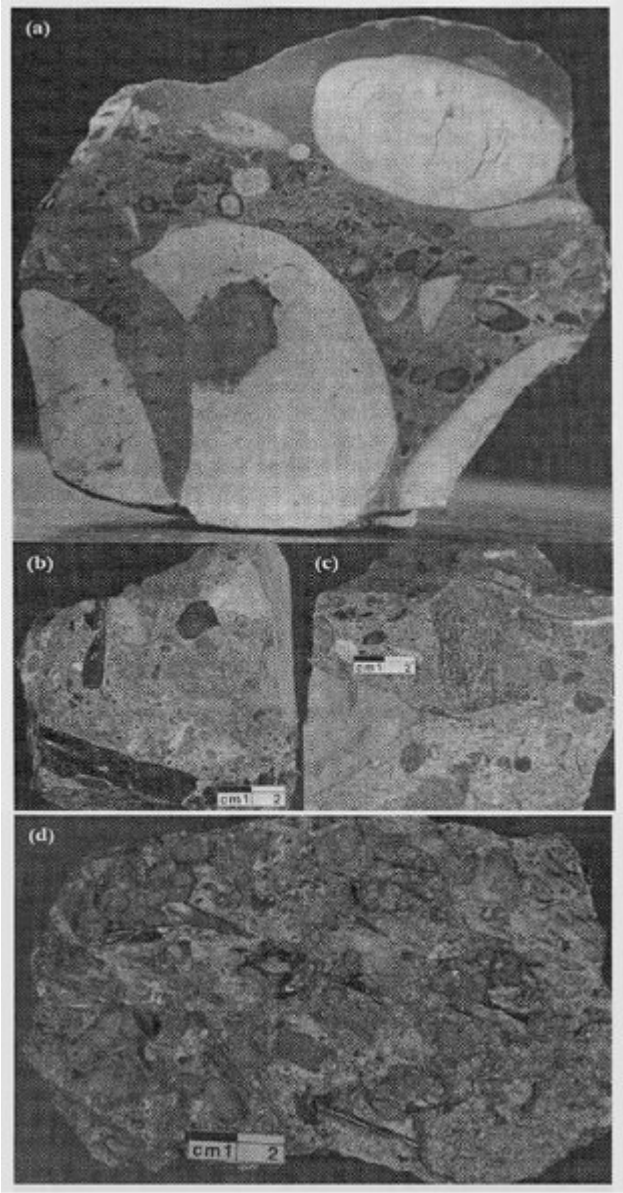
(Figure 4.1) The historical (Richardson, 1911) and current (Warrington et al., 1980) lithostratigraphical terminology of the uppermost Triassic–lowest Jurassic strata of south-west Britain. Chronostratigraphical units are shown at the right.



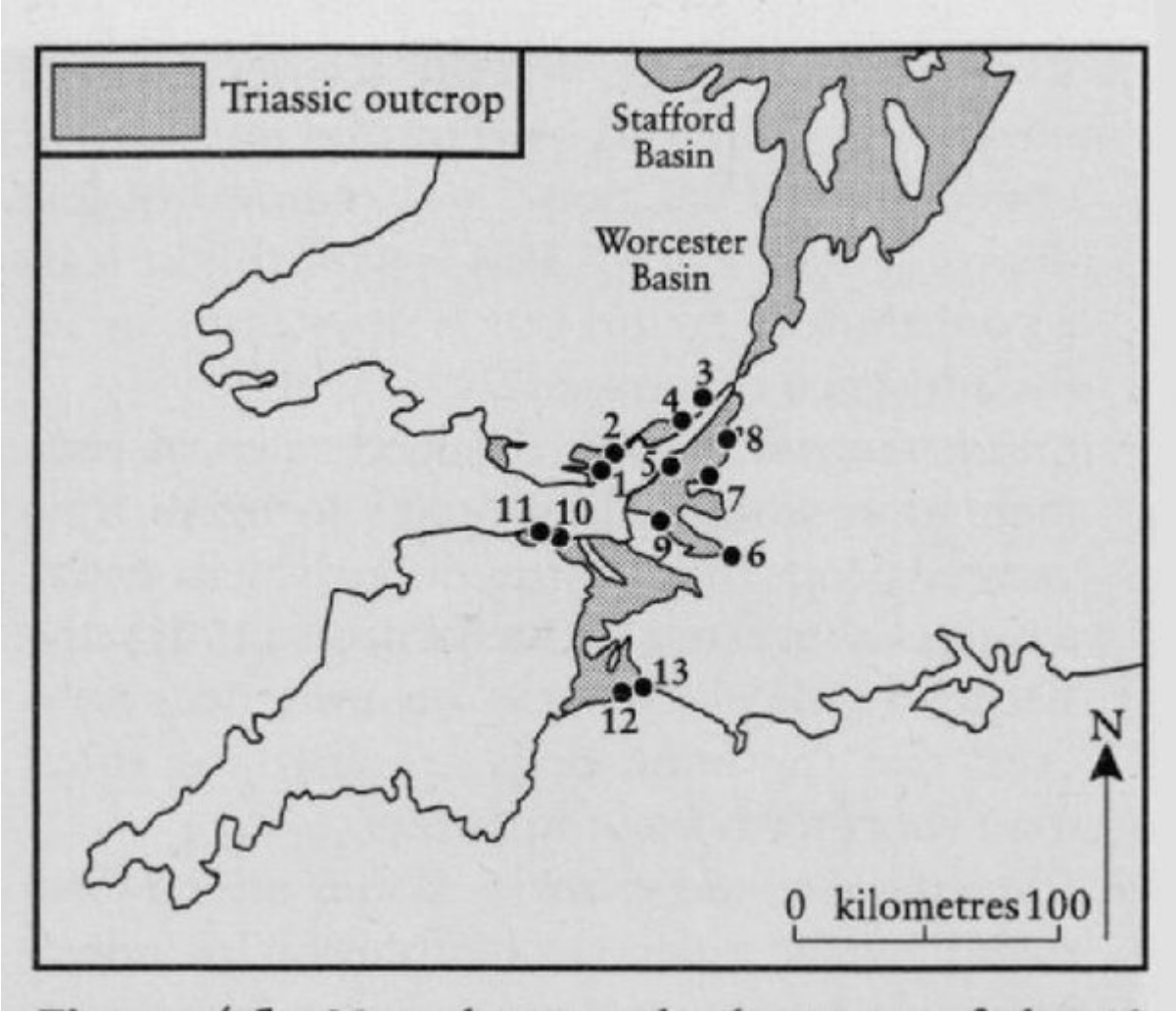
(Figure 4.2) Two classic Penarth Group successions in southern England, on (a) the west Somerset coast, based on Lilstock and St Audries Bay, and (b) the south Devon coast, based on Culverhole and Charton Bay. (After Durrance and Laming, 1982.)



(Figure 4.3) Palaeogeography of the British Isles during the Rhaetian Age. The classic sections in South Wales, Gloucestershire, Somerset, and Devon accumulated on marginal areas of the Welsh and Cornubian islands. The Langport Member is most fully developed in south. (After Poole, 1979.)



(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 4.5) Map showing the locations of the 13 Penarth Group GCR sites: (1) Lavernock to Penarth; (2) Stormy Down; (3) Wainlode Cliff*; (4) Westbury Garden Cliff*; (5) Aust Cliff*; (6) Hapsford Bridge; (7) Barnhill; (8) Wetmoor*; (9) Lulsgate; (10) St Audries Bay*; (11) Blue Anchor Point*; (12) Culverhole Point*; (13) Pinhay Bay. * Denotes that the site also exposes important Triassic red beds.*