British Cambrian to Ordovician Stratigraphy

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Chapter 4

Cambrian of South Wales: St David's area

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INTRODUCTION

The St David's peninsula exposes a fairly complete succession of Cambrian rocks from the Comley Series up to the mid-Merioneth, the St David's Series being well represented. Several of the rock units are of distinctive lithologies, and, despite the very extensive faulting in the area, St David's was historically the first area in Britain in which satisfactory early and mid-Cambrian stratigraphical and palaeontological successions were worked out.

The earliest Geological Survey maps of the area, produced in 1857, grouped together the rocks now known as Precambrian, the Caerfai Group and the Solva Group within the 'Cambrian'; the overlying 'Lingula Flags' was regarded as 'Lower Silurian'. Harkness and Hicks (1871) established the rock succession much as it is recognized today, placing the base of the Cambrian at a prominent conglomeratic unit; they classified the 'quartziferous' rocks below as 'pre-Cambrian' or 'Laurentian' and the coarse sediments above the conglomerate and below the trilobite-bearing Menevian Group as Lower Cambrian or 'Longmynd Group'. In place of the 'Longmynd Group', Hicks (1881b, p. 297) later established the Caerfai and Solva groups, with the conglomerate being at the base of the Caerfai Group. Cowie *et al.* (1972) proposed names for Hicks' informal divisions of the Caerfai Group, but the Solva is still subdivided only into informal units.

Further study led Hicks (1877) to separate the 'quartziferous' rocks into two divisions, the 'Pebidian' (now interpreted as volcanic rocks) and 'Dimetian' (intrusive rocks). However, Hicks' interpretation of the Pebidian and Dimetian as Precambrian brought him into conflict with Geikie (1883), who would not accept the presence of 'pre-Cambrian' rocks in areas mapped by the Survey as Cambrian. Pearson and Nicholas (1992) tell how this controversy became heated and was resolved only when Green's (1908) detailed mapping demonstrated an angular unconformity at the base of the

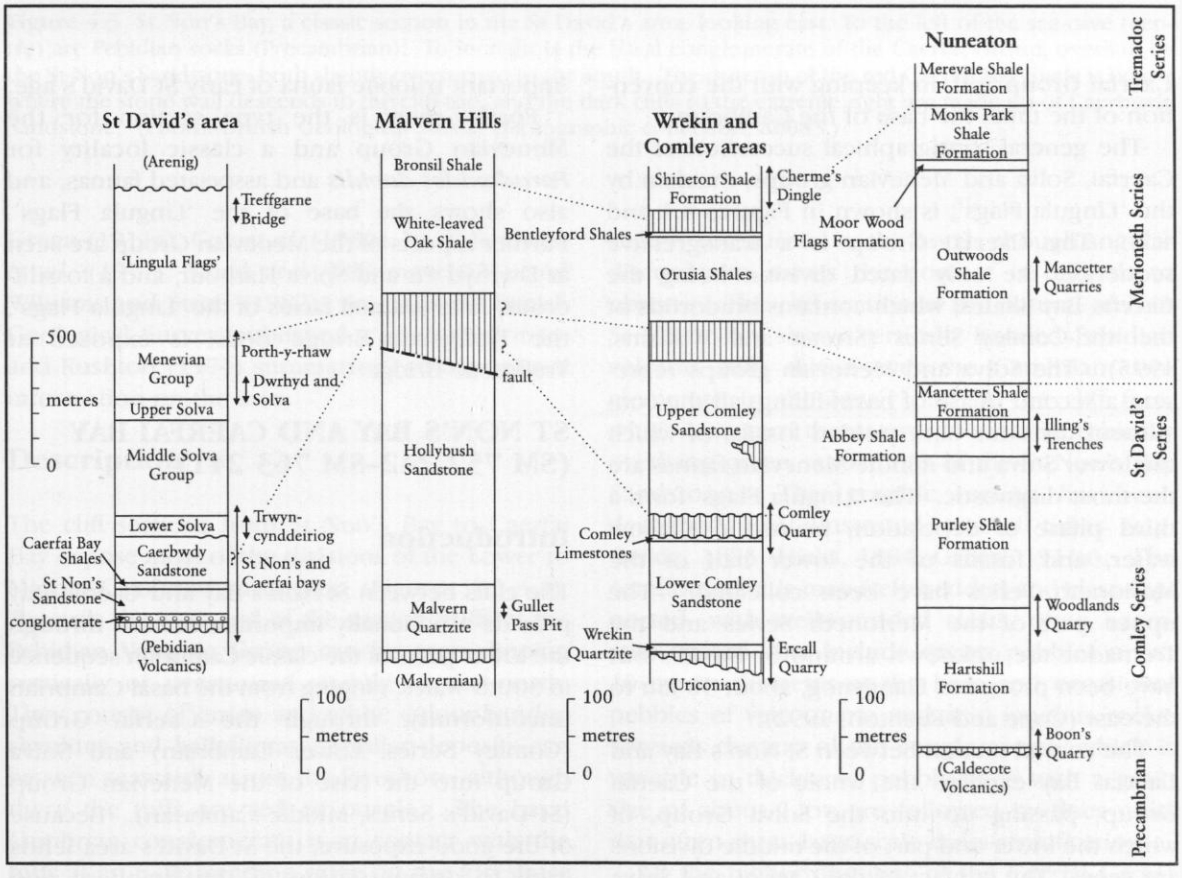

Figure 4.1 Correlation of the principal Cambrian sequences in South Wales and England, modified from Rushton (1974, figs 2, 3). The stratigraphical ranges of the GCR sites are indicated. For the location of Treffgarne Bridge, see Figure 8.1.

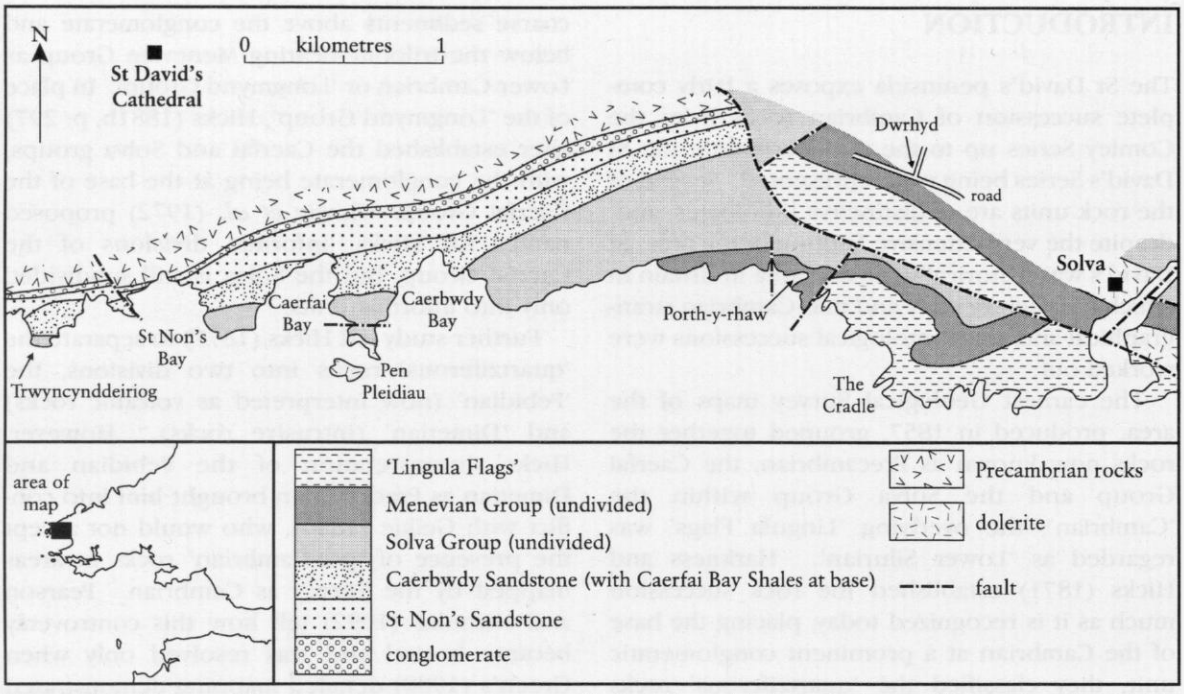

Figure 4.2 Sketch of the Cambrian geology between St David's and Solva, south-west Wales, after the British Geological Survey (1973), with locations of the GCR sites.

Caerfai Group and, in keeping with the convention of the time, the base of the Cambrian.

The general stratigraphical succession of the Caerfai, Solva and Menevian groups, overlain by the 'Lingula Flags', is shown in Figures 4.1 and 4.2. The Caerfai Group is a transgressive sequence, the only dated division being the Caerfai Bay Shales, which contains bradoriids of the mid-Comley Series (Siveter and Williams, 1995). The Solva and Menevian groups represent a second phase of basin-filling; all the constituent divisions have yielded fossils, of which the lower Solva and middle Menevian faunas are the most diagnostic. The 'Lingula Flags' form a third phase of deposition, mainly in shallow water, and fossils of the lower half of the Merioneth Series have been collected. The upper part of the Merioneth Series and the Tremadoc are unknown around St David's but have been proved at Llangynog, about 50 km to the east (Cope and Rushton, 1992).

The coastal section between St Non's Bay and Caerfai Bay exposes the whole of the Caerfai Group, passing up into the Solva Group, of which the lower and part of the middle divisions are seen. The contact of the Caerfai and Solva groups is well exposed to the west of St Non's Bay at Trwyncynddeiriog and there yields an important trilobite fauna of early St David's age.

Porth-y-rhaw is the type section for the Menevian Group and a classic locality for *Paradoxides davidis* and associated faunas, and also shows the base of the 'Lingula Flags'. Further aspects of the Menevian Group are seen at Dwrhyd Pit and Solva Harbour, and a fossiliferous, finer-grained facies of the 'Lingula Flags', the Treffgarne Bridge Beds, is exposed at Treffgarne Bridge.

ST NON'S BAY AND CAERFAI BAY (SM 752 242–SM 763 241)

Introduction

The cliffs between St Non's Bay and Caerfai Bay provide a nationally important section through the lower parts of the classic Cambrian sequence in South Wales, ranging from the basal Cambrian unconformity, through the Caerfai Group (Comley Series, Lower Cambrian) and Solva Group into the base of the Menevian Group (St David's Series, Middle Cambrian). Because of the good exposure, the St David's area lends itself to demonstration of stratigraphical and sedimentological features. Excursion guides and geological accounts have been published by

Figure 4.3 St Non's Bay, a classic section in the St David's area, looking east. To the left of the sea-cave (centre) are Pebidian rocks (Precambrian). To its right is the basal conglomerate of the Caerfai Group, overlain by the St Non's Sandstone, both slightly overturned to the south. The outcrop of the red Caerfai Bay Shale is below where the stone wall descends to the cliff-top, and the dark cliffs to the extreme right are made up of Caerbwdy Sandstone. (Photo: British Geological Survey photographic collection, A6083.)

Green (1911a), Cox *et al.* (1930a, b), T. R. Owen *et al.* (1971), Stead and Williams (1971) and Williams and Stead (1982). In 1973 the British Geological Survey published a geological map, and Rushton (1974) summarized stratigraphical information on the area.

Description

The cliff sections from St Non's Bay to Caerfai Bay expose most of the divisions of the Lower to Middle Cambrian succession (Figures 4.2–4.4). Towards the west end of the section, tuffs of the Pebidian Volcanic Group can be seen dipping vertically or overturned slightly to the north. They consist of green and white colour-banded rhyolites and halleflintas. Similar deposits can be seen seawards across the foreshore, although there the tuffs are red or purple. The basal Cambrian conglomerate is in contact with the tuffs at an E–W trending ridge on the foreshore below St Non's Chapel and can be seen to the east on several sea stacks. The base is sharp and slightly overturned to the north, though angular discordance across the contact is difficult to observe. The cliff section at the natural arch in St Non's Bay shows vertically banded Pebidian volcanic tuffs thrust over the Cambrian conglomerate in the lower part of the cliff face, which is in turn thrust over the stratigraphically overlying green sandstones of the St Non's Bay Sandstone. This graphic section has been described and illustrated several times (e.g. Geikie, 1883; Hicks, 1884; Green, 1911a). The conglomerate is massively bedded and clast-supported, with well-rounded clasts, often haematite coated, that include quartz pebbles up to 10 cm in diameter at the base and occasional pebbles of vein quartz and acid igneous rocks. Towards the top of the conglomerate, which is variable in thickness, pebbly beds with a grain size of about 1 cm are followed by finer units that often show large-scale cross-stratification.

All the higher divisions of the Caerfai Group can be seen in the cliffs around St Non's Bay but are more accessible in Caerfai Bay. The St Non's

Figure 4.4 Caerfai Bay, looking east. Thickly bedded Caerbwdy Sandstone dips steeply to the South, overlain by more thinly bedded units of the Solva Group, a considerable part of which is faulted out. At the extreme right is a dolerite intrusion associated with part of the Menevian Group. (Photo: British Geological Survey photographic collection, A6088.)

Bay Sandstone, exposed at the northern end of Caerfai Bay, consists of soft, green, medium- to coarse-grained feldspathic sandstones containing epidote and chlorite, and include subsidiary siltstones. The strata dip south at 70° to 80°. Beds are generally less than 1 m thick and are massive and unfossiliferous; most are structureless, but large-scale tabular cross-stratification can be seen in some sandstones, while some siltstones show climbing ripple cross-lamination. One bed on the east side of the bay has an irregular base with a channel cutting down into the sandstone below. The channel-fill consists of cross-laminated sandstone and the rest of the bed is homogenized. Trace fossils include *Skolithos*, U-shaped burrows filled with coarse sediment, and escape burrows showing backfill structures.

The uppermost part of the St Non's Sandstone consists of purple siltstones, some units of which are bioturbated, show *Skolithos* burrows, and are cemented by calcite (Turner 1979). These appear to pass up rapidly into the Caerfai Bay Shales, which are about 15 to 25 m thick (Turner 1979; Landing *et al.* 1998), and consist of cleaved mudstones of a distinctive brick-red colour that show little internal structure because they are homogenized by ubiquitous bioturbation. Williams and Stead (1982) recorded the feeding burrow *Teichichnus*. There are several interbeds of water-laid crystal tuffs up to 8 cm thick. Internally these show cross-lamination and convolute lamination, and commonly have sharp erosive bases, sometimes with load casts or a coarse basal lag (Turner 1979; Williams and Stead 1982). The tops may show an irregular bioturbated top with parallel laminated sand and mud above. The tuff beds, which are the first indication of contemporaneous volcanic activity in the Cambrian of South Wales, have yielded a radiometric age of 519 ± 1 Ma (Landing *et al.* 1998).

The Caerfai Bay Shale is the lowest horizon in Pembrokeshire from which fossils have been obtained, although from localities other than Caerfai Bay. Hicks (in Harkness and Hicks, 1871,

p. 396) recorded brachiopods (*Lingulella primaeva* Hicks) and an ostracod ('*Leperditia?*' *cambrensis* Hicks). Siveter and Williams (1995) made further collections, discussed below.

The red shales pass gradually up into the purple Caerbwdy Sandstone. The transition has thin (1–2 cm) purple sandstone beds that become commoner and thicker upwards. When fully developed, the Caerbwdy Sandstone consists of unfossiliferous fine- to medium-grained, thickly bedded (up to 1 m), massive sandstones. They have been quarried locally for building-stone. The sandstones are usually poorly sorted and are micaceous, feldspathic and somewhat argillaceous. Cross-bedding and graded bedding occur very occasionally, and some beds show ripple cross-laminated and parallel-laminated intervals with muddy drapes. Bioturbation is common, with *Skolithos* and bedding-parallel burrows present. Near the junction with the overlying Solva Group some beds become pebbly, with rounded quartz grains and igneous fragments.

The junction of the Solva Group and Caerbwdy Sandstone is exposed on the east side of Caerfai Bay (7617 2420). It was here that Jones (1940) cited evidence for an unconformity between the Solva and Caerfai groups. He interpreted an offset in the base of the Solva Group as an erosional contact on the uneven surface of Caerbwdy Sandstone, with a considerable break in deposition. However, Stead and Williams (1971) suggested that this contact is faulted, and reported a more gradual transition from purple to green beds higher in the cliff-face that can be verified also on the west side of the bay (7578 2411), where the transition is not complicated by faulting. This is in agreement with the boundary seen at Trwyncynddeiriog (see site report, below).

Towards Pen y Cyfrwy, the western headland of Caerfai Bay, beds of the lower Solva Group are gently folded and faulted against the Caerbwdy Sandstone. The lower beds consist of green, medium-bedded, coarse to pebbly sandstones, intercalated with finer sandstones and thin mudstones. The thicker sandstones often show truncated tabular cross-stratification on a large scale, while finer units may show ripple cross-lamination. The pebbly units disappear up sequence, giving way to thinly bedded sandstones, siltstones and mudstones. Fossils occur at about this level at Trwyncynddeiriog.

The stratigraphy of the remainder of the Solva Group around Caerfai Bay is affected by strike-faulting. On the east side (Figure 4.4) the cliffs are made up of steeply dipping, fine- to medium-grained green sandstones in thick, massive beds that generally lack sedimentary structures. Thickly bedded green and purple sandstones representing part of the middle Solva Group extend south to a major strike fault that runs across the headland, south of which the Menevian Group is exposed dipping south at about 40°. The latter consists of dark- and light-grey mudstones typical of the group (see Porth-y-rhaw) and is overlain by a felsite sill. Towards the sill, where the beds are thermally spotted and bleached, are localities that yielded *Onymagnostus barrandei* (Hicks) and good material of *Plutonides hicksii* (Salter) to Salter and Hicks (1869, pl. 3).

Interpretation

This site provides the best stratigraphical section through the lower parts of the Cambrian sequence in South Wales, from the basal Cambrian unconformity upwards. The unconformable nature of the contact of the basal conglomerate of the Caerfai Group on the Precambrian Pebidian Volcanic rocks is difficult to ascertain in natural exposures, and in many places the contact is clearly faulted. However, Green (1908), by detailed mapping of subdivisions of the Pebidian Volcanic Group, was able to demonstrate regional unconformity; he also made a trench that exposed an unconformable contact between the Cambrian conglomerate and the underlying Dimetian granophyre, which intrudes the Pebidian Group. The coarse nature of the basal conglomerate and large-scale cross-stratification in the finer beds indicate that it was deposited in shallow-water, possibly intertidal, environments (Crimes, 1970a). Orientation of the tabular cross-bedding suggests transport from the NNE. Many clasts in the conglomerate are derived from the Pebidian volcanics, but pebbles of Dimetian granophyre are practically unknown.

The St Non's Bay Sandstone was deposited in shallow water. The presence of cross-bedding limited to channel-fillings and the escape burrows indicate rapid deposition of individual beds. Most of the sandstones were presumably intensely bioturbated in well-oxygenated environments. Although all earlier workers reported a gradational contact between the St Non's

Sandstone and the Caerfai Bay Shales, Landing *et al.* (1998) interpreted the top bed of the St Non's Sandstone as a caliche horizon (presumably indicative of subaerial erosion in a hot arid climate) and interpreted the contact with the overlying Caerfai Bay Shales as an unconformity which they compared with the unconformity at the base of the Branchian in south-eastern Newfoundland. However, published maps of the St David's peninsula (British Geological Survey 1973) offer no evidence to suggest an unconformity between the two formations across their entire outcrop, and Landing *et al.*'s suggestion remains to be documented.

Compared with the St Non's Sandstone, the finer grain-size of the Caerfai Bay Shales implies less energetic environments of deposition, though the sedimentary structures in the tuff beds indicate origins from waning flow events, such as storms. The red colour of the mudstones was shown by Turner (1979) to be caused by diagenetic alteration of iron silicates in oxidizing conditions; he surmised that reducing conditions were not developed because organic productivity was low or because the organic matter present was oxidized before burial of the sediment.

Features of the Caerbwdy Sandstone again indicate rapid deposition in high-energy environments. Crimes (1970a, fig. 27) suggested that deposition took place below wave-base, and that the whole Caerfai Group therefore appears to show a transgressive sequence with deposition in a gradually deepening sea. However, the presence of *Skolithos* burrows in the Caerbwdy Sandstone suggests shallow-water deposition, comparable to that in the overlying Solva Group.

The identification of the bradoriid arthropod *Indiana lentiformis* (Cobbold) in the Caerfai Bay Shales has for the first time provided a correlation with the Callavia Sandstone (Ac2) of the Comley succession in Shropshire (Siveter and Williams, 1995) and allows correlation of the Caerfai Bay Shales with the Branchian Series. The underlying divisions of the Caerfai Group, are, by inference, also referred to the Lower Cambrian. However, the correlation of the Caerbwdy Sandstone in relation to the Comley–St David's series boundary remains conjectural. Locally the lower beds of the Solva Group yield the oldest trilobite faunas known from South Wales, which represent the *oelandicus* Zone (see Trwyncynddeiriog site report) and allow reference of the whole Solva Group succession to the St David's Series.

Although there has been discussion over the nature of the boundary between the Caerbwdy Sandstone and the lower Solva Group, most evidence indicates that sedimentation was continuous, though development of pebbly beds may indicate shallowing. However, the succession higher in the Solva Group at this site is much affected by strike-faulting, and the transition upwards into the Menevian Group is faulted out. Sedimentary structures and *Skolithos* burrows in the sandstones of the lower Solva Group suggest energetic deposition above wave-base (Crimes, 1970a). Features in the middle Solva Group suggest similarly rapid deposition of the sandstones, with quieter environments for deposition of the finer sediments. Crimes (1970a) identified a source of sediments to the south-east.

The Menevian Group is represented only by the lower part of the group, referable to the *fissus* Zone. The Menevian is considered further in the Porth-y-rhaw site report (see below).

Conclusions

The extensive coastal exposures from St Non's Bay to Caerfai Bay provide the best and most instructive section through the lower parts of the Cambrian sequence in South Wales. The lowest beds, deposited in shallow water after erosion of the underlying Precambrian volcanic rocks, are the representatives of the Lower Cambrian marine transgression. The general upward succession of the Caerfai Group, the conglomerate, green sandstones and red shales, appear to represent deposition in shallow, though progressively deeper, water. The red shales contain the only fossils that demonstrate the presence of Lower Cambrian rocks in South Wales and also contain volcanic ash that has been dated as 519 million years old. After an episode of shallowing around the boundary between the Caerfai and Solva groups, the overlying succession, which contains Middle Cambrian fossils, suggests a second cycle of gradual deepening.

TRWYNCYNDDEIRIOG (SM 746 239–SM 748 240)

Introduction

This site lies west of the St Non's Bay–Caerfai Bay site and shows part of the same succession but is important because it is the lowest horizon

from which St David's (Middle Cambrian) fossils have been found in Wales; these serve to date the succession.

Salter and Hicks (1869, p. 52) reported the discovery of fossils in the lower part of the Solva Group, and Hicks (in Harkness and Hicks, 1871) described the fauna as from a 'headland near Nun's well'. Until the discovery of useful fossils in the Caerfai Bay Shales (Siveter and Williams, 1995), this was the oldest fauna of stratigraphical value in South Wales, and it remains of significance, underpinning the whole Solva succession. Further collections have been made by Dr M.Z. Farshori (Smith and White, 1963, p. 404) and M. Lewis (1987, unpublished).

Description

The headland of Trwyncynddeiriog exposes sandstones of the Solva Group overlying the Caerbwdy Sandstone (Figure 4.5). Interpretations of the boundary between these divisions as exposed in Caerfai Bay have differed (see site report, above), but here the boundary is transitional. The rocks are sub-vertical, dipping north at about 80°. The purple Caerbwdy Sandstone occurs as fairly uniform beds of fine-grained and micaceous sandstone, ranging in thickness from 10–30 cm. Towards the top they become coarse and pebbly, with rip-up clasts of red mudstone, and some beds fine upwards. Bases are often erosive on finer sandstones intercalated between them. A green sandstone bed 15 cm thick is followed by 30–40 cm of purple sandstone with red muddy drapes, before the transition to the Solva Group is reached.

The lower Solva Group sandstones are very similar to the Caerbwdy sandstones, apart from their colour. At the base, they consist of thinly bedded, grey-green, pebbly sandstones, 10–30 cm thick, with erosive bases on intercalated finer sandstones and mudstones; the mudstones are micaceous and commonly lenticular. Some thicker sandstone beds show large-scale tabular cross-stratification, and some finer sandstones show truncated cross-lamination. The sandstones may also wedge out laterally and may show convolute lamination, erosive bases and mud rip-up clasts. However, graded bedding and sole structures are absent (Crimes, 1970a). Towards the extreme south of the headland the coarse pebbly sandstones disappear, and the beds consist of thinly bedded sandstones and mudstones several centimetres thick. The strata

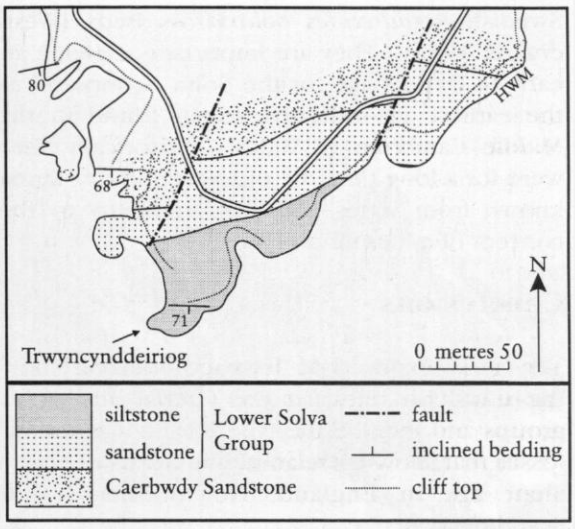

Figure 4.5 Geological map of Trwyncynddeiriog, after mapping by Lewis (1987, unpublished).

dip south at about 85°.

Probably less than 50 m of Solva Group strata are exposed, all referable to the 'lower Solva Beds' of Hicks, which are about 50 m thick. These beds, which are the type strata for the trilobites *Bailiella lyellii* (Figure 4.8c), *Condylopyge cambrensis*, *Eccaparadoxides harknessi* and *Plutonides sedgwickii*, all described by Hicks (in Harkness and Hicks, 1871), have also yielded other trilobites, hyolithids and sponge spicules.

Interpretation

The gradual transition seen from purple sandstones of the Caerbwdy Sandstone, through purple and green beds, into the green lower Solva sandstones, suggests that there was no appreciable break in sedimentation, nor any striking change in environments, at this time, supporting the view of Stead and Williams (1971) rather than that held by Jones (1940) with reference to Caerfai Bay. The Solva Group is interpreted as having accumulated in shallow, energetic environments, probably above wave base (see St Non's Bay site report, above).

The fauna contains species similar or identical to those found in other low St David's (early Middle Cambrian) strata in Britain, Sweden and Newfoundland, and indicates that the beds are referable to the *Paradoxides oelandicus* Zone (Figure 2.2). Rushton (1966, p. 8) correlated them with the upper or *pinus* Zone of the

Swedish *Paradoxides oelandicus* Beds (Westergård, 1936). They are important as giving an early St David's age for the Solva Group and as the earliest age-indicative fossils found in the Middle Cambrian of Wales. Historically they were for a long time the oldest significant fauna known from Wales and lent credibility to the concept of a 'Cambrian Fauna'.

Conclusions

The rocks exposed at Trwyncynddeiriog show the transition between the Caerfai and Solva groups and include the type locality for several fossils that allow correlation with rocks of equivalent age in England, Newfoundland and Scandinavia.

PORTH-Y-RHAW (SM 783 243–SM 786 241)

Introduction

Porth-y-rhaw is a classic geological locality of international importance. It exposes a fairly continuous sequence of strata from beds of the upper Solva Group up through the Menevian Group (St David's Series, Middle Cambrian). These rocks have yielded trilobite faunas ranging from an approximate equivalent of the *gibbus* Zone up to the *punctuosus* Zone and comprise one of the most complete zonal sequences for the Middle Cambrian known in Britain. The trilobite faunas enable correlation with strata both in Britain and elsewhere, and the site is the type area for several species of trilobites and other groups.

Salter discovered the locality of Porth-y-rhaw by accident in 1862, when he was mistakenly taken there by boat instead of to Solva Harbour. His discovery of the giant trilobite *Paradoxides davidis* and a prolific associated fauna (Salter, 1863, 1864b) enabled him to distinguish the beds from the 'Lingula Flags', and the name 'Menevian' was introduced for them by Hicks and Salter in 1866. Hicks subdivided the Menevian Beds into three divisions:

3. sandstones and shales with *Orthis hicksii*,
2. black flags and shales with *P. davidis*, and
1. grey flags with *P. hicksii*.

All three can be seen at Porth-y-rhaw. These divisions remain only as informal units, referred to as 'lower', 'middle' and 'upper' Menevian.

The locality is mentioned in accounts of the St David's area, notably by Cox *et al.* (1930a), who described the succession in detail, and in guides to the area (Cox *et al.*, 1930b; Owen *et al.*, 1971; Stead and Williams, 1971; Williams and Stead, 1982). Numerous fossils have been collected, and many museums house material from Porth-y-rhaw, but most valuable are the stratigraphically systematic collections of Lewis (unpublished; Jefferies *et al.*, 1987, p. 438) in the National Museum of Wales.

Description

Porth-y-rhaw is a small coastal inlet, on the eastern side of which the type section of the

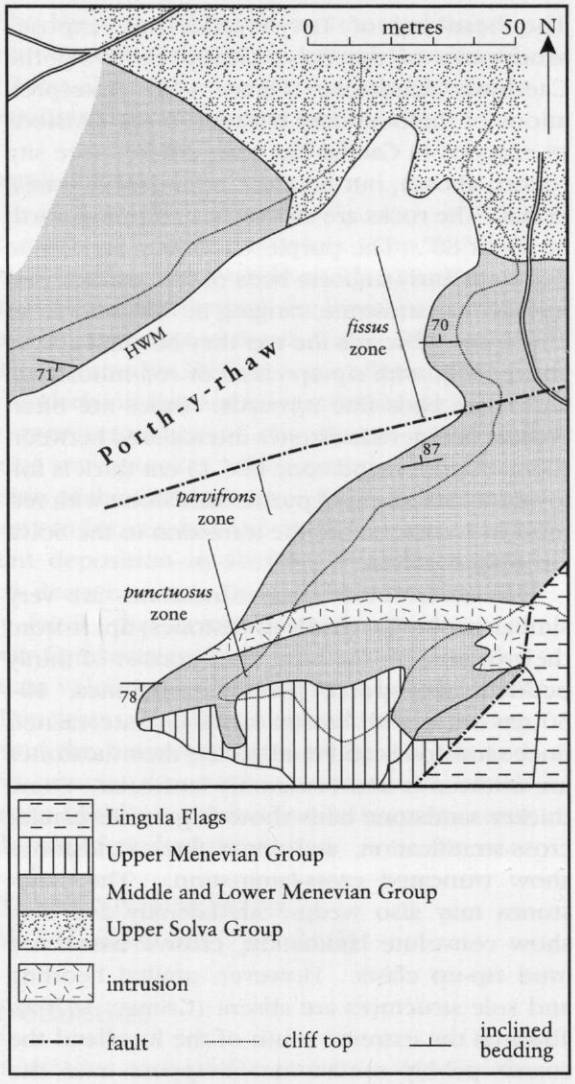

Figure 4.6 Geological map of Porth-y-rhaw, after Jefferies *et al.* (1987).

Figure 4.7 Eastern side of Porth-y-rhaw, showing dark mudstones of the lower and middle Menevian Group intruded by a dolerite sill (near the caves). The upper Menevian is at the extreme seaward end of the outcrop. (Photo: R.M. Owens.)

Menevian Group is exposed (Figure 4.6). The cliffs to the west expose the upper part of the Solva Group, which passes gradually upwards into beds of the lower Menevian Group (which they closely resemble), the boundary being poorly defined by Hicks (1881b, p. 298). To the east of the inlet (Figure 4.7) a normal fault throws the upper Menevian Group against the 'Lingula Flags'.

At the inland end of Porth-y-rhaw are grey flaggy sandstones and mudstones of the upper Solva Group overlain by the lower Menevian Group. The rocks are generally vertical or dip south at 80°. Though affected by minor faults, the succession is relatively complete. Green-grey sandstones and siltstones predominate and are medium- to coarse-grained, massive and thickly (10–50 cm) bedded. They often contain large horizontal and vertical burrows filled with dark-grey mudstone, some of which show back-fill structures. Dark-grey mudstones a few centimetres thick are intercalated between sandstones. The mudstones are commonly associated with thin, fine-grained sandstones, with sharp boundaries, that pinch and swell laterally and show ripple cross-lamination. Fossils are rare, but *Bailiaspis dalmani* (Angelin) and *Plutonides aurora* (Salter) are recorded from the upper Solva and suggest the presence of the *gibbus* Zone, whilst the base of the Menevian has yielded *Plutonides hicksii* (Salter) and *Tomagnostus fissus* (Linnarsson) and is referred to the base of the *fissus* Zone.

Up-section the grey sandstones become thinner and fewer. Thinly bedded, grey, flaggy siltstones alternate with dark-grey mudstones on a scale of a few millimetres to several centimetres, giving the rocks a striped appearance. Thin lenticular sandstones with ripple cross-lamination persist into these finer beds. The layers are planar but show much microfaulting. Internally, the dark-grey mudstones show little disruption, whereas lighter-grey silty mudstones contain abundant dark-grey mudstone lenses and dark flecks of organic matter and in places appear mottled, probably because of bioturbation. Certain beds contain the trilobites *Eodiscus punctatus* (Salter) *sensu lato*, *Peronopsis scut-*

alis (Hicks), *Plutonides hicksii* (Salter) and *Tomagnostus fissus*, with the brachiopod *Linnarssonia sagittalis* (Davidson), and are referable to the *fissus* Zone. The whole lower Menevian succession is about 100 m thick.

The lower Menevian Beds pass gradually upwards into cleaved mudstones of the middle Menevian Group, also approximately 100 m thick. They consist of well-laminated dark-grey mudstones and light-grey silty mudstones with sharp boundaries, alternating on a scale of several millimetres. Some disruption occurs in the lighter-grey layers, probably due to bioturbation. Thin black organic-rich layers, 2–3 mm thick, are occasionally intercalated. Thin lenticular sandstone interbeds show ripple cross-lamination and loaded and bioturbated bases. The beds are pyritous, and contain layers with numerous phosphate nodules (Hicks, 1875b). Thin, pale beds of metabentonite resemble those in equiv-

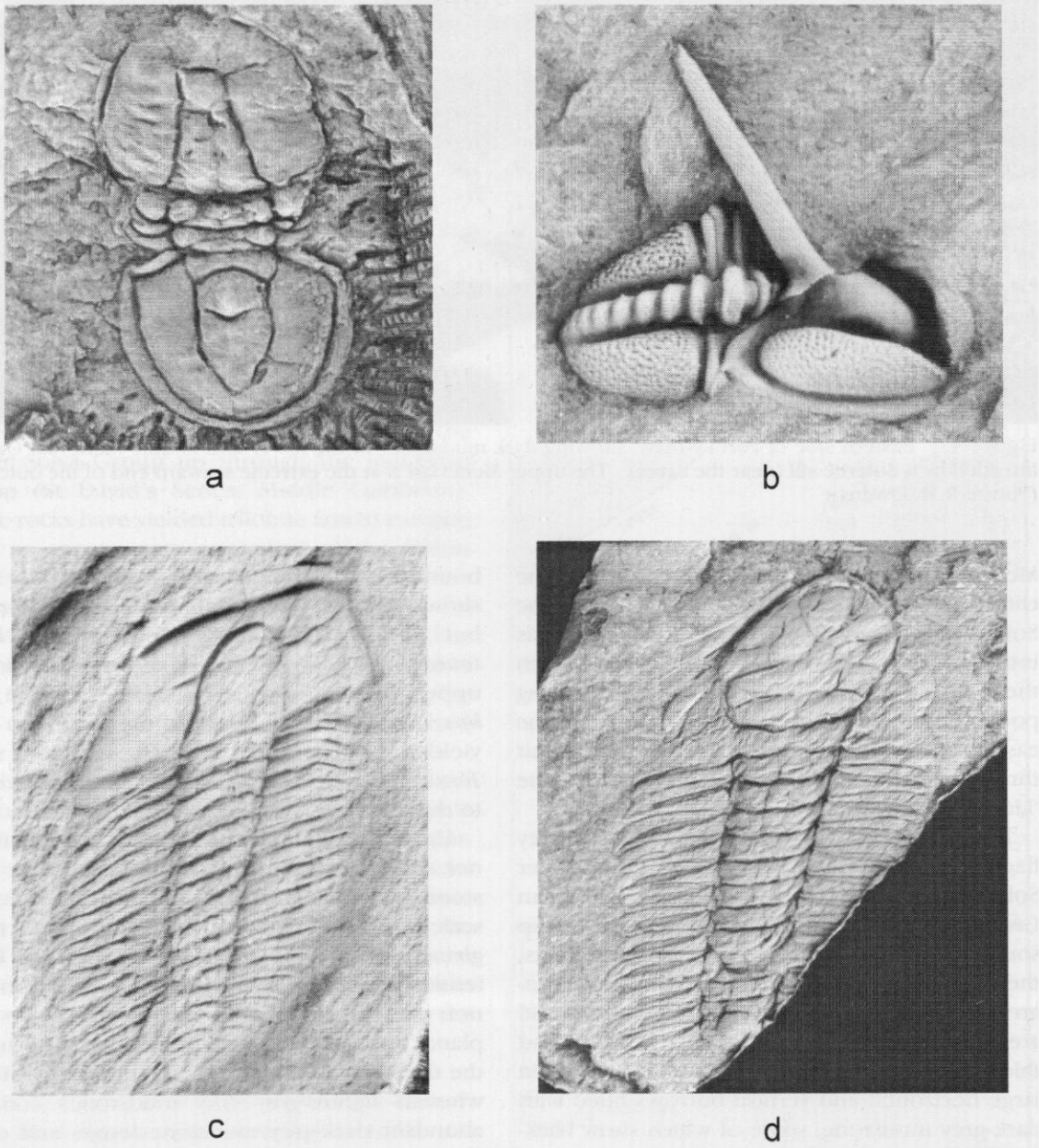

Figure 4.8 Middle Cambrian Trilobites from South Wales. (a) *Onymagnostus davidis* (Hicks), ×4, from Solva Harbour. (b) *Eodiscus punctatus* (Salter), ×8, from Porth-y-rhaw. (c) *Bailiella lyelli* (Hicks), ×3, from Trwyncynddeiriog. (d) *Plutonides hicksii* (Hicks), ×2.5, from Dwrhyd. (Photos: M. Lewis.)

alent strata in North Wales and St Tudwal's Peninsula (Roberts and Merriman, 1990).

The lower part of the middle Menevian Group yields trilobites including *Cotalagnostus lens* (Grönwall), *Eodiscus punctatus sensu lato* (Figure 4.8b), *Onymagnostus davidis* (Hicks) (Figure 4.8a), *Peronopsis scutalis* and '*Solenopleura*' *applanata* (Hicks), and the brachiopod *Linnarssonia sagittalis*. These are representative of the *parvifrons* Zone, and Lewis collected richer faunas from corresponding beds on the western side of the inlet. The higher beds are referable to the *punctuosus* Zone and are the type strata for several of the trilobites found, which include *Anopolenus henrici* Salter, *Eodiscus punctatus sensu stricto*, *Holocephalina primordialis* Salter, *Meneviella venulosa* (Hicks), *Ptychagnostus punctuosus* (Angelin) *sensu stricto* and *Solenopleuropsis variolaris* (Salter), but the locality is most famous for *Paradoxides davidis* Salter, '*Paradoxides* one and a half feet or more in length ...' (from Salter, 1864a, p. 234). These spectacular fossils are difficult to collect but have nevertheless attracted collectors who have damaged the locality and many specimens through faulty practice. The fossiliferous mudstones are intruded by two vertical dolerite sills, each about 4 m wide. The middle Menevian Group is the source of the sponges *Protospongia fenestrata* Salter and *P. hicksii* Hinde and of controversial echinoderm-like animals, the cornute *Protocystites menevensis* Hicks (revised by Jefferies *et al.*, 1987), and the cinctan *Elliptocinctus vizcainoi* Friedrich (1995).

The middle Menevian Group is succeeded abruptly but conformably by sandstones and intercalated mudstones of the upper Menevian Group, said to be about 30 m thick. The sandstones are massive, forming beds 10 cm to 1 m in thickness, consisting of coarse sandstones with quartz and feldspathic pebbles, and finer sandstones with muddy partings. Grey mudstones resembling those in the rest of the Menevian occur between sandstones. The sandstones yield *Billingsella? hicksii* (Davidson) (Cocks, 1978, p. 34). Hicks reported collecting *Paradoxides* and '*Conocoryphe*', but the specimens remain undescribed and the finds have never been repeated. On their basis, however, Hicks referred these beds to the Menevian, although lithologically they resemble the 'Lingula Flags', which are present to the east of Porth-y-rhaw. The 'Lingula Flags' consist of alternations of pale-grey, fine-grained siliceous sandstones with grey mudstones. The sandstones are thinly bedded with sharp planar boundaries and are generally a few centimetres to 20 cm thick. Dr M. Lewis (in ms) reported the presence of *Agnostus pisiformis* (Wahlenberg), the only record of this species in Wales, and indicative of the basal Merioneth Series or possibly uppermost St David's.

Interpretation

The succession at Porth-y-rhaw, supplemented by evidence from other sites close by (Dwrhyd Pit, Caerfai Bay and Solva Harbour), provides the most complete zonal sequence for the St David's Series, ranging from the base of the *fissus* Zone up to the *punctuosus* Zone, exposed in Britain. It is the type locality for several trilobite and other species and is famous for yielding *Paradoxides davidis*. The faunas enable correlation of the Menevian Group with equivalent rocks in North Wales (see site reports for Afon Llafar and Porth Ceiriad), the Midlands, south-east Newfoundland and the zones of the *Paradoxides paradoxissimus* zonal group in Scandinavia. The lower and middle Menevian Group may be correlated with the Abbey Shale Formation of the Nuneaton district (see site report for Illing's Trenches), where the faunal succession is very similar but the Menevian Group is thicker and much more completely exposed. The assignment of the sandstone beds at the top of the sequence to the upper Menevian rather than to the 'Lingula Flags' is based only on Hicks' unverified record of *Paradoxides*; if this correlation is accepted they may partly correspond to the homotaxial strata of the *Paradoxides forchhammeri* Zone of the Scandinavian sequence. Lithologically, however, the sandstones mark the beginning of the 'Lingula Flags' cycle of deposition, and, in this respect, the sequence corresponds with that in the Harlech Dome (see site report for Afon Llafar).

There is little published on the environmental interpretation of the beds exposed at Porth-y-rhaw. The burrows with backfill structures in the sandier beds near the base of the sequence indicate rapid deposition from strong currents, while the fine-grained sandstones were deposited from waning-flow events. However, unlike the strata of the underlying Solva Group, deposition was probably below wave base. The

absence of graded bedding and sole marks makes an origin from turbidity flows also unlikely, so the environmental setting is unclear. The sandstones become less significant upwards, presumably as the source of coarse clastic sediment either became exhausted or was drowned. The strongly laminated appearance of the typical Menevian Beds suggests that accumulation occurred under quiet conditions in restricted environments with low but fluctuating levels of oxygenation. Light-grey mudstones and siltstones are bioturbated and represent better oxygenated environments; they may be the result of low-concentration turbidity-type flows. Darker layers, preserving more organic matter, represent periods of low oxygenation in which burrowing organisms were excluded. The thin sandstones with cross-lamination and loaded bases were probably deposited from low-concentration waning-flow events, which may have introduced better oxygenated water into the basin. The increase in darker-coloured mudstones upwards implies that low oxygen levels became predominant in the middle Menevian. However, the abundant phosphate nodules indicate that at least some thickness of sediment must have been oxygenated to allow their precipitation, according to the mechanisms currently proposed for their formation (see site report for Ogof Ddû and references therein).

The sudden appearance of sandstones at the top of the Menevian sequence marks the initiation of current-agitated conditions, with deposition of sandstones from event episodes such as turbidite or storm events. This continued into 'Lingula Flags' times, and Crimes (1970a) reported sedimentary structures, such as convoluted and cross-bedding, ripple-marked beds and coarse conglomeratic sandstones, in higher parts of the 'Lingula Flags' sequence. These beds are inferred to have been deposited in shallow water, from currents flowing from the south or south-west. The presence of shallow-water sandstones in both the underlying upper Solva and the overlying upper Menevian groups suggests that although the typical dark Menevian mudstones were deposited in quiet, restricted environments, water depths were probably not great.

Conclusions

The inlet of Porth-y-rhaw is a classic geological locality of international value and provides a standard sequence of Middle Cambrian fossils used for correlation in Britain and abroad. It is the type locality for many species and is the only place in South Wales to show fossils at the transition between the Middle and Upper Cambrian. Lack of responsible fossil collecting practice in the past highlights the need for its preservation in the future.

DWRHYD PIT (SM 791 247)

Introduction

This instructive site is complementary to Porth-y-rhaw. It more clearly exposes beds near the base of the lower Menevian Group (St David's Series, Middle Cambrian) that represent the *fissus* Zone. The trilobite fauna is more diverse than in the corresponding zone at Porth-y-rhaw and is well preserved, allowing correlation with equivalent beds in other areas of Britain and Scandinavia.

Dwrhyd is the name of a cottage, now demolished, near to fossiliferous exposures long known to collectors; many of the museum specimens recorded from 'near Nine Wells' are probably from there. The locality was mentioned by Cox *et al.* (1930a, b), Owen *et al.* (1971) and Stead and Williams (1971), and, being easy of access, it has been much used for teaching. Fossils from the site have been described by Lake (1906–1946), but no detailed account of the fauna has been published.

Description

A major strike fault repeats the strata seen at Porth-y-rhaw in the Nine Wells valley, thus exposing the lower Menevian Group in the roadside cutting near Dwrhyd (Figure 4.2), where approximately 10 m of strata are exposed, dipping south-east at about 30°. Thinly bedded grey and dark-grey silty mudstones and siltstones show a colour banding that is mostly sharp but occasionally slightly diffuse; as at Porth-y-rhaw, the darker mudstone bands show little evidence of disturbance, whereas the lighter bands occasionally contain dark-grey lenses and organic-rich flecks, indicating disruption probably due to bioturbation. Fine-grained flaggy sandstones up to 1 cm thick may show parallel or ripple cross-lamination. White-weathering seams approximately 20 cm thick are reported to represent ashy material (e.g. Nicholas, 1915; Rushton, 1974), and

some may be highly fossiliferous.

The more massive lower beds, exposed in the rock face along the lane running north-east to Llanungar Fach, have yielded *Bailiaspis* cf. *dalmani* (Angelin), *Eodiscus* sp. and *Plutonides hicksii* (Salter). The higher beds in the bank alongside the main road are similar in character, but more fissile, and contain numerous ferruginous nodules. The fauna includes the trilobites *Eodiscus punctatus scanicus* (Linnarsson), *Hartshillia inflata* (Hicks), *Hypagnostus truncatus* (Brögger), *Peronopsis scutalis* (Hicks), *P. hicksii* (Figure 4.8d) and *Tomagnostus fissus* (Linnarsson), along with the brachiopod *Linnarssonia sagittalis* (Davidson), hyolithids and sponge spicules. Dwrhyd is the type locality for the cinctan echinoderm *Davidocinctus pembrokensis* Friedrich (1993).

Interpretation

The rocks exposed here closely resemble the lower Menevian Group as represented at Porth-y-rhaw (see site report), and the fauna provides a fuller representation of the zonal information found there. Environments of deposition are considered to have been similar. The *fissus* Zone trilobite fauna allows correlation with equivalent beds in North Wales and Warwickshire and indicates equivalents of the *Ptychagnostus atavus* and *Tomagnostus fissus* Zone of the Scandinavian zonal scheme.

Conclusions

Dwrhyd Pit is of national importance, being easily accessible and exposing clearly fossiliferous mudstones of the lower Menevian Group. The fossils are comparable to those found in corresponding strata at Porth-y-rhaw.

SOLVA HARBOUR (SM 801 241 AND SM 802 240)

Introduction

Outcrops in the cliffs on either side of Solva Harbour expose rocks of the lower and middle Menevian Group (St David's Series, Middle Cambrian). These beds yield faunas indicative of the *parvifrons* Zone. This site supplements the Porth-y-rhaw site, and together they provide the best-documented faunal sequence in the British Middle Cambrian.

Cambrian rocks exposed in Solva Harbour range from the lower Solva Group up to the 'Lingula Flags', but the succession is disrupted by major faulting along the inlet, which displaces outcrops of 'Lingula Flags' and truncates the igneous intrusions. The locality in the Menevian Group behind the lifeboat house was visited during the Geologists' Association excursion of 1930 (Cox *et al.*, 1930b).

Description

On the north-west side of Solva Harbour (Figure 4.9), beds of the middle Menevian Group are exposed behind the old lifeboat house, about 10 m from the base of a thick felsite sill. They consist of thinly-bedded grey-green mudstones and silty mudstones, dipping south-west at about 40°. The mudstones are well laminated, with dark-grey laminae up to 5 mm thick, black laminae 1–2 mm thick and pale-grey laminae also 1–2 mm thick that show signs of disruption. White-weathering phosphate nodules are abundant along certain horizons parallel to bedding, and ferruginous nodules also occur. The rocks are occasionally bleached, resembling the horizons seen at Dwrhyd Pit, and in places appear spotted. Fossils collected include *Eodiscus punctatus punctatus* (Salter), *Meneviella venulosa* (Salter), '*Solenopleura*' *applanta* (Hicks) and species of *Onymagnostus* and *Peronopsis*, with brachiopods such as *Linnarssonia sagittalis* (Davidson) and hyolithids. These indicate the *parvifrons* Zone.

On the south-east side of the harbour, the sections in the Menevian Group occur below the same felsite sill, dipping south-west at about 45°. They consist of thinly bedded, olive-green and grey well-laminated mudstones, with paler layers showing signs of bioturbation. Pyritic layers and lenses, 1–2 mm thick, and phosphate nodules occur and are often associated. The rocks all have a greenish tinge and often appear spotted due to thermal alteration. Faunas similar to those cited above occur about 40 m below the base of the sill. At a higher level, about 20 m below the sill, *Paradoxides davidis* (Salter) has been found (Cox *et al.*, 1930b), indicating the *punctuosus* Zone. Farther east the 'Lingula Flags' are well exposed (Rushton, 1974, pl. 2B).

Interpretation

The middle Menevian strata exposed in Solva

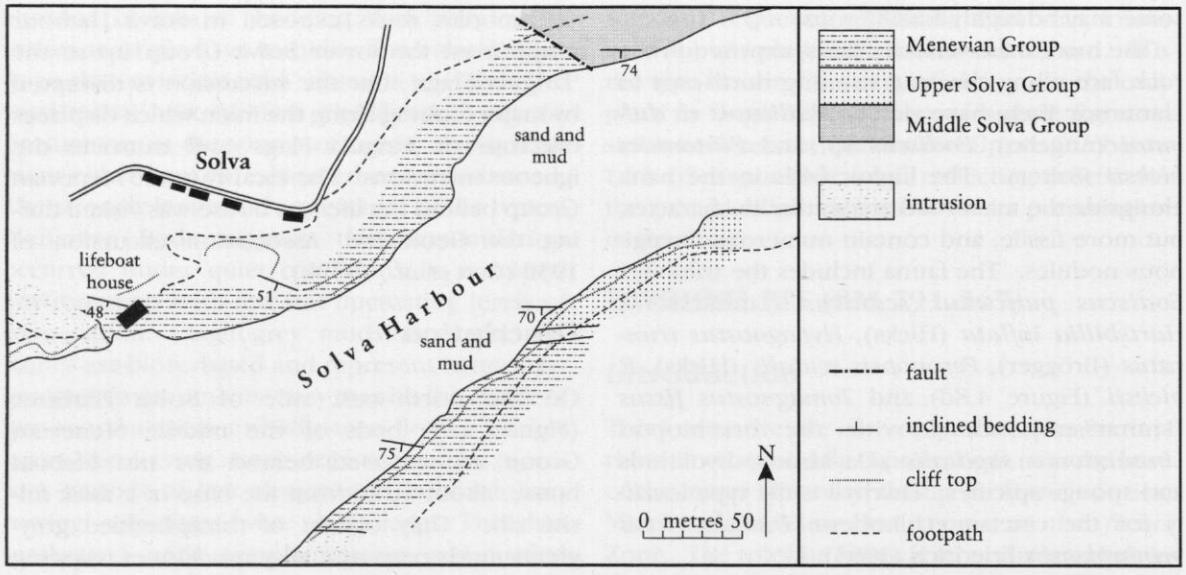

Figure 4.9 Geological sketch-map of Solva Harbour, after Lewis (1987, unpublished).

Harbour closely resemble those seen in the type section at Porth-y-rhaw, and their depositional environments are considered to have been similar. However, the abnormal greenish colour of the rocks there is probably due to thermal alteration by a large felsite sill (Fearnsides in Cox *et al.*, 1930b, p. 417). The continuous sequence from the *parvifrons* Zone into the *punctuosus* Zone resembles that seen at Porth-y-rhaw, and together the two sites form the best standard zonal scheme for correlation of the Middle Cambrian in Britain.

Conclusions

This site exposes easily accessible fossiliferous middle Menevian mudstones, complementing those of the *parvifrons* Zone at Porth-y-rhaw. They help to provide a standard for correlation of rocks of this age, both in Britain and abroad.

TREFFGARNE BRIDGE (SM 959 228)

Introduction

This site, the type locality of the Treffgarne Bridge Beds (see Figure 8.1), contains trilobites of the *Olenus* Zone of the Merioneth Series (Upper Cambrian) and is biostratigraphically the best constrained locality in the 'Lingula Flags' of south-west Wales. It complements the coastal section seen at Porth-y-rhaw, and correlation with the Maentwrog Formation in North Wales suggests the diachronous occurrence of shallow-water facies from South to North Wales.

The 'Lingula Flags' were recorded in the Haverfordwest area by Marr and Roberts (1885, p. 477, pl. 15, fig. 2), and corresponding beds were described in several other areas of south-west Wales (see Rushton, 1974, p. 90). On Ramsey Island they were named the 'Ogof Velvet Formation' by Kokelaar *et al.* (1985), and that term may prove applicable across the whole area for the sandier facies. The rocks near Treffgarne Bridge occur in a faulted area bounded by Precambrian and Arenig volcanic rocks and they assumed importance when fossils diagnostic of age were discovered there (Lake, 1906–1946, pp. 10, 58). The local name 'Treffgarne Bridge Beds' was proposed for these strata by Cowie *et al.* (1972), and the general geology of the area is described by Thomas and Cox (1924).

Description

Exposures occur in cuttings along the roadside and in the quarry, described by Marr and Roberts (1885), about 20 m of strata being intermittently exposed. They are well-bedded flaggy mudstones and sandstones dipping north at about 45°. The sequence is predominantly of grey, silty mudstones, which may be structureless or finely interlaminated with dark-grey, finer-grained mudstones. Hard, fine-grained siliceous sand-

stone occurs in laminae and thin beds, generally 1 mm to 5 cm in thickness; these are often lenticular, especially when only a few millimetres thick, and finely interlaminated with silty mudstones. Some of the thicker beds show ripple cross-lamination and structures resembling convolute laminations. Fossils include the brachiopod *Lingulella davisii* (M'Coy) and the trilobites *Homagnostus obesus* (Belt), *Olenus cataractes* Salter and *Olenus mundus* Lake, the latter two of which Rushton (1983) considered to be conspecific.

Interpretation

The 'Lingula Flags' facies exposed at this locality is more argillaceous than elsewhere in South Wales, such as at Porth-y-rhaw (see site report). In other areas, sandstones can reach 50 cm in thickness, and Cox (1915) recorded conglomeratic beds 15 cm thick. Trace fossils and sedimentary structures are very common (Crimes, 1970a) and include convolute and current-bedding, symmetric, asymmetric, linguoid and interference ripples (e.g. at Porth-y-rhaw). These all indicate rapid deposition in shallow water, often above wave base, from currents directed from the south or south-west. The beds at Treffgarne Bridge generally lack these structures and may represent more distal deposits from similar currents.

Fossils are not common in the 'Lingula Flags', so the presence of fossils diagnostic of the *Olenus* Zone (*cataractes* Subzone) at Treffgarne Bridge allows correlation of these deposits with the upper part of the Maentwrog Formation of the Harlech Dome (see site report for Nant y Graean). As in the Harlech Dome, the faunas indicate that the 'Lingula Flags' facies of Pembrokeshire spans horizons from late St David's or early Merioneth Series (at Porth-y-rhaw) to the upper part of the *Olenus* Zone (Treffgarne Bridge). There is no conclusive evidence for beds of Ffestiniog age in the area, but the typical species *Lingulella davisii* is present with *Olenus* and may therefore occur earlier in South Wales than in North Wales. These beds of Maentwrog age thus suggest that the onset of shallow-water deposition (above wave base) occurred earlier in South Wales than in North Wales, where rippled beds are restricted to the Ffestiniog Flags Formation.

Conclusions

The site near Treffgarne Bridge yields fossils of the *Olenus* Zone that enable the Treffgarne Bridge Beds to be correlated with other deposits of similar age in Britain. The Treffgarne Bridge Beds were deposited in a shallow sea with periodic currents. They are more muddy than rocks of the same age elsewhere in South Wales, but they reveal that shallowing occurred earlier in South Wales than in North Wales.