Porth-y-Mor, Anglesey

[SH 490 885]–[SH 493 876]

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Introduction

The foreshore sections to the north and south of Porth-y-Mor on the north-east coast of Anglesey (Figure 5.4) afford some of the best and most accessible exposures through Old Red Sandstone fluvial fining-upward cycles in the Anglo-Welsh Basin. The sections occupy an important place in the history of research into fluvial sedimentology, for it was here that Allen (1965a) first recognized ancient examples of epsilon cross-bedding and showed it to be formed by lateral accretion on the point bars of meandering river channels. Also, the sections form part of the only outcrop of Old Red Sandstone strata preserved in north Wales. The GCR site is the type locality of the Porth-y-Mor Formation and, at its southern end near Traeth Lligwy, exposes the overlying Traeth Lligwy Formation. Coastal cliffs at Traeth Bach 800 m north-west of Porth-y-Mor, and 200 m north-west of the GCR site boundary, provide good exposure of the underlying unit of the Old Red Sandstone (the Traeth Bach Formation) and also merit protected status. This folded and cleaved Anglesey succession lies about 110 km northwest of the nearest Devonian outcrop in the Welsh Borderland, providing an important constraint on Devonian palaeogeographical reconstruction, and on the timing and nature of late Caledonian orogenic events.

Description

The Anglesey succession of Devonian red beds was first described in detail by Greenly (1919), who, although recognizing its gross similarities with the Lower Old Red Sandstone of south Wales and the Welsh Borderland, viewed it as the deposits of a separate northern basin. Allen (1965a) subdivided the succession into four formations (which he referred to as 'Beds'). These are, in ascending order, the Bodafon Formation, Traeth Bach Formation, Porth-y-Mor Formation and Traeth Lligwy Formation. Apart from the localized, conglomeratic Bodafon Formation, the formations are exposed in the coastal cliffs between Traeth Dulas [SH 487 888] and Traeth Lligwy [SH 487 877]. The Porth-y-Mor site lies within this tract, exposing the eponymous Porth-y-Mor Formation and the overlying Traeth Lligwy Formation. Allen gave details of the petrology and sedimentary structures of the rocks, documenting heavy-mineral assemblages, palaeocurrent indicators and the distribution of trace fossils. He also provided palaeoenvironmental and palaeogeographical interpretations, invoking alluvial-fan, fluvial in-channel, alluvial-floodplain and lacustrine depositional environments (see also Allen, 1970).

The Bodafon Formation ranges from 3 m to 45 m in thickness and comprises conglomerates and pebbly sandstones with minor red siltstone lenses. It is exposed on the coast at Trwyn Cwmrwd [SH 492 902], 2 km NNW of the GCR site, where up to 7.6 m of pebbly sandstones and thin conglomerates rest unconformably on vertically foliated gneisses and dip gently seawards. The conglomerates are extraformational ('exotic), the clasts comprising mainly quartzite, schist, gneiss and vein quartz derived from the local basement and ranging from cobble to pebble grade, with a few boulders.

The Traeth Bach Formation is at least 130 m thick, the lowest 100 m being exposed in the low cliffs at Traeth Bach [SH 487 888]–[SH 489 887]. The formation is dominated by red calcrete-rich siltstones, with minor extraformational conglomerates, pebbly and thin sandstones (Figure 5.5). The calcrete is mainly in the form of nodules, but massive mature dolomite and limestone calcretes occur at several levels, the thickest (5.2 m) lying about 95 m from the base of the section. The pebbles in the conglomerates are mainly of local Precambrian and Ordovician rocks.

The Porth-y-Mor Formation is estimated to be about 347 m thick and is the thickest unit within the local Devonian succession. The section commences on the south side of Traeth yr Ora and dips consistently to the south at about 27°. The contact with the underlying Traeth Bach Formation is concealed beneath the beach to the north. The exposed succession, about 225 m thick, comprises a series of fining-upward cycles. Allen (1965a) recognized 43 cycles, each

constructed of a lower conglomerate and sandstone and an upper muddy siltstone. Calcareous nodules (calcrete glaebules) are common throughout the siltstone units and locally form the dominant element, coalescing to form continuous beds of impure limestone and dolomite. In the following description of the section, the cycle numbers are those of Allen (1965a), as shown on his log of the section (Figure 5.5). A 1.4 m-thick calcrete lies at the base of the exposed succession, underlying Cycle 1. There are substantial exposure gaps between cycles 10 and 11 at Porth-y-Mor [SH 4922 8830]–[SH 4933 8806] and in the cove to the south [SH 4935 8803] between cycles 12 and 13. Apart from the pale grey limestones and brown-weathering dolomites, the lithologies in the Porth-y-Mor Formation are typically red or purple. The siltstones exhibit a northerly dipping cleavage throughout.

Conglomerates are normally present at the base of each cycle, where they rest on an erosion surface cut in the underlying siltstone, ranging from a few centimetres to over 1 m in thickness. Exotic and intraformational types are represented, but the former only occurs at the base of Cycle 1, where a massive 3.4 m-thick unit comprises rounded to angular clasts, ranging up to cobble grade in size, of quartzite, schist, gneiss, vein quartz and cleaved mudstone. These clasts are readily matched with rock types in adjacent Precambrian and Lower Palaeozoic outcrops. In contrast, the intraformational conglomerates, which occur throughout the remaining part of the section, are composed of rounded pebbles and granules of red and green siltstone, fine-grained, red sandstone and limestone, as well as reworked calcrete nodules. They record the reworking of Old Red Sandstone sediments from elsewhere within the basin of deposition.

In every cycle, the basal conglomerate is overlain by, and commonly grades upwards into, a much thicker sandstone unit. Coarse- to fine-grained sandstones are commonly interbedded in the lower parts of these units, but fine- and very fine-grained sandstones with sporadic siltstone partings generally dominate the upper levels. This fining upwards is reflected in the range of tractional sedimentary structures in the sandstones. The coarser lower sandstones and basal conglomerates commonly exhibit large-scale tabular or trough cross-bedding in sets up to 0.45 m thick. In contrast, the overlying finer-grained sandstones are characterized by co-sets of small-scale cross-lamination separated by planar-laminated intervals. This succession of sedimentary structures is seen particulary well in cycles 1 and 2, which contain the thickest sandstone bodies in the succession.

In ten cycles, the basal sandstone and conglomerate unit exhibits a distinctive set of shallow-dipping bedding surfaces. Each surface is tangential with the top of the sandstone, and, in an opposing sense, with the scoured base of the unit, giving a sigmoidal form (Figure 5.6). This pattern of bedding surfaces is epsilon cross-bedding (Allen, 1963a), first recognized in an ancient sedimentary sequence here (Allen, 1965a).

The surfaces cross-cut the vertical lithological changes within the conglomerate and sandstone units, but the upward-fining character, and the upward succession of tractional structures seen in the cycles overall is visible within each cross-bed of the epsilon sets. Critically, palaeocurrent directions indicated by the internal tractional features show that current flow was consistently parallel to the strike of the epsilon cross-bedding surfaces. The latter dip predominantly towards the east, but epsilon cross-sets with either westerly or southerly dipping surfaces are also present.

The upper argillaceous parts of the Porth-y-Mor cycles are typically devoid of tractional sedimentary structures, apart from thin beds of cross-laminated sandstone, which are common at the base and locally present at higher levels. Calcrete nodules, commonly cylindrical in shape and aligned perpendicular to bedding, are scattered throughout. They regularly form part of vertical profiles in which their size and frequency increases upwards until the host siltstone is absent from capping beds of massive limestone or dolomite (Allen, 1964a, 1974d). In thin section, the limestones display a complex range of textures and fabrics (Allen, 1965a). Brecciation is common, with darker masses of inclusion-rich, microcrystalline calcite cross-cut by intersecting veins of clear, coarsely crystalline calcite. Tubular root-related structures (rhizoliths) are also present.

Palaeocurrent indicators in the Porth-y-Mor Formation show that depositing currents largely flowed from the north-east. This is consistent with the orientation of associated linear channel and scour features, and of primary current lineation present in the plane-bedded sandstones. Trace fossils include a few sporadic burrows throughout, and some arthropod tracks high in the formation [SH 4940 8779], but no body fossils have yet been discovered. The conformable top of the formation is placed at the base of the lowest of the distinctively bioturbated sandstones that characterize the succeeding Traeth Lligwy Formation, in which burrow traces are abundant.

The Traeth Lligwy Formation forms the cliffs on the north side of Traeth Lligwy [SH 494 878]–[SH 493 875] at the southern end of the GCR site. The basal 24 m of the formation are exposed, preserved in the axial area of an E–W-trending syncline. They are of sandstones and siltstones, in thinner beds than the Porth-y-Mor Formation below. Red, very fine-grained sandstones ranging from 0.15 m to 2.1 m thick, but averaging 0.53 m, are interbedded with red, sandy, siltstones from 0.07 m to 1.2 m thick. Calcrete is confined to a few horizons of nodules and conglomerates are absent, but organic burrowing structures are abundant in the sandstones. The thickest sandstone is flat-bedded in its lower part and small-scale cross-bedded in its upper part.

Interpretation

Allen's (1965a) synthesis of the sedimentary processes and depositional environment of the Anglesey Old Red Sandstone succession was an important early study of fluvial sedimentology. The succession accumulated in a depositional basin flanked to the south-west by an upland area of Precambrian and Lower Palaeozoic rocks. These older rocks were the source of alluvial-fan gravels (the Bodafon Formation), which accumulated along the basin margin. Away from this margin, these interdigitate with the overlying Traeth Bach and Porth-y-Mor formations. In the GCR site calcareous muddy siltstones of the Traeth Bach Formation were interpreted by Allen as the deposits of ephemeral, non-saline playa lakes. Subsequently, a broad meandering, SE-trending river belt was established, within which the Porth-y-Mor Formation was deposited.

The overlying Traeth Lligwy Formation is interpreted as the deposits of more permanent flood basin lakes, the reduced amount of calcrete and abundance of burrowing structures suggesting a higher water-table and less prolonged periods of subaerial exposure of the sediments.

The conglomerate and sandstone units of the Porth-y-Mor Formation represent river channel deposits. The pattern of upward-fining above a basal erosion surface, and the associated succession of sedimentary structures, are consistent with an upward reduction in the velocity and bed shear rate of the depositing currents. These conditions are encountered on the point bars of a meandering stream where the fastest and most-powerful currents are associated with the deepest part of the channel, close to the outer bends of the meanders. Here, the river erodes into its earlier floodplain sediments and deposits its coarsest bedload. In contrast, the currents flowing across the upper parts of point bars formed on the inside bends of the meanders are much slower, and deposit finer-grained sediment. Lateral migration of the river channel and lateral accretion of its point bars generate the upward-fining channel sequence.

The channel conglomerates and sandstones of the Porth-y-Mor Formation are noteworthy in being the first rocks in the stratigraphical record in which epsilon cross-bedding and its significance were recognized. Allen (1965a) demonstrated that the sigmoidal surfaces, dipping perpendicular to the flow direction shown by associated tractional structures, represent the surfaces of meander point-bars, and therefore, that each epsilon cross-set records the process of incremental, sustained lateral accretion. At a time when the understanding of ancient sedimentary, fluvial fining-upwards units was in its infancy, the discovery and interpretation of these features showed that they were the products of laterally migrating, meandering channels of mixed bedload rivers (Allen, 1965a, 1970). On the basis that the thickness of the epsilon cross-sets should correspond to the bankfull depth of the channel in which they were deposited, Allen (1965a) estimated that the rivers that supplied the sediment of the Porth-y-Mor Formation were likely to be at least 60 km long and 20 m wide, and perhaps up to 600 km long and 90 m wide.

The upper siltstones of the Porth-y-Mor cycles record the accumulation of fine-grained sediment on extensive river floodplains. The calcareous nodules and limestone and dolomite beds display many of the features of modern calcretes and dolocretes. They record the diagenetic growth of carbonate within soil profiles during periods of prolonged subaerial exposure in a semi-arid, seasonally wet climate (Allen, 1974d). Allen's (1965a) description of the Porth-y-Mor examples was the first and most detailed account of Old Red Sandstone calcrete in Wales, following its recognition by Burgess (1961) in Ayrshire and Pick (1964a) at Portishead (see GCR site report, this chapter). The Traeth Lligwy Formation is interpreted as the deposits of perennial lakes, a fades not seen elsewhere in the Anglo-Welsh Basin.

Early palaeogeographical models envisaged the Anglesey Old Red Sandstone succession as deposited in a narrow gulf opening to the northeast, connected to the Midland Valley of Scotland, and structurally isolated from the sequences of

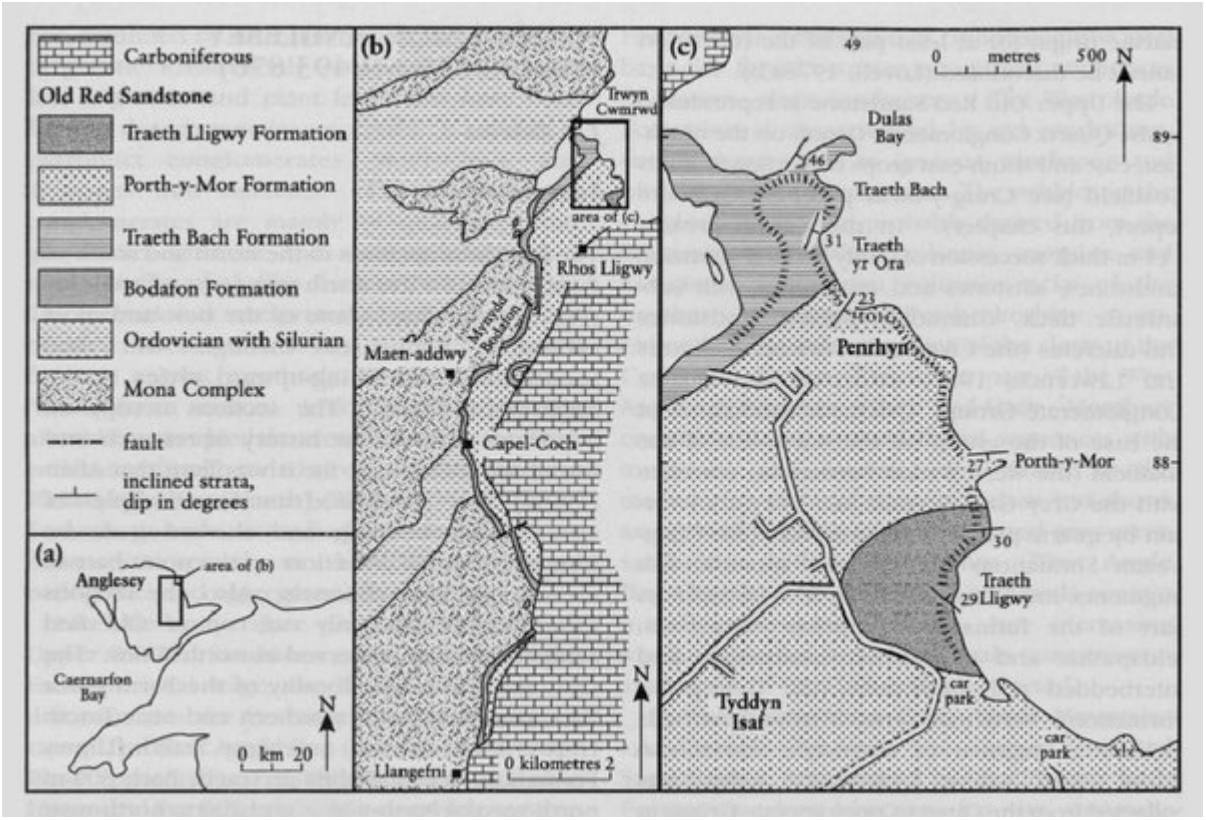
south Wales and the Welsh Borderland (Greenly, 1919; Wills, 1952). Allen (1965a) noted the similarity in lithofacies and cyclicity of the Porth-y-Mor Formation to the Dittonian and Breconian rocks of Pembrokeshire and the Welsh Borderland. He also noted that although the heavy-mineral assemblages are similar to those of Pembrokeshire, they are different to those of the Welsh Borderland. He viewed the Anglesey succession as lying at the margin of a broad depositional tract connected to the main basin to the south, supplied with sediment sourced some distance to the northwest by south-easterly flowing rivers. This remains the favoured palaeogeographical interpretation (Allen, 1974a; Allen and Crowley, 1983; Bluck *et al.,* 1992), although the age of the succession remains unproved in the absence of fossil or other direct dating evidence. Structural and stratigraphical constraints provide a time-span only between the Ludlow and Dinantian, inclusive (Allen, 1965a; Allen and Williams, 1979a). A Mid-Devonian age has been suggested (Hurst *et al.,* 1978), but the presence of the folding and cleavage makes this unlikely (Allen and Williams, 1979a; Hurst *et al*., 1979). Allen (1965a) attributed the deformation to the widely recognized Mid-Devonian (late Caledonian–Acadian) tectonic event and correlated the Porth-y-Mor Formation with the Dittonian (Lochkovian) succession of south Wales on the characteristic cyclicity of the fades (Allen, 1974b, 1977). The thick calcretes on both sides of Traeth yr Ora, including the one at the base of the exposures on the south side, are reminiscent of the thick, regionally developed Psammosteus Limestone in south Wales and the Welsh Borderland, which would support Allen's correlation. However, no fish remains have yet been found in the Porth-y-Mor Formation, in contrast to their common presence In the Dittonian succession in south Wales and the Welsh Borderland, and the age of the Anglesey succession remains to be proved.

Conclusions

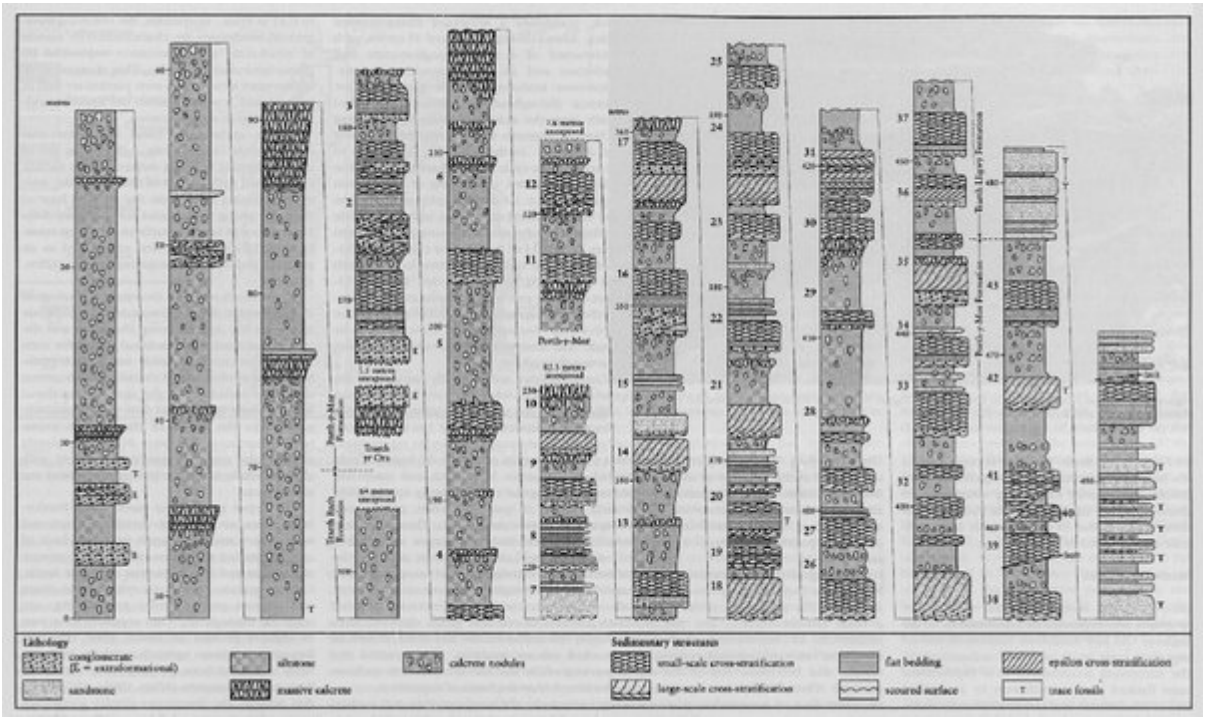
The Porth-y-Mor site is one of the best, accessible sections of Old Red Sandstone alluvial cyclic deposits in the UK. It occupies a unique place in the history of sedimentological research, the excellent exposures including examples of epsilon cross-bedding, first recognized in an ancient sedimentary sequence here. The well-developed profiles of soil carbonate (calcrete) were amongst the first to be described in detail in the Anglo-Welsh Basin. The importance of the site also lies in the presence of the unique lake deposits of the Traeth Lligwy Formation.

The site, set within the cleaved and folded Anglesey Old Red Sandstone succession, provides evidence to suggest that this northern sequence shared the same sediment source as parts of the Lower Old Red Sandstone of south Wales. The two areas may have been part of an extensive, continuous depositional tract prior to Mid-Devonian (Acadian) deformation and uplift. However, the Porth-y-Mor rocks have yet to yield fossils to indicate their precise age, and the site offers opportunities for further palynological and microfossil research.

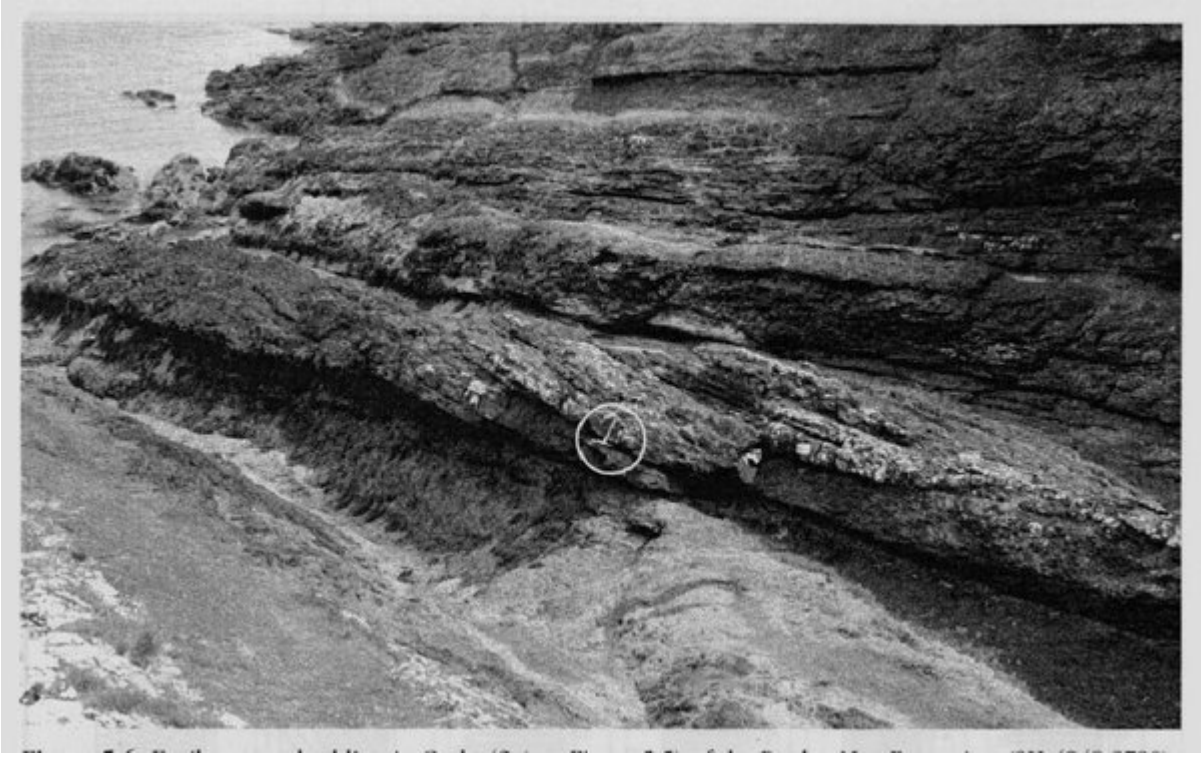
References



(Figure 5.4) Geology of the Porth-y-Mor GCR site, Anglesey. Map (a) shows location of Map (b). Map (b) shows the main outcrop of Old Red Sandstone in Anglesey and location of Map (c). Map (c) shows the geology of the Porth-y-Mor site. Maps (b) and (c) after Allen (1965a).



(Figure 5.5) Graphic log of section of coastal exposures between Traeth Dulas and Traeth Lligwy measured by Allen (1965a). The Traeth Bach Formation is from 0 m to 129.54 m (425 feet), the Porth-y-Mor Formation is from 129.54 m to 477.01 m (1565 feet) and the Traeth Lligwy Formation is from 477.01 m to 498.96 m (1637 feet). Thicknesses above the base of the section are shown in metres. The numbers in bold are Allen's cycle numbers in the Porth-y-Mor Formation. After Allen (1965a).



(Figure 5.6) Epsilon cross-bedding in Cycle 42 (see (Figure 5.5)) of the Porth-y-Mor Formation [SH 4940 8780]. Hammer for scale (circled). (Photo: J.R. Davies.)