Freshwater West, Pembrokeshire

[SR 884 996]–[SR 887 988]

Potential ORS GCR site

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Introduction

Foreshore and cliff exposures at Freshwater West (Figure 5.57) in the Pembroke peninsula south of Milford Haven provide a magnificent, continuously exposed, easily accessible section (depending on tides) of the entire Old Red Sandstone succession. The basal Lower Old Red Sandstone rocks rest unconformably on marine rocks of Wenlock age at the north end of the section, the strata dipping steeply and younging southwards. At the southern end of the section, Upper Old Red Sandstone rocks are conformably overlain by the Dinantian Lower Limestone Shale Group. The section was first mapped in detail and described by the [British] Geological Survey (Dixon, 1921, 1933a,b). Field guides by Williams (1971, 1978), Allen *et al.* (1981b) and Williams *et al.* (1982), and detailed study by Marshall (1977, 2000a,b) have highlighted the importance of the section. Together with the presence of the Townsend Tuff Bed and the Chapel Point Calcretes Member, the recent discoveries of an early Devonian microflora (Higgs, 2004) and of exceptionally well-preserved burrowing traces (*Beaconites barretti;* Morrissey and Braddy, 2004) have added to that importance. This is the Old Red Sandstone section most visited by geologists and students in southern Britain because of its completeness and the superb exposure of all of the formations. Varied sedimentary structures and trace fossils can be studied in detail on wave-polished surfaces. The site provides an easily demonstrable picture of the evolving nature of sandbody architecture in the Lower Old Red Sandstone (Williams and Hillier, 2004). It also provides the most proximal, complete and accessible section through the unconformity-bounded Ridgeway Conglomerate Formation, and is important in having yielded fragments of the late Devonian fish *Holoptychius* from the basal beds of the Skrinkle Sandstones Group (Dixon, 1921). Furthermore, the Flimston Bay Fault, which transects the entire rock sequence with increasing amount of throw to the south, provides an additional, spectacular feature.

Description

Descriptions of the section have been given by Dixon (1921, 1933a,b), Williams (1971, 1978), Allen *et al.* (1981b) and Williams *et al.* (1982). Marshall (2000a,b) described the Upper Old Red Sandstone in detail. Freshwater West lies in the Pembroke peninsula south of Milford Haven and south of the Ritec Fault (Figure 5.58). The strata at Freshwater West occupy the southern limb of the Castlemartin Corse Anticline (Hancock, 1973), dip steeply (50°–80°) southwards and are locally overturned. The southern third of the section, in the Upper Old Red Sandstone, lies within the Castlemartin Tank Range, and permission to visit must be obtained in advance from the Commandant, Merrion Camp, Castlemartin.

The section can be reached from the B4319. From this road above Little Furzenip [SR 885 994] there is a magnificent view of the steeply dipping succession, exposed in a rock platform between high-tide and low-tide levels. The Old Red Sandstone comprises most of the section (Figure 5.59), outcrops being confined in the north to the foreshore between Little Furzenip and the main beach of Freshwater West [SR 8872 9900]. To the south, the Ridgeway Conglomerate Formation and Skrinkle Sandstones Group crop out in cliffs about 35 m high. The north-trending Flimston Bay Fault, a Variscan dextral wrench fault, bisects the entire section, displacing the strata about 120 m in the middle of the outcrop. This fault also isolates the Little Furzenip stack from the headland and is marked by a shatter zone on Great Furzenip headland [SR 887 987]. It dies out through a myriad of small splay faults immediately north of Little Furzenip and does not affect the rock sequence on the northern limb of the Castlemartin Corse Anticline (Hancock, 1973).

At the northern (Little Furzenip) end of the section, the basal Old Red Sandstone rests unconformably on marine Silurian rocks of Wenlock age, the Gray Sandstone Group (Williams, 1971, 1978; Bassett, 1974; Allen and Williams, 1979b; Allen *et al.,* 1981b; Williams *et al.,* 1982). The Gray Sandstone Group consists of conglomerates, green fine- to medium-grained sandstones, thin limestones and dark grey mudstones. The group is truncated by an irregular scoured, channelled surface that is overlain by the basal Old Red Sandstone rocks, the Freshwater East Formation. This is 18.45 m thick and comprises conglomerates in its lower part, with finer-grained sandstones above. The conglomerates are green to dark grey, of cobble-and pebble-grade, and are interbedded with fine-to medium-grained sandstones and green-grey mudstones. They are framework supported and include clasts up to 450 mm of quartzitic and lithic sandstones, vein quartz and olive-green mudstone in a coarse-grained sandstone matrix, some of the clasts matching lithologies in the underlying Silurian strata. The conglomerates are massive or cross-bedded with internal scour surfaces and overlie erosion surfaces. The upper, finer-grained beds contain lingulids, plant remains, arthropod tracks, *Pachytheca* and ostracoderm fragments (Dixon, 1921; Richardson and Lister, 1969; Williams, 1978).

The Freshwater East Formation is succeeded by the Moor Cliffs Formation. This is 119.56 m thick and consists predominantly of red and green mudstones in which calcrete glaebules and tubules are abundant, commonly arranged in pseudo-anticlinal structures. Subordinate lithologies include very fine- to fine-grained sandstones, exotic and intraformational conglomerates and airfall tuffs. The Townsend Tuff Bed is the thickest (2.81 m) of the tuffs. It crops out on the foreshore immediately north of Little Furzenip [SR 8847 9946] and is visible when the sand cover is removed. It lies 37.89 m above the base of the Moor Cliffs Formation (in contrast to 300 m on the northern limb of the same fold) and is succeeded by 13.53 m of beds in which there are five thin (0.01–0.11 m), pink-purple dust tuffs (markers B, C, E, F and G of Allen and Williams, 1982; Marker D is apparently absent here because of erosion). These are overlain by the Pickard Bay Tuff Bed, which is 1.25 m thick (Allen and Williams, 1982). A medium- to coarse-grained, cross-bedded litharenite lies 56 m above the Townsend Tuff Bed and forms a prominent rib on the foreshore and Little Furzenip headland. The sandstone rests on an erosion surface and the cross-bedding is in four to six tabular sets. The highest beds of the formation crop out on Little Furzenip headland [SR 8851 9939], where red mudstones, in beds up to 5.7 m thick, contain abundant calcrete, mainly in the form of large concretions and rods, which locally show a preferred orientation parallel to cleavage or are arranged in pseudo-anticlinal festoons. The calcretes are arranged in stacked profiles and are correlated with the Chapel Point Calcretes Member of Pembrokeshire and the Psammosteus Limestone (Bishop's Frome Limestone) of the Anglo-Welsh Basin.

The abrupt junction between the Moor Cliffs Formation and the overlying Freshwater West Formation is well exposed on the southern side of Little Furzenip headland. The latter is 345.78 m thick and can be examined in great detail on the wave-polished foreshore section between the headland and the base of the Ridgeway Conglomerate Formation to the south (Williams, 1971, 1978). The lower part of the formation (the Conigar Pit Sandstone Member) is sandstone-dominated (e.g. Williams and Hillier, 2004), whereas mudstone predominates in the upper part (the Rat Island Mudstone Member). The Conigar Pit Sandstone comprises intraformational conglomerates, very fine- to medium-grained sandstones and calcrete-bearing mudstones, commonly arranged in upward-fining cycles (Figure 5.60). The conglomerates contain calcrete and mudstone clasts, mainly of pebble grade, and overlie low-relief erosion surfaces. They and the coarser sandstones contain fish fragments at four horizons, including plates, spines and scales of pteraspids, onchids and traquairaspids. The member can be examined in detail near the range warning sign [SR 8857 9917]. The sandstones are mainly fine grained, red and green, parallel or cross-bedded (Figure 5.61), and fine upwards into ripple cross-laminated units. Some of the sandstone-conglomerate bodies are stacked into thick complexes with lateral accretion surfaces. Many of the sandstones and some mudstones are bioturbated. Concentrations of burrowing activity occur at two horizons and include exceptionally preserved examples of *Beaconites barretti* (Morrissey and Braddy, 2004). Plant debris occurs in some sandstones, and spores (including two new species) have been recovered from green mudstone layers within green sandstones 112 m and 160 in from the base of the member (Higgs, 2004). The microflora is assigned to the middle part of the *Emphanisporites–micrornatus–Streelispora–newportensis* (MN) Zone of mid-Lochkovian age.

The mudstones of the Conigar Pit Sandstone Member are laminated or massive, blue-mottled and contain small burrows. Some very fine-grained sandstone-mudstone complexes contain desiccation cracks and arthropod tracks. Some soft-sediment deformation structures in the form of sandstone balls in mudstone occur locally. Calcrete is common in the mudstones, including nodules, massive limestone and veins, and in pseudo-anticlinal fans. The top of the Conigar Pit Sandstone is placed at the top of the highest thick (5.18 m), green sandstone complex, which has a rare extraformational conglomerate at its base.

The Rat Island Mudstone Member consists mainly of thick, red mudstones that are blue-mottled, laminated and contain calcrete in the form of nodules, pseudo-anticlinal fans and some massive horizons. There are a few very fine-grained, ripple-laminated sandstones with *Beaconites antarcticus.* There are also some prominent thick (2.05 m), coarse, pebble intraformational conglomerates with burrows and fish scales.

The disconformable junction between the Rat Island Mudstone and the overlying Ridgeway Conglomerate Formation is placed at the base of an intraformational conglomerate-mudstone complex. The mudstones in the Ridgeway Conglomerate are different from those in the underlying Rat Island Mudstone in being brighter red and ill-sorted, with scattered granules and small pebbles of vein quartz and carbonate. The sandstones are also different in that they are phyllarenitic in composition. The Ridgeway Conglomerate Formation (Williams, 1971, 1978) is a broadly upward-coarsening sequence of red, sandy mudstones with calcrete and ill-sorted mudrocks, fine- to coarse-grained litharenites rich in metamorphic and sedimentary rocks, and exotic, mainly clast-supported, petromict conglomerates (Figure 5.62). The formation is 115 m thick and contains eleven conglomerate bodies ranging from 0.6 m to 9 m thick, which make up 30 m of the formation. These overlie erosion surfaces and are massive or have weak internal cross-bedding or horizontal bedding, with some clast imbrication. The conglomerates are mainly framework-supported, with clasts ranging from 4 mm to 64 mm (Figure 5.63), but a 9 m-thick unit 14 m below the top of the formation contains vein quartz boulders up to 30 cm, the largest recorded anywhere in the formation. The clasts are of protoquartzite, lithic greywacke, siltstone and vein quartz, with a marked increase in abundance of phyllite debris in the higher conglomerates. The matrix is coarse-grained, lithic sandstone with rare carbonate cement. The thick conglomerates are poorly to fairly sorted, with some clast imbrication. The thinner units are matrix-supported and contain irregular gravel seams and lenses, outsize clasts and isolated gravel-filled scours.

The sandstones in the formation are fine- to coarse-grained litharenites, many of them rich in phyllite fragments. They are massive or graded, parallel bedded or cross-bedded and locally burrowed. The mudstones are mainly thick and bright red and are ill-sorted, with quartz grains and granules, as well as seams of vein quartz, carbonate debris and exotic granule-and fine pebble-grade detritus. Calcretes occur as nodular, prismatic, massive and vein horizons.

The Ridgeway Conglomerate Formation is overlain with no local angular discordance, but with regional unconformity, by the Skrinkle Sandstones Group. The abrupt facies change is well exposed in the cliff and foreshore [SR 8873 9891]. Fish scales (*Holoptychius*)are recorded from a very fine-grained sandstone in the cliff immediately above the junction (Dixon, 1921).

The Skrinkle Sandstones Group comprises two formations, the Gupton Formation and the West Angle Formation (Marshall, 1977, 1978, 2000a,b). The Gupton Formation is subdivided into the Lower Sandstone Member and overlying Stackpole Sandstone Member. Marshall (e.g. 2000a) carried out a detailed analysis of the facies present and their associations. The Lower Sandstone Member is 55 m thick and crops out in the cliffs and foreshore [SR 8876 9885], where it consists of thick, lenticular and tabular sandstones and pebbly sandstones that coarsen and thicken upwards. These show an upward change through three facies associations from lowermost small multi-storey sandstones in a background of mudstone and siltstone to thicker single-storey sandstones and then to stacked, pebbly, sandstone-based fining-upward units. The Stackpole Sandstone Member is exposed on the foreshore and in the cliff near the headland of Great Furzenip [SR 8875 9878]. It comprises a lower heterolithic, mudstone-dominated unit that includes a laminated fades of thinly bedded sandstones and mudstones passing up into fining-upward couplets of rippled sandstones and mudstones. An upper sandstone-dominated unit comprises pale yellow-white quartz arenites arranged in wedging and mutually eroded bodies. The sandstones are mainly parallel-laminated, and scour-and-fill structures are abundant. Where the ground rises to meet the headland of Great Furzenip, the white sandstones of the Stackpole Sandstone Member are overlain by the West Angle Formation. The lower part of this formation (the Conglomerate Member) consists of red sandstones, conglomerates and mudstones, and is markedly different in texture and composition from the underlying beds. The sandstones and conglomerates are rich in lithic debris and there is an abundance of cakrete in the mudstones, the fades being arranged in fining-upward couplets. Thin sheets of intraformational conglomerate and overlying rippled sandstone occur within the mudstones.

The upper part of the West Angle Formation (Red-Grey Member) is predominantly red, but is characterized by the incoming of sporadic grey-green sandstones and pebbly sandstones with well-preserved plant fragments. The sandstones occur at the bases of fining-upward sequences capped by calcretized red mudstones. Grey mudstones with freshwater microfossils, coalified plant debris and lingulids appear higher in the member, along with a few sheets of phosphatized pebble conglomerate. The topmost beds of the formation are interbedded red and grey sandstones with mudstone interbeds capped by a mature, calcareous sandstone with well-rounded quartz pebbles and sparse marine brachiopods and bryozoa.

Interpretation

The unconformity between the Moor Cliffs Formation and the Gray Sandstone Group at the base of the section represents a gap of at least 6 Ma, from the late Wenlock (Homerian) to the Lochkovian. This contrasts with the situation at Albion Sands, where the basal Old Red Sandstone facies has a gradational relationship with the Gray Sandstone Group (Hillier, 2000; Hillier and Williams, 2004). The lower part of the Freshwater East Formation is interpreted as a proximal alluvial deposit. The sheet-like, heterolithic units in the upper part represent deposition in an alluvial coastal-plain environment, with wave ripples and the presence of lingulids suggesting episodic marine influence, perhaps in estuarine tidal-flats or as storm washovers (Williams and Hillier, 2004).

The Moor Cliffs Formation is dominated by red mudstones that were traditionally referred to overbank deposition of a high-sinuosity fluvial systems in an alluvial coastal-plain setting (Allen and Williams, 1978; Williams *et al.,* 1982). Recently, however, detailed examination of the mudrocks of the Lower Old Red Sandstone has revealed a range of possible origins (Marriott and Wright, 1996, 2004; Marriott *et al.,* 2005). These authors propose a depositional environment similar to a modern tropical dryland river system *in* which moderately sinuous, anastomosing ephemeral rivers reworked muddy floodplain sediment during seasonal flooding. The floodplain sediments were pedifled to varying degrees as calcic vertisols (calcretes) and mud soil aggregates that were reworked by wind and/or water as sand- or silt-sized pelleted aggregates. Infrequent major flood events caused extensive stripping of sediment from the floodplain surface and the deposition of sand sheets. Ephemeral lakes formed in depressions on the floodplain after floods, trapping aeolian dust. Marriott and Wright (2004) recognize four mudrock facies:

- Heterolithic facies dominated by red mudstone with minor interbedded intraformational conglomerates (Type B of Allen and Williams, 1979b) and extraformational conglomerates (Type A of Allen and Williams, 1979b) and sandstones. These occur as low-angle inclined or horizontal units. The former are interpreted as lateral accretion deposits of the point bars of meandering channels, with the mudstone deposited from bedload as pedogenic mud aggregates. The horizontal units may be the products of rapid, crevassing events.
- Pedified purplish red to brownish red mudstones with calcrete nodules, pseudo-anticlines and slickensided surfaces.
- Brownish red burrowed mudstone units with *Beaconites*- and *Arenicolites*-type burrows. These commonly contain wave-rippled bed-forms and are interpreted as the deposits of shallow, semi-permanent floodplain lakes, although bioturbation, desiccation and pedogenesis largely destroyed any fine lacustrine lamination.
- Massive, brick-red mudstones, interpreted as fluvial deposits of silt- and sand-sized pedogenic aggregates, although aeolian reworking of some of the deposits may have also taken place.

Marriott and Wright (1993, 1996, 2004) suggested a dynamic environment in which stable periods with minor flood events produced steady aggradation of the floodplains. These were interrupted occasionally by major flood events when vast amounts of sediment were stripped and deposition in river channels took place.

The alluvial architecture of the sandstones of the Moor Cliffs Formation has been intensively studied (e.g. Williams and Hillier, 2004), particularly in the interval immediately above the Townsend Tuff Bed (Allen and Williams, 1982; Love, 1993; Love and Williams, 2000; Love *et ed.,* 2004). The sheet-like finer-grained sandstones were probably the products of unconfined sheet flooding over the floodplain. The coarser, cross-bedded sandstone 56 m above the Townsend Tuff Bed is an amalgamation of units produced by sheet-flood events, its erosive incision reflecting a drop in sea level that was possibly induced tectonically (Williams and Hillier, 2004).

The common presence of calcrete nodules in the formation is evidence of repeated, seasonal wetting and drying of the floodplain in a semiarid climate. The thick succession of stacked, mature calcretes (Stage III of Machette, 1985) of the

Chapel Point Calcretes Member points to a prolonged period of non-deposition, sediment starvation and basin shut-down. Each mature profile is estimated to have taken 10 000 years (e.g. Allen, 1974d, 1986), although Marriott and Wright (2004) note that rates of carbonate formation are highly variable, depending on factors including the porosity of the parent sediment and the carbonate content of the percolating water. Hundreds of thousands to millions of years may have been required for Stage III calcrete formation. The regional extent of these calcretes demonstrates 'shut-down' of the Anglo-Welsh Basin, after which sediment provenance, fish fauna and ichnofacies all changed.

The change in basin architecture instigated deposition of the more proximal Freshwater West Formation. The common cyclic arrangement of the facies in fining-upward sequences in the lower part (the Conigar Pit Sandstone Member) points locally to a fluvial origin in high-sinuosity meandering streams, as evidenced by common lateral accretion surfaces (Williams, 1978; Allen *et al.,* 1982). However, the basin infill architecture is variable, with unconfined sheet-flood fades also being abundant (Williams and Hillier, 2004). The basal part of the member here is more mud-rich than elsewhere in Pembrokeshire, perhaps due to its elevated position in the hanging-wall of the Ritec/Benton Fault (Williams and Hillier, 2004). A northerly provenance is indicated by palaeocurrent directions, in contrast to the southerly derived Ridgeway Conglomerate Formation above. The Rat Island Mudstone Formation is of muddy floodplain origin similar to that of the Moor Cliffs Formation (Marriott and Wright, 1993, 1996, 2004; Marriott *et al.,* 2005).

The Ridgeway Conglomerate Formation is interpreted as the deposits of an alluvial-fan system that prograded northwards over fringing alluvial mudflats or playas from an emergent southern source (Williams, 1971; Williams *et al.,* 1982; Tunbridge, 1986; Ekes, 1993). The source area may have formed as a result of uplift in the footwall of a fault in what is now the Bristol Channel during Acadian deformation (Marshall, 2000a). At least some of the red mudrock inter-beds in the formation owe their origin to deposition from bedload of pedogenic mud aggregates reworked from muddy floodplains (Ekes, 1993). Other mudrock facies represent mudflows on the fan surface (Williams *et al.,* 1982).

The Skrinkle Sandstones Group is interpreted as the fill of a post-Acadian synrift, fault-bounded basin in which alluvial-fan, lacustrine, braidplain delta and high-energy braidplain deposition took place successively in two superimposed sequences, the first an axial basin-fill, the second transverse fill (Marshall, 2000a,b). The Ritec Fault bounded the basin to the north, the succession thickening southwards in the hanging-wall of a fault in the present-day Bristol Channel. The first phase of the axial basin filling commenced with deposition of the Lower Sandstone Member of the Gupton Formation. Marshall (2000a,b) interpreted the three facies associations of the member respectively as small sheet-flood systems in a lacustrine or floodplain setting; isolated channel-fills; and meandering channel deposits. The coarsening- and thickening-upward nature of the succession suggested to Marshall a distal to proximal change and a SE-prograding terminal fan system. The lower part of the Stackpole Sandstone Member (mudstone-rich heterolithic association) is interpreted as lacustrine and lake-delta deposition, the upper (quartz arenite association) as high-energy, fluvial braidplain deposition. The textural maturity of the sandstones suggests long axial transport paths rather than local sourcing from the footwall of the Ritec Fault.

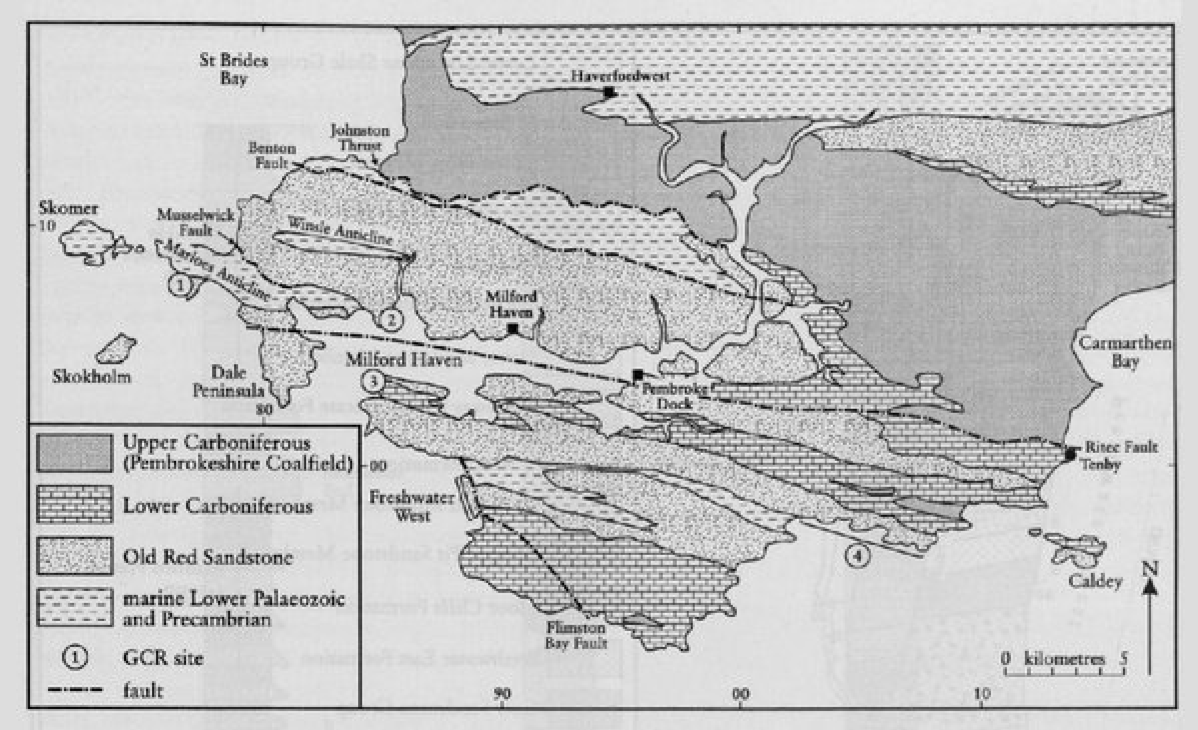
The West Angle Formation represents the second, transverse, basin-fill succession. Palaeocurrent directions in the lower part (the Conglomerate Member) indicate south and south-west drainage. Lateral accretion sets indicate point-bar formation and meandering river channels, with thin sheets of intraformational conglomerate and overlying rippled sandstone in the mudstone floodplain fades probably representing sheet-flood events. The upper part of the West Angle Formation (Red-Grey Member) is interpreted by Marshall (2000b) as recording the start of the Carboniferous transgression. The sporadic green beds and plant fragments point to a higher water-table on the alluvial floodplain. The progressive incoming of grey mudstones with freshwater microfossils, coafified plant debris and lingulids higher in the member suggests lacustrine deposition. The sheets of phosphatized pebble conglomerate contain bryozoa and sharks' teeth and indicate sporadic marine inundation prior to the main Carboniferous transgression. The calcareous sandstone at the top of the sequence has north-directed palaeocurrents and is interpreted by Marshall as a coastal barrier sand, with the underlying beds being lagoonal and washover fan deposits.

Conclusions

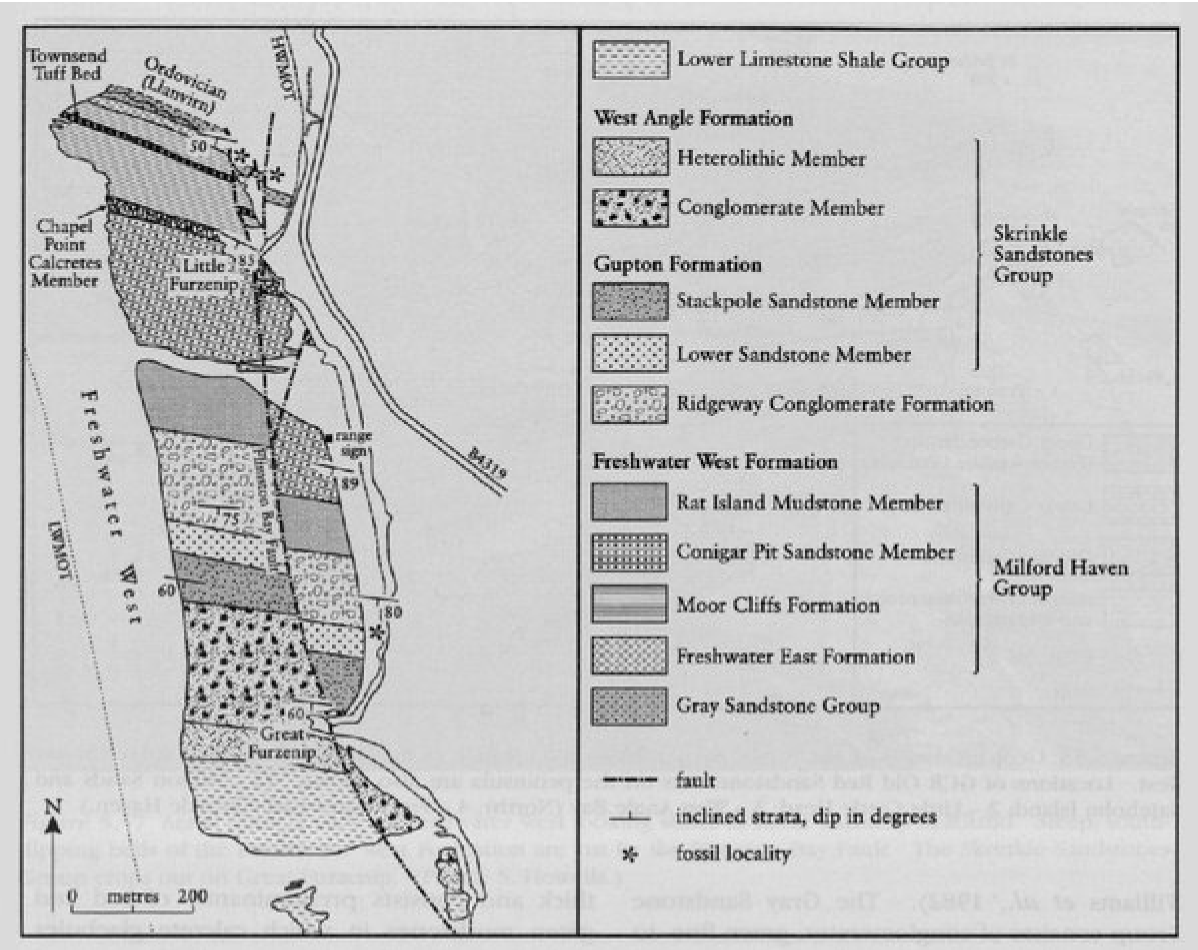
The importance of this site lies in the magnificent exposure of the entire Old Red Sandstone succession and the ease of accessibility of most of the rocks, which attracts large numbers of students and researchers. It is the classic section of the Lower Old Red Sandstone in southern Britain. The site has played a crucial role in the understanding of Old Red Sandstone-basement relationships in the Anglo-Welsh Basin, and of the tectonic and sedimentary history of the basin. The detailed sedimentological studies carried out here have vastly increased our knowledge of the terrestrial depositional environments of the Devonian. Also of prime importance is the part the site has played in the elucidation of the effects of contemporaneous faulting in controlling deposition. Along with the West Angle Bay (North) and Freshwater East-Skrinkle Haven sites, this site provides a complete picture of the transition into the overlying Carboniferous marine succession. Recent palynological study has added to the stratigraphical importance of the site by yielding an Early Devonian plant spore assemblage. Exceptionally well-preserved trace fossils provide an insight into the early animals that inhabited dry land for the first time.

References

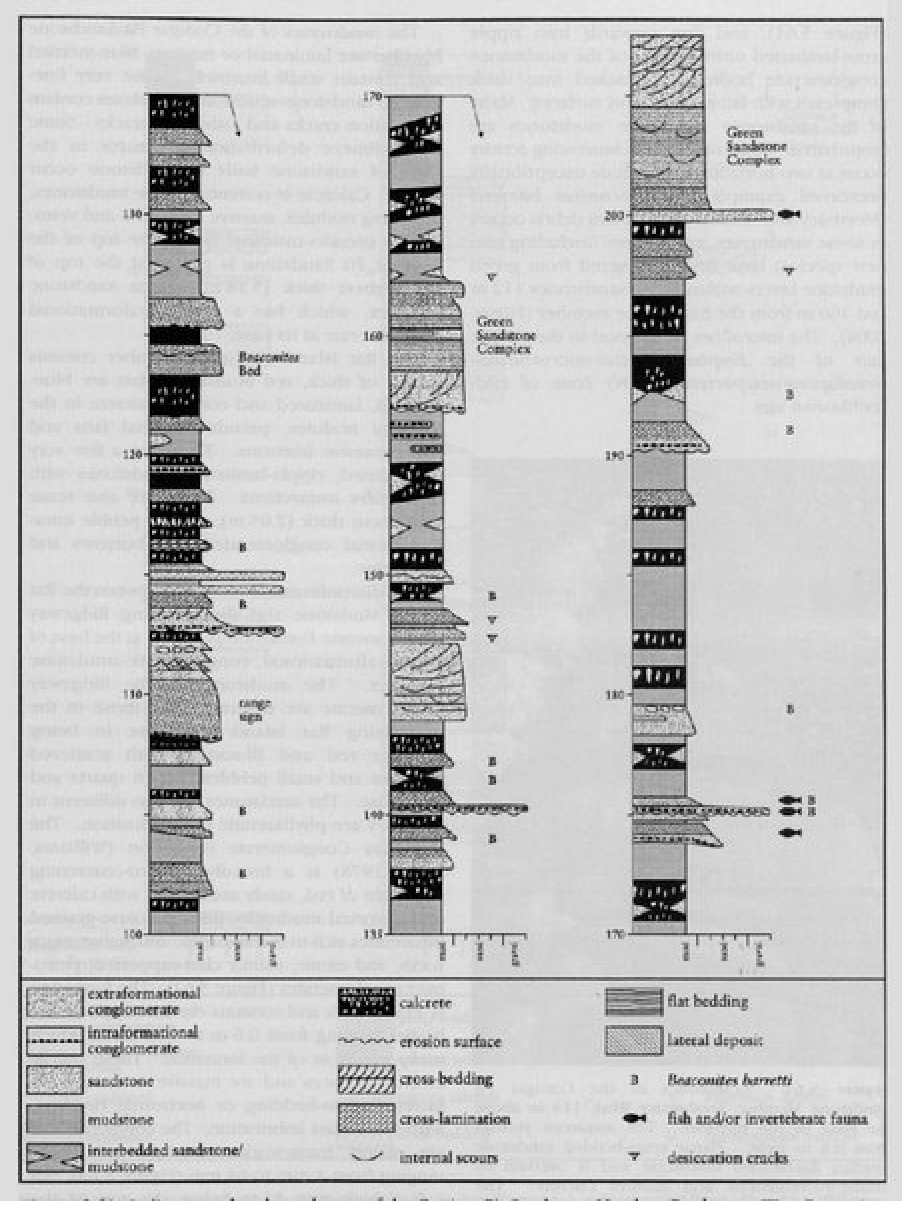
(Figure 5.57) Aerial oblique view of Freshwater West looking south to Great Furzenip headland. Steep, south-dipping beds of the Freshwater West Formation are cut by the Flimston Bay Fault. The Skrinkle Sandstones Group crops out on Great Furzenip. (Photo: S. Howells.)



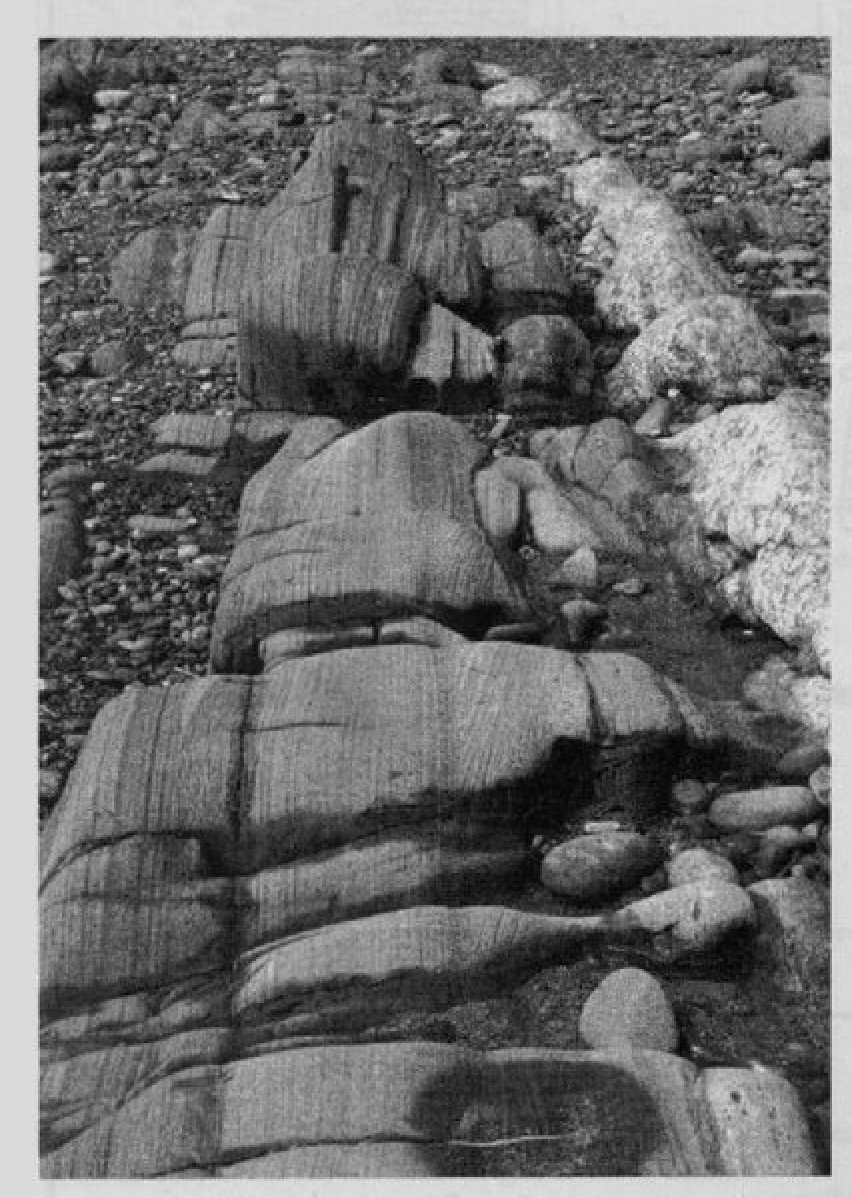
(Figure 5.58) Geological map of the Pembroke peninsula and location of the potential GCR site at Freshwater West. Locations of GCR Old Red Sandstone sites on the peninsula are also shown. (1 — Albion Sands and Gateholm Island; 2 — Little Castle Head; 3 — West Angle Bay (North); 4 — Freshwater East–Skrinkle Haven.)



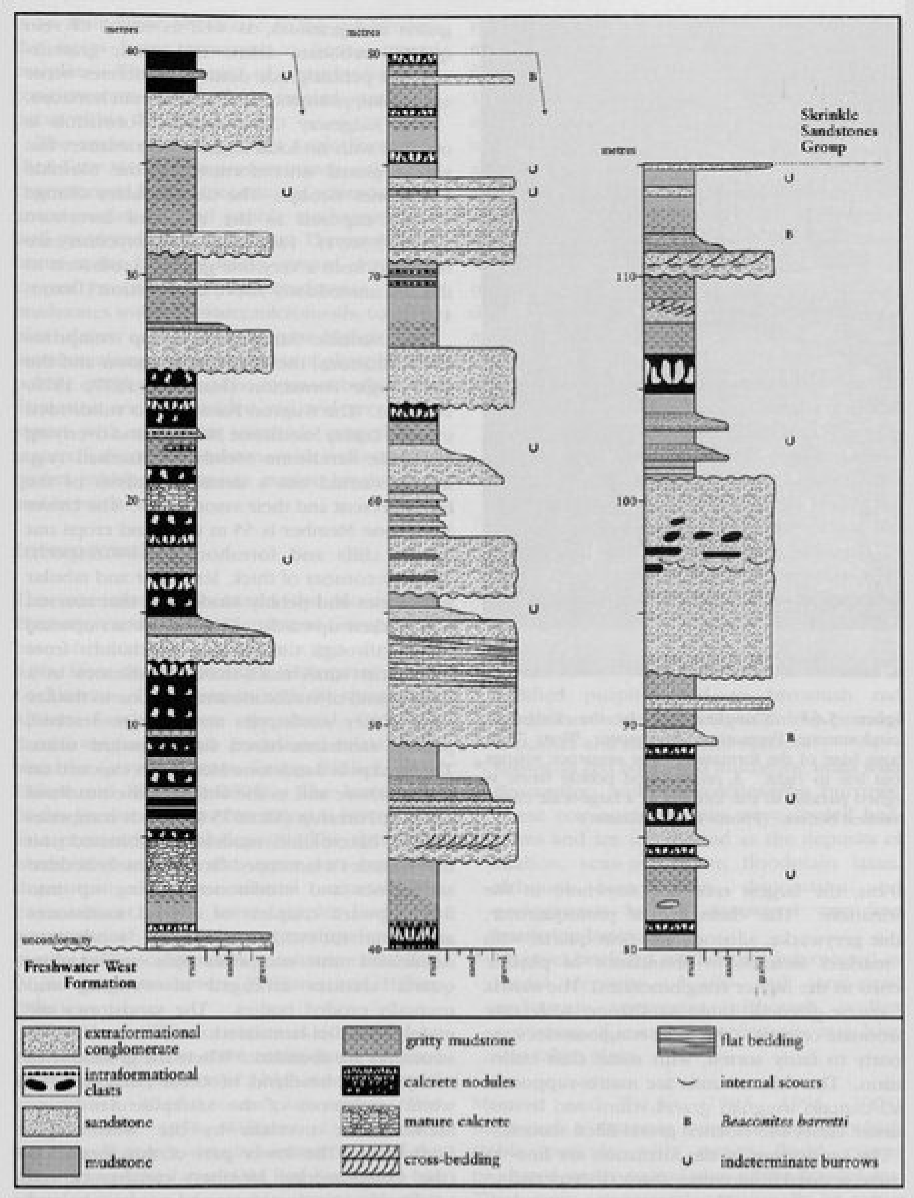
(Figure 5.59) Geological map of Freshwater West. Based on Williams (1978), Allen et al. (1981b) and Williams et al. (1982).



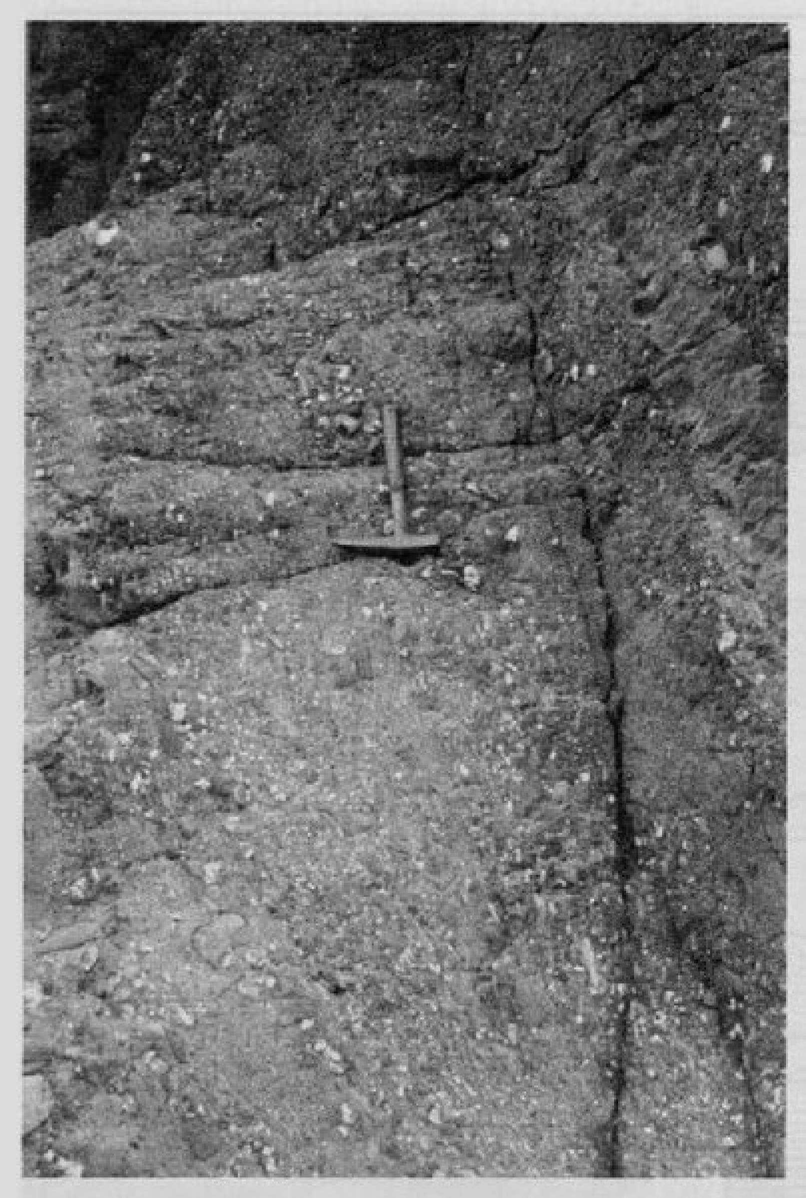
(Figure 5.60) Sedimentary log through part of the Conigar Pit Sandstone Member, Freshwater West Formation at Freshwater West. Thicknesses are in metres from the base of the member. Based on Allen et al. (1981b) and Williams et al. (1982).



(Figure 5.61) Sandstones of the Conigar Pit Sandstone Member, Freshwater West, 114 m above the base of the member. The sequence youngs from left to right. Planar cross-bedded sandstone overlies flat-bedded sandstone and is overlain by sandstone/mudstone and massive calcrete. The sandstones are interpreted as sheet-flood deposits. (Photo: B.P.J. Williams.)



(Figure 5.62) Sedimentary log of the Ridgeway Conglomerate Formation at Freshwater West. Based on Williams et al. (1982) and Allen et al. (1981b).



(Figure 5.63) Conglomerate in the Ridgeway Conglomerate Formation, Freshwater West, 73 m above base of the formation. The sequence youngs from left to right. A pronounced pebble fabric is aligned parallel to the foresets of a large-scale cross-stratified bedset. (Photo: B.P.J. Williams.)