Freshwater East–Skrinkle Haven, Pembrokeshire

[SS 021 981]–[SS 082 974]

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Introduction

The sea cliffs and foreshore of south Pembrokeshire, south Wales offer the best exposures of the Old Red Sandstone in southern Britain. This 8 km-long, well-exposed along-strike section, also known as 'Tenby Cliffs', extends from Freshwater East in the west to Skrinkle Haven in the east (Figure 5.64). It gives a complete transect through the Old Red Sandstone, from the junction with the Silurian Gray Sandstone Group at Freshwater East, through the Lower Devonian Red Marls, the ?Middle Devonian Ridgeway Conglomerate Formation, the Upper Devonian Skrinkle Sandstones Group and the junction of the Skrinkle Sandstones Group with the overlying Carboniferous Lower Limestone Shale Group at Skrinkle Haven. The strata lie on the southern limb of the Pembroke Syncline (or northern limb of the Freshwater East Anticline), dipping very steeply to the NNE or being almost vertical. With the strata striking almost parallel to the coast, individual beds can be traced laterally for long distances, allowing detailed measurement of sandbody sizes and confirmation of the lateral persistence of marker beds such as calcretes and ash-fall tuffs. It should be noted, however, that large parts of the cliffs are inaccessible and dangerous.

Of particular interest is the group of eight closely spaced marker tuff beds within the Moor Cliffs Formation, the most distinctive of which are the Townsend Tuff Bed, Pickard Bay Tuff Bed and Rook's Cave Tuff. Their identification, combined with the extensive exposures, has allowed a detailed analysis of the alluvial architecture and sedimentary environments of parts of the succession, notably of that between the Townsend and the Pickard Bay Tuff beds (Allen and Williams, 1982) and of the Moor Cliffs Formation as a whole (Love, 1993; Love and Williams, 2000). The Townsend Tuff Bed and Rook's Cave Tuff between Manorbier Bay and Presipe preserve a unique set of trace fossils at their junctions with the underlying floodplain mudstones (Allen and Williams, 1981a; Morrissey and Braddy, 2004). The Ridgeway Conglomerate is important because of its derivation from a local southerly source and the implications for Mid-Devonian tectonics and palaeogeography. The site also includes the type locality of the Upper Devonian Skrinkle Sandstones Group. The section east of Manorbier was included in a field guide by Williams *et al.* (1982).

Description

The foreshore (depending on extent of sand cover) and cliffs on the north-east side of Freshwater East bay expose the Basement Group (of Dixon, 1921) and the lower part of the Moor Cliffs Formation (the Lower Marl Group of Dixon). The Basement Group lies disconformably on fossiliferous sandstones and mudstones of the Gray Sandstone Group of Wenlock age. Dixon (1921, p. 41) gave a section and Bassett (1982b) described the succession. A basal conglomerate-sandstone 1.4 m thick is overlain by the lower part of the mudstone-dominated Moor Cliffs Formation, in which there are four complexes of green mudstones and green or pale grey, micaceous sandstones. The lowest green beds yielded a spore assemblage (Richardson and Lister, 1969). These green beds contain sporadic lingulids and ostracoderm fragments, together with the vascular plants *Cooksonia, Hostinella,* and *Tautilicaulis* (Edwards, 1979b). Malachite occurs on joint faces. There are fine examples of calcretes in the intervening red mudstones, as well as some airfall tuffs. Hancock *et al.* (1982) gave details of the structures.

West Moor Cliff provides exposures of the lower part of the Moor Cliffs Formation, Swanlake Bay exposes the upper part. Allen and Williams (1982) included the Swanlake Bay section in their detailed sedimentological analysis of the section between the Townsend Tuff Bed and the overlying Pickard Bay Tuff Bed. Allen (1974e) analysed cycles in the overlying Freshwater West Formation at Manorbier Bay (SS 057 976; SS 059 973) and at Swanlake Bay [SS 043 981]. Marriott and Wright (1993, 2004) gave a detailed description of the mudrocks of the Moor Cliffs Formation.

Love and Williams (2000, fig. 4) and Love *et al.* (2004) gave detailed lithofacies profiles of part of the Moor Cliffs Formation at its type locality of East Moor Cliff and from Priest's Nose to Rook's Cave in the cliff east of Manorbier Bay (Figure 5.65). The section analysed extends from about 25 in below to 50–60 in above the Rook's Cave Tuff, which lies about 90 m below the Townsend Tuff Bed. Marriott and Wright (1993) examined 17 m of strata below, and 69 m above the Rook's Cave Tuff, 40 m west of Rook's Cave.

The cliffs to the east of Priest's Nose expose a magnificent strike section of the Moor Cliffs Formation (e.g. Marriott and Wright, 2004). The sequence is dominated by calcretized, red mudstones/siltstones, many showing pseudo-anticlinal structures (Figure 5.66). There are a few, thin, fine- to medium-grained sandstones, as well as some thin lenses and lenticular sheets of intraformational conglomerate (Allen and Williams, 1979b) and a very few thin, extraformational conglomerate lenses. Conspicuous, laterally persistent slots occur where softer airfall tuffs have been weathered out. The Rook's Cave Tuff buried an irregular surface with shallow depressions and channels, probably occupied by water, separated by inter-pond, slightly eroded tracts of mud (Williams *et al.,* 1982). Organic burrow structures ('trumpet marks' of Allen and Williams, 1981a) and arthropod tracks (Morrissey and Braddy, 2004) occur at the base of the tuff (Allen and Williams, 1981a). Love and Williams (2000) record six tuffs in the 60 m of beds above the Rook's Cave Tuff.

At Old Castle Head (Figure 5.67) a deep slot marks the outcrop of the Townsend Tuff Bed (Figure 5.68), which is visible only at very lowest water-level. Details of the Townsend Tuff Bed at East Moor Cliff [SS 0456 9762], Priest's Nose [SS 0586 9723] and Old Castle Head [SS 0741 9664] were given by Allen and Williams (1981a). It comprises a complex of three superimposed, normally graded airfall tuffs (falls A, B and C). Thickness of the complex ranges from 2.44 m at Priest's Nose to 3.39 m at Old Castle Head. Crystal tuffs at the bases of the falls grade up into porcellanous dust tuffs. The basal fall (A) is the thinnest (0.17–0.47 m) and has a sharp, non-erosional top strewn with faecal debris. Organic structures on its top at East Moor Cliff include those described by Allen and Williams (1981a) as 'burrow tops', and 'trumpet' and 'bread roll' marks, possibly related to *Beaconites.* Fall B ranges from 1.17 m at Priest's Nose to 1.72 m at Old Castle Head. At East Moor Cliff it is 1.42 m thick and comprises crystal and dust tuffs interbedded at mainly centimetre scale. Fall C ranges from 1.10 m at Priest's Nose to 1.15 m at East Moor Cliff and 1.2 m at Old Castle Head. At all three localities it has an irregular base overlying an erosion surface.

Williams *et al.* (1982) gave details of the section at Presipe [SS 0690 9707] near a major dextral wrench fault. The west cliff of the bay exposes a fine mudstone/siltstone-dominated section below the Rook's Cave Tuff, which lies high up in the north-west corner of the bay 5.85 m below a prominent fine- to medium-grained, cross-bedded sandstone. The section shows a magnificent development of calcretized mudstones and calcretes, with nodule fans displaying pseudo-anticlinal structure ((Figure 5.66); Love, 1993; Love and Williams, 2000; Love *et al.,* 2004). Bedding planes in the section in the central part of the bay preserve a range of trace fossils, including arthropod tracks and large scour marks and *Beaconites* burrows (Morrissey and Braddy, 2004). Mud-filled desiccation polygons and rippled surfaces are also seen. The beds are arranged in upward-fining cycles and some of the sandstones contain fine examples of soft-sediment deformation.

The Chapel Point Calcretes Member, the local name for the regionally developed Psammosteus Limestone, forms the top of the Moor Cliffs Formation. It crops out near King's Quoit [SS 0596 9733] and comprises 10–15 m of massive, purple careously weathered calcrete, which form a pronounced notch on the foreshore (Figure 5.69) and alcove in the cliff. Immediately overlying it is a very distinctive conglomerate 1.5–2.2 m thick and containing angular quartz pebbles (Williams and Hillier, 2004). The calcrete is at least 11.2 m thick at Conigar Pit to the east (Williams *et al.,* 1982).

The overlying beds comprise the Conigar Pit Sandstone Member at the base of the Freshwater West Formation. Conigar Pit [SS 0724 9696] provides a magnificent type section of the Conigar Pit Sandstone Member (Williams *et al.,* 1982), with the junction with the underlying Chapel Point Calcretes Member exposed at low-water mark [SS 0722 9680]. The Conigar Pit Sandstone mainly comprises a stacked succession of upward-fining cycles of intraformational conglomerates, sandstones and mudstones with calcretes. The conglomerates are of small pebble grade, massive or cross-bedded and contain ostracoderm fragments. The sandstones are fine- to medium-grained and ripple cross-laminated and contain *Beaconites* burrows and mud-filled desiccation cracks. The most notable feature of the section is the occurrence of eleven sandstone-mudstone lateral accretion complexes. They range from 0.7 m to 3.09 m thick, the epsilon cross-bedding being magnificently seen and showing southerly flow direction. North- and west-directed sets are also present (Williams *et al.* 1982).

The calcareous siltstones of the Rat Island Mudstone Member of the Freshwater West Formation are exposed at Manorbier (Wright and Marriott, 1996) and on the headland south of Skrinkle Haven (Marriott and Wright, 1993, 1996, 2004). Their junction with the vertical Ridgeway Conglomerate Formation [SS 0800 9718] is erosional, although the basal conglomerate appears to pass laterally into red and green siltstones high in the face. However, a small fault at this point may complicate the relationship (Williams, 1971).

Williams (1971) described the Ridgeway Conglomerate. It is attenuated to 47 m at Skrinkle Haven and consists of interbedded siltstones, sandstones and extraformational conglomerates (Williams, 1971, fig. 5). Four conglomerate beds comprise 9 m of the formation. One 4.5 m-thick, green conglomerate lies 24 m above the base of the formation. Imbricated pebbles are set in a coarse-grained sandstone matrix with a carbonate cement. A thick (4 m) mature, massive calcrete overlies the conglomerate. Ekes (1993) noted abundant, metre-thick, massive calcretes showing pseudo-anticlinal 'gilgai' -type structures. The pebbles of the Ridgeway Conglomerate have not yet been matched with older formations (Allen, 1974a), but palaeocurrent evidence and decreasing pebble size northwards indicate a southerly derivation (Williams, 1971; Allen, 1974a; Cope and Bassett, 1987; Powell, 1989; Ekes, 1993).

Skrinkle Haven is the type locality of the Skrinkle Sandstones Group, which unconformably overlies the Ridgeway Conglomerate. Williams (1971) provided a description. It is 91 m thick and includes a lower quartzite unit (15.5 m) and upper conglomerate unit 54 m thick. The upper unit contains a 0.35 m-thick, grey and red mottled siltstone containing *Lingula* sp. and bivalves including *Modiola* sp.. The top of the Skrinkle Sandstones Group is sharp, where green sandstones are overlain by grey shales of the Lower Limestone Shale Group.

Interpretation

Allen and Williams (1982) interpreted the succession between the 'Townsend and Pickard Bay Tuff beds as having been deposited in an extensive mudflat environment, with sporadic fluvial channels. Widespread calcretes point to periodic subaerial exposure of the mudflats and precipitation of carbonate in the vadose zone. The ubiquitous destruction of sedimentary lamination is attributed to organic bioturbation.

Allen and Williams (1982) were unclear as to whether the mudflats were subjected to tidal influence (an interpretation that they favoured), as suggested by the strong currents that affected the ashfall tuffs, although the evidence of variability of palaeocurrents is lacking. Marriott and Wright (1993, 1996) ruled out tidal influence during deposition of the Moor Cliffs Formation, favouring an unstable, flashy alluvial-floodplain system with ephemeral stream channels subject to common erosional events that reworked earlier soil horizons and the floodplain sediments. Love and Williams (2000) also discounted any marine influence. The alluvial-floodplain facies associations indicate prolonged periods of stability, non-deposition and soil formation. The calcretes indicate a seasonally wet, monsoonal, sub-tropical climate. Love and Williams (2000) and Marriott and Wright (1996) favoured an active, channelized depositional floodplain setting for much of the mudstones and siltstones, rather than a strictly overbank model favoured by earlier workers (e.g. Allen and Williams, 1981b). The floodplain channels were ephemeral, extremely broad and with low relief and flow, depositing mud and silt as bedload aggregates. Love (1993) and Love and Williams (2000) emphasize the role of land-plant colonization, with the primitive, shallow-rooted vegetation being unable to protect the floodplain from the rapid removal of sediments and calcrete soils during wet-season flooding.

Love and Williams (2000) and Love *et al.* (2004) interpret the sedimentary architecture of the Moor Cliffs Formation as the product of deposition by sporadic, large, broad, sandy channel systems with highly variable discharges and ephemeral flow, and by ephemeral, flashy, shallow streams on extensive interfluvial areas. Marriott and Wright (2004) envisage an environment analogous to a modern dryland system in which mud-dominated, moderately sinuous ephemeral rivers reworked floodplain muds during seasonal flooding. There is little evidence to support the conventional view that the mudstones/siltstones were deposited by suspension from standing water. For the heterolithic mudstone, sandstone–conglomerate mudrock facies and the massive brick-red mud-rocks, Marriott and Wright (1996, 2004) favour active deposition of mud/silt aggregates from bedload. Rippled bodies and laminated sheets were deposited in through-draining larger channels and lumps of silt/mud aggregates and calcrete clasts were transported as coarse sand and gravel bedload in the shallow inter-distributary channels and deposited as bar forms. Units of burrowed mudrocks are attributed to lacustrine deposition in floodplain lakes, the pedified and desiccation-cracked, calcrete-prone mudrocks to steady aggradation on the flood-plain during relatively stable periods, occasionally interrupted by flood events (see Freshwater West GCR site report, this chapter, for a fuller account of Marriott and Wright's important work). The strong cyclicity of the succession and of the calcrete palaeosols, which show increasing upward maturity, is attributed by Love and Williams (2000) to autocyclic processes of fluvial avulsion and aggradation.

The Conigar Pit Sandstone is interpreted by Hillier and Williams (2004) to represent a range of fluvial environments. Multi-storey sandstone bodies occupied the main channel belts and were mainly laterally accreted channel sand-bodies. Also present are heterolithic sandstone/ mudstone beds representing ephemeral channel deposition and sheet sands deposited from unconfined sheet floods. The Rat Island Mudstone comprises four facies, as detailed by Marriott *et al.* (2005) at a section [SS 0580 9775] on the west side of Manorbier Bay. These authors compare the environment to the Channel Country of central Australia, where mud sheet-flood deposits on a muddy braidplain border anastomosing fluvial systems. Intraformational conglomerates with mudstone and calcrete clasts were deposited as gravels in slightly sinuous, ephemeral channels, and heterolithic mudstone/sandstone units were deposited as accretionery benches in the channels. Pedified, purplish red mudstones with carbonate nodules are palaeo-vertisols (Stage II or III calcretes of Machette, 1985). Brick-red, pelleted mudstones were probably deposited as fine sand-sized aggregates in bed-load during sheet-flood events. Subaerial exposure between flows was sufficiently long to allow pedogenic processes to form immature calcrete vertisols. Alternatively, the upper parts of the beds of pelleted mudrocks may have been deposited as aeolian dust. The facies are stacked in fining-upward units, 2.5 m-5 m thick, representing ephemeral channel-zone deposition in which fluvial reworking of the palaeo-vertisols as clay pellet bedload took place.

The age of the Ridgeway Conglomerate Formation remains unknown. Unconformities at its base and top constrain it to between late Early and Mid-Devonian age (Marshall, 2000a,b). Allen (1974a) suggested that its base marks an important depositional break that extended into Mid-Devonian, and perhaps even into Late Devonian, times. Williams (1971) favoured a Mid-Devonian age, but later (Williams, 1978) suggested a late Early Devonian age. Powell (1989) gave a Siegenian (Early Devonian) age, but provided no evidence on which this is based. It is now clear that the formation post-dates the Acadian deformation (B.P.J. Williams, pers. comm.).

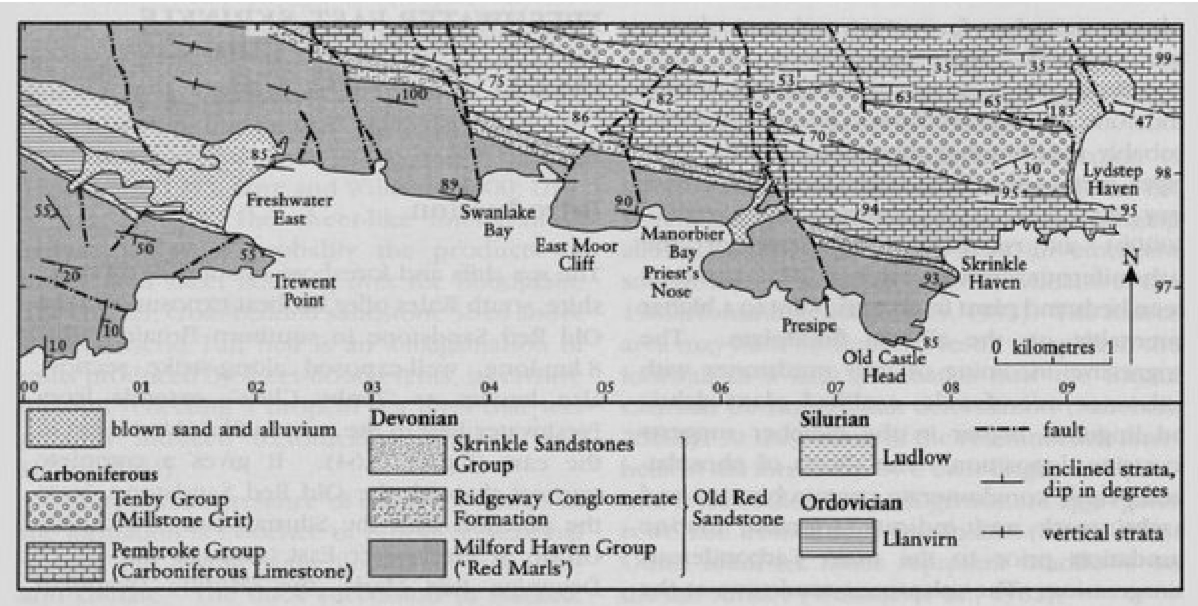
Allen (1974a) compared the Ridgeway Conglomerate Formation to the sediments of modern semi-arid playa-basins and alluvial-fans, with the conglomerates probably being of local origin; an alluvial-fan–braided river setting has also been suggested by several authors (e.g. Williams, 1971; Williams *et al.,* 1982; Powell, 1989; Ekes, 1993). The sediments were probably sourced from Lower Palaeozoic or ?Precambrian outcrops in the Bristol Channel Landmass to the south. Tunbridge (1986) and Cope and Bassett (1987) suggested that Mid-Devonian tectonics in the Bristol Channel area produced this positive area.

The Skrinkle Sandstones Group is of Late Devonian to Early Carboniferous age. It was deposited in a fault-bounded basin (the Tenby–Angle Basin), of which the Ritec Fault marked the northern limit (Powell, 1989; Marshall, 2000a,b). No detailed sedimentological work has been carried out at Skrinkle Haven, but Marshall interpreted the succession in West Angle Bay (North) to the west (see GCR site report, this chapter) as the product of alluvial-fan, alluvial-plain and lacustrine deposition. This was controlled by movements of the basin-bounding faults, within an overall transgressive regime as subsidence on the southern margin of the Wales–Brabant Massif was matched by rising sea level in early Carboniferous times.

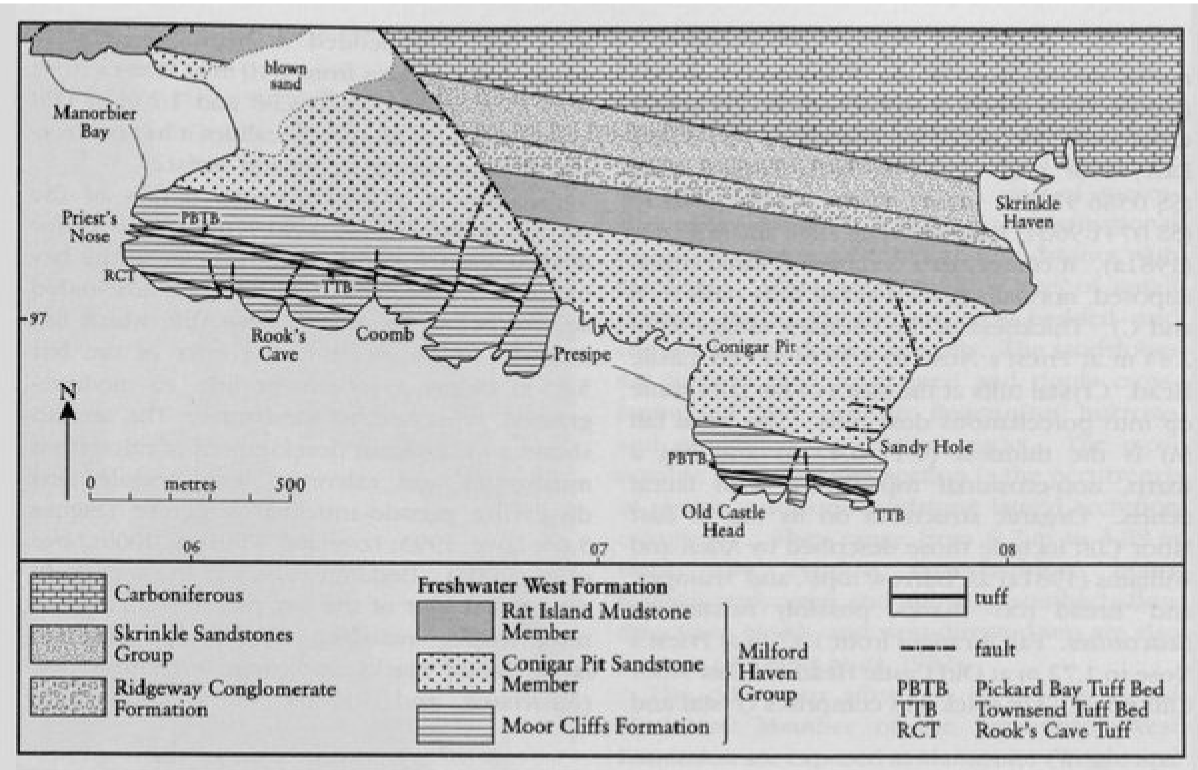
Conclusions

The magnificent, cliff exposures along this 6 km-long section of coast reveal the entire succession of Old Red Sandstone strata in south Pembrokeshire. The high quality and lateral persistence of the extensive exposures of near-vertical strata allow detailed analyses of facies and their architecture. The modern sedimentological research of the section has been instrumental in the elucidation of the alluvial environments of the Old Red Sandstone, ranging from the distal floodplains of Late Silurian and Early Devonian times to the more proximal alluvial-fan deposition of the southerly sourced Early–Mid-Devonian Ridgeway Conglomerate Formation and the Upper Devonian Skrinkle Sandstones Group. Of special interest are the marker ashfall tuffs, of which the Townsend Tuff Bed, Rook's Cave Tuff and Pickard Bay Tuff Bed are the principal ones. These preserve a unique set of trace fossils, including faecal pellets, burrow-fills and arthropod tracks at their junctions with the flood-plain mudstones. The magnificent exposures of calcretes, showing varying stages of maturity and gilgai-type pseudo-anticlinal structures, as well as the facies and architecture of the sandbodies and mudrocks, have been utilized to model the contemporaneous sub-tropical, semi-arid, seasonally wet climate of Late Silurian and Devonian times.

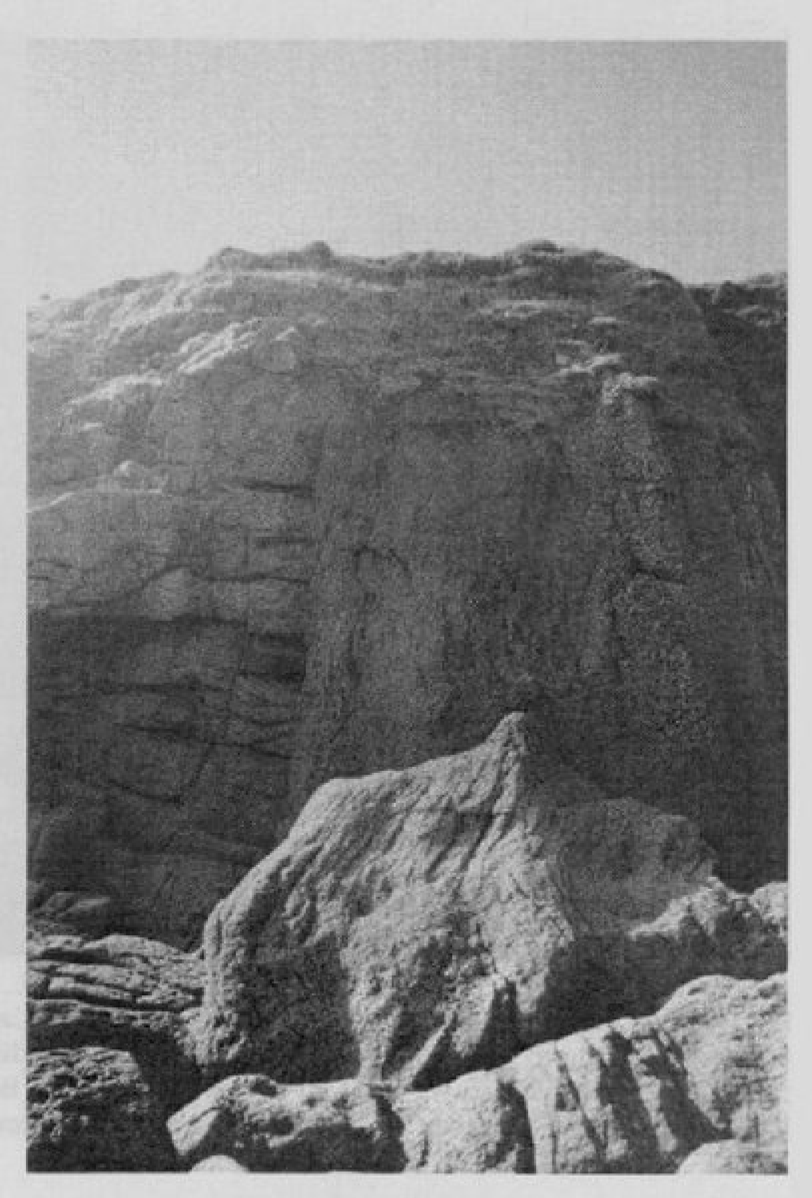
References



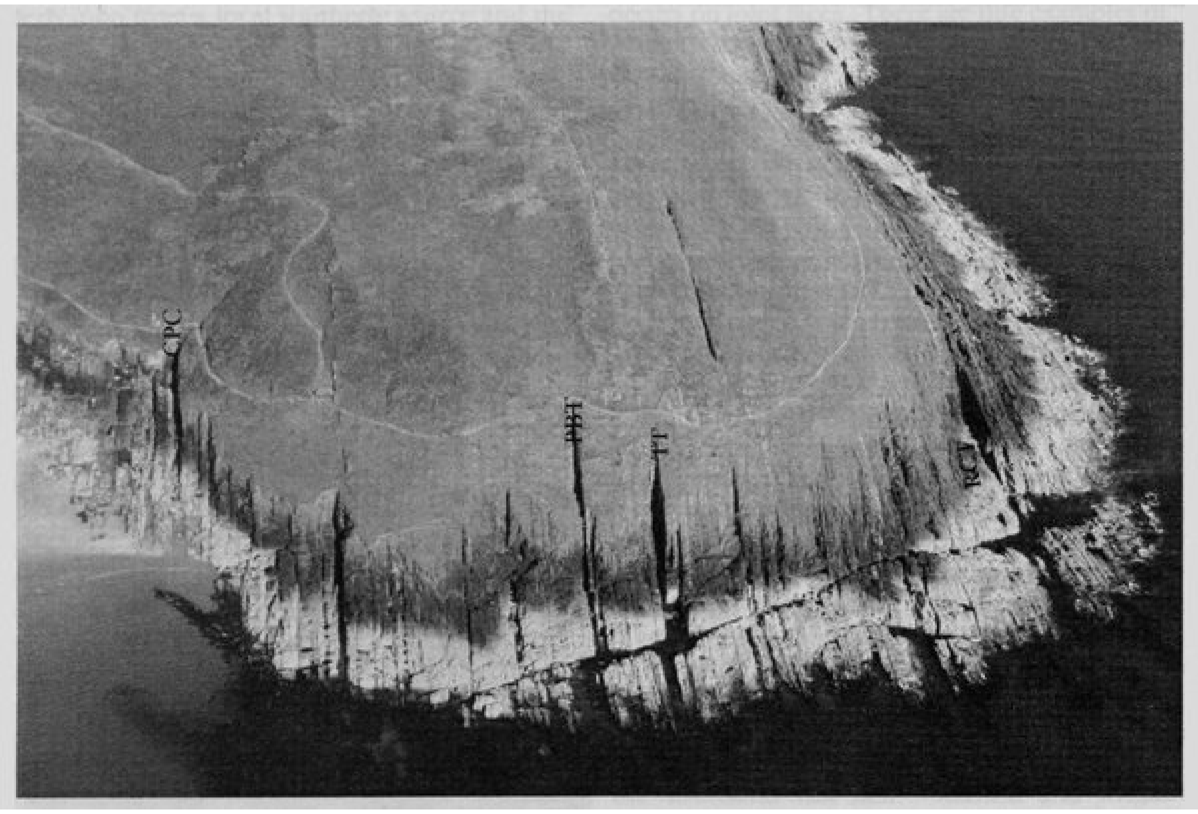
(Figure 5.64) Geological map of the Freshwater East–Skrinkle Haven coast section. After British Geological Survey 1:50 000 sheets 244 and 245 (England and Wales), Pembroke and Linney Head (1983).



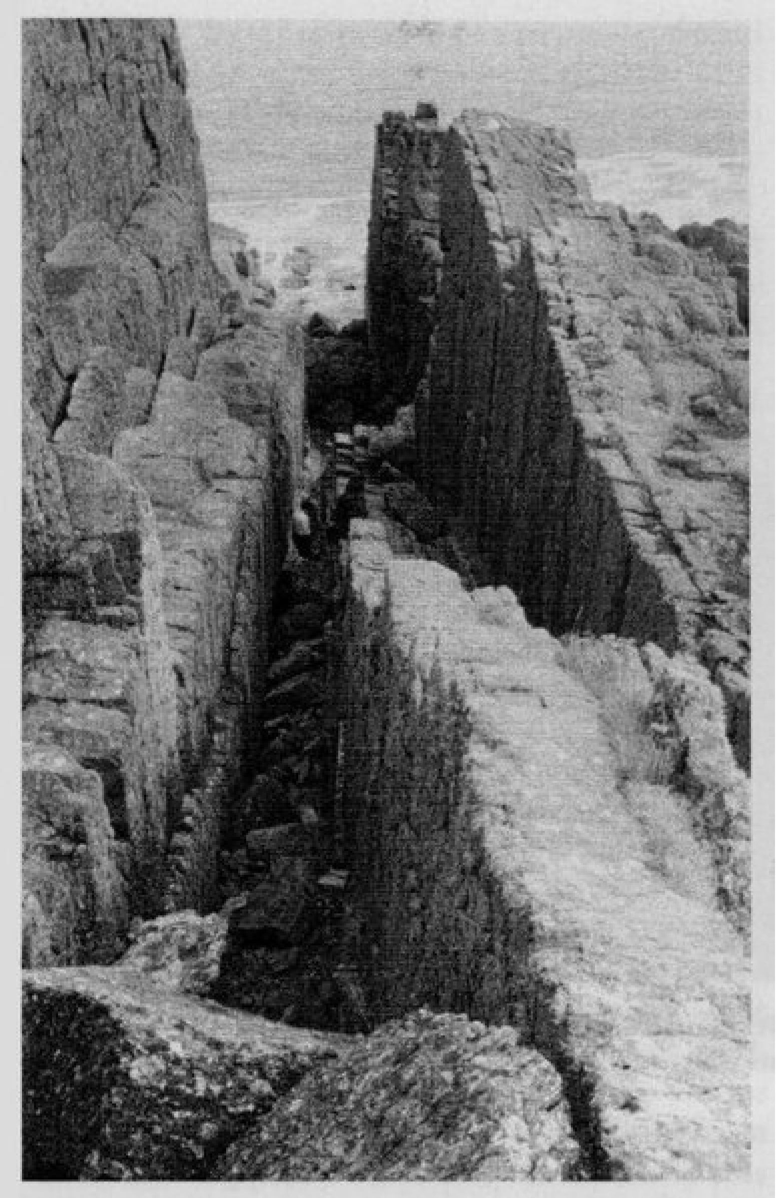
(Figure 5.65) Geological map of the Manorbier–Skrinkle Haven coast section. After Williams el al. (1982).



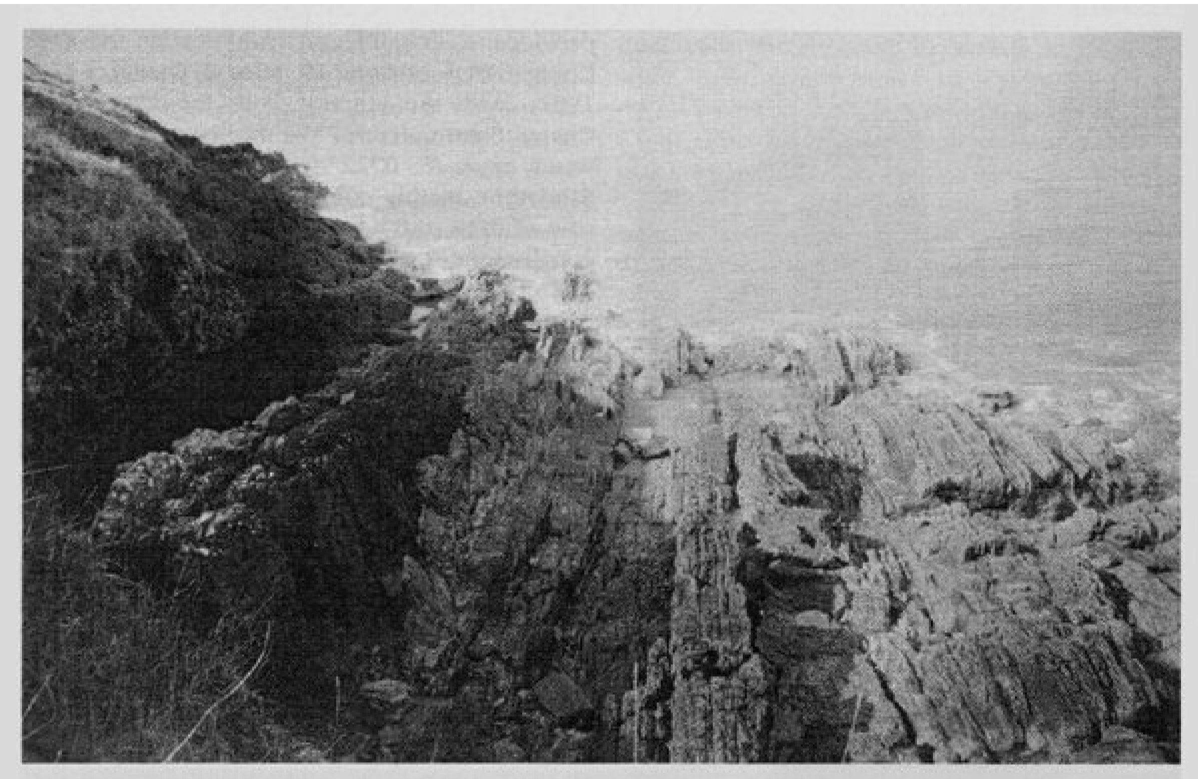
(Figure 5.66) Calcrete forming pseudo-anticlinal structure, Moor Cliffs Formation, Presipe. View looking west, near-vertical sequence younging left to right. (Photo: W.J. Barclay.)



(Figure 5.67) Oblique aerial view looking east of Old Castle Head. Vertical strata of the Moor Cliffs Formation. The strata young to the north (right to left) and a Fault displaces them dextrally. Tuffs are marked by slots in the cliffs (RCT — Rook's Cave Tuff; TT — Townsend Tuff Bed; PBT — Pickard Bay Tuff Bed; CPC — Chapel Point Calcretes Member). Other slots probably mark unnamed tuffs. (Photo: S. Howells.)



(Figure 5.68) The Townsend Riff Bed, Old Castle Head. View looking east, sequence younging right to left. (Photo: B.P.J.



(Figure 5.69) Near-vertical basal beds of the Freshwater West Formation. View looking WSW at southern end of Manorbier Bay. The Chapel Point Calcretes Member forms the notch on the left, the sequence younging left to right. (Photo: W.J. Barclay.)