Ogof Ddû (Rhiw-for-Fawr)

[SH 512 381]–[SH 515 379]

Introduction

The section at Ogof Ddû is a site of international stratigraphical and historical importance. It exposes a section from the Ffestiniog Flags Formation, through the Dolgellau Formation (both Merioneth Series), into the Lower Sandstone and Lower Mudstone members of the Dol-cyn-afon Formation (Tremadoc Series) and is much the best section at these stratigraphical levels. It is the only section through the entire Dolgellau Formation, several horizons of which yield zonally significant trilobites. The low Tremadoc Beds yield abundant early-zonal subspecies of the graptolite *Rhabdinopora flabelliformis.* Sedimentary features allow interpretation of the conditions of deposition in the Welsh Basin during the late Merioneth and early Tremadoc epochs: the Merioneth—Tremadoc boundary is well exposed, and an isotopic date obtained from a volcaniclastic bed just below the base of the Tremadoc currently gives the best indication of the age of the base of the Ordovician anywhere in the world.

Salter studied the section at Ogof Ddû and listed many fossils thence (Salter, 1866b, p. 250). Fearnsides (1910) gave a more detailed description and a measured section, since when it has become a reference section for the Dolgellau and lower Tremadoc rocks. It was logged and the radioactivity of the sequence was measured (summary in Ponsford, 1955), and it proved a key locality in the sedimentological study of Prigmore (1994). The site is easily accessible and accounts have been included in geological guides to the Ynyscynhaiarn area (Roberts, 1979; Cattermole and Romano, 1981). Following detailed mapping, Howells and Smith (1997) rationalized the lithostratigraphy and gave details of the biostratigraphy, and their account is followed here.

Description

The section at Ogof Ddû (Figure 3.9) and (Figure 3.10) is an old sea-cliff cut into the side of the small hill Rhiw-for-fawr, on the western limb of the northward-plunging Ynyscynhaiarn (Tremadog) Anticline. Bedding dips north-west or WNW at about 35–40°, and cleavage dips steeply at about 80° in a similar direction. The section is described here working up the sequence from east to west.

Merioneth Series

The section (Figure 3.9) begins in the upper part of the Ffestiniog Flags Formation, which consists of alternations of dark-grey, poorly laminated silty mudstones with pale-grey, fine- to medium-grained massive sandstones. The sandstones are around 5–40 cm thick but show changes of thickness laterally; they have sharp contacts and show climbing ripple cross-lamination, scour and fill structures, loaded bases and convolute lamination. Trace fossils include *Rusophycus, Cruziana* and *Skolithos.* The brachiopod *Lingulella davisii* (*M'Coy*) is common at several horizons, occurring as disarticulated valves in a current-stable orientation. The top of the Ffestiniog Flags Formation is taken where sandstone beds die out. The overlying 6 m of strata are transitional between the Ffestiniog and Dolgellau formations and consist of finely laminated dark-grey silty mudstones and structureless silty mudstones, with pale-grey pyritous siltstone laminae occurring every few centimetres.

West of a small break in exposure at a slack in the cliff face, the rocks are more typical of the Dolgellau Formation and consist of dark-grey and black laminated carbonaceous silty mudstones, with two or three laminae per millimetre. Organic carbon content is high and bioturbation is completely absent. Siltstone laminae occur throughout, and are common near the base, where some bedding planes are covered with the brachiopod *Orusia lenticularis* (Wahlenberg). The trilobite *Parabolina spinulosa* (Wahlenberg) is reported, and these beds yielded the types of the non-olenid trilobites *Cermatops discoidalis* (Salter) and *Maladioidella abdita* (Salter), respectively redescribed by Hughes and Rushton (1990) and Rushton and Hughes (1996).

The overlying 40 m of strata are of similar black mudstones, with rare siltstones and mudstones from low-concentration turbidity flows. Ponsford (1955) found that the black mudstones of the Dolgellau Formation were more radioactive than the adjacent formations, the radioactive source being uranium concentrated in phosphate nodules and in some of the darker mudstone hands. The mudstones are fossiliferous at several levels, and the zones of *Parabolina spinulosa, Leptoplastus, Protopeltura praecursor, Peltura minor* and *P. scarabaeoides* have all been recognized (Rushton in Howells and Smith, 1997, fig.5), mostly by means of olenid trilobites that are considered to have been adapted to dysaerobic environments.

Just above the *Orusia* beds are several pale-grey, pyritous, fine-grained, micaceous sandstones, up to 5 cm thick, which consist of recrystallized argillaceous material. They probably represent volcanic ash deposits. Towards the middle of the formation there are fewer black laminae and more lighter-grey mudstones, possibly introduced by waning-flow events. Some of the lighter-grey laminae show disruption, possibly due to bioturbation. Study of polished slabs shows a few pale-grey event beds, 7 mm thick, which fine upwards from quartz-rich siltstone to clays (Prigmore, 1994). Towards the top of the Dolgellau Formation [SH 5142 3795] a thicker, medium- to coarse-grained volcaniclastic sandstone occurs low down in the cliff-face (Figure 3.11)a. This thins rapidly from 30 cm to 3 cm thick across 10 m of outcrop. It consists of sub-angular grains of quartz and feldspar in a matrix of recrystallized argillaceous material and is presumably a reworked volcanic ash deposit. Zircon crystals from it have been dated at 491 ± 1 Ma (Davidek *et al.,* 1998). Below this sandstone are several levels with calcareous concretions up to 100 x 60 cm across (Figure 3.11)b that tend to be nucleated on thin sandy beds. They show a cone-in-cone structure, and some contain trilobites representing subzones of the *minor* and *scarabaeoides* zones. The shales above the sandstone contain the brachiopod *Eoorthis* and trilobites of the *scarabaeoides* Zone, including *Richardsonella? invita* (Salter).

At the top of the Dolgellau Formation the black shales pass into dark-grey mudstones of the Dol-cyn-afon Formation. Howells and Smith (1997) followed Ponsford in placing the boundary between the Dolgellau and Dol-cyn-afon formations at the level where phosphates first appear abundantly in the section. They occur in a 5 cm thick band, with a few sandstone lenses and laminae, forming a distinctive horizon 6 m above the 30 cm volcaniclastic sandstone. The possible occurrence of *Parabolina acanthura* (Angelin) there is consistent with, but not diagnostic of, the *Acerocare* Zone.

Tremadoc Series

The lower part of the Dol-cyn-afon Formation (the 'Tremadoc Slates' of early writers) consists of dark-grey silty mudstones that coarsen upwards into massively bedded silty sandstones that are about 100 m thick. These beds are the informal 'Lower Sandstone Member' of Howells and Smith (1997), equivalent to the 'Tynllan Beds' of Fearnsides (1910). The basal beds are well laminated but with signs of disruption and contain white-weathering phosphate nodules lying along the bedding at intervals of a few centimetres. Above the base the dark- and light-grey lamination becomes increasingly disrupted, producing an indistinct mottled texture. Bioturbation becomes increasingly important upwards, with small mudstone-filled *Chondrites* burrows cutting across the lamination. Beds of pale-grey mudstone up to 10 cm thick occur occasionally. They have sharp bases, become gradually darker-coloured upwards and may show synsedimentary microfaulting; phosphate nodules often occur towards their tops. Fine- to medium-grained sandstone laminae occur throughout the sequence, but especially near the base of the Lower Sandstone Member, where they form three or four upwardly coarsening cycles every 10 cm. Brachiopods and phosphate nodules are abundant, and *Rhabdinopora flabelliformis socialis* (Salter) covers the bedding planes of intervening mudstones, the lowest being some 8.5 m above the basal phosphatic horizon (Figure 3.9).

Up section, the sandstone laminae increase in thickness and frequency and pass into massive, pale-grey, fine- to medium-grained sandstones, ranging from 2 cm to 1.5 m in thickness, or even thicker towards the top of the member. They are mostly structureless and contain numerous rhyolitic clasts. Fining-upwards sequences about 10 cm thick also occur. The commonest fossils are brachiopods, including *Broeggeria,* with a few trilobites.

West of the Lower Sandstone Member is a grassy depression through which Fearnsides (1910) mapped the outcrop of his '*Dictyonema* Band', though the graptolite has never been found *in situ* there. To the west, the lower part of the Lower Mudstone Member (equivalent to the 'Moelygest Beds' of Fearnsides (1910)) consists of a monotonous sequence of strongly cleaved dark-grey silty mudstones, structureless and thoroughly disrupted by bioturbation. Phosphate nodules are common, and thin siltstone laminae occur sporadically. No fossils are known.

Interpretation

The Ffestiniog Flags Formation is considered to represent deposition in shallow near-shore environments with regular current activity. Sedimentary structures seen at Ogof Ddû and in correlative strata at localities nearby (Crimes, 1970a) imply that deposition occurred in a storm-dominated, sub-tidal or littoral environment. The *Skolithos* burrows and other traces indicate fairly energetic conditions and well-oxygenated water. Crimes (1970a) reported that currents acted from the south or south-west. Mud-cracks reported by Fearnsides (1912) suggest shallow to emergent conditions. The great thickness of these shallow-water deposits, some 650 m in the Ynyscynhaiarn Anticline but up to 1050 m elsewhere in the Harlech Dome (Allen and Jackson, 1985), indicates that sedimentation kept pace with subsidence for a considerable period. The beds transitional to the Dolgellau Formation may represent more distal deposits generated from storm currents similar to those that gave rise to the coarser sandstones of the Ffestiniog Flags Formation, though the undisturbed lamination in these beds implies lower levels of oxygenation.

The black shales of the Dolgellau Formation accumulated under predominantly anoxic conditions and represent a combination of fallout of organic matter and hemipelagic sediment from the water column, with rare siltstones and mudstones from low-concentration turbidity flows. Features of the lighter-grey mudstones that are conspicuous towards the middle of the Dolgellau Formation indicate a slight increase in oxygenation. As similar phenomena are recognized at a corresponding level elsewhere in the Harlech Dome (Prigmore, 1994), they may reflect a basin-wide increase in oxygenation at that level. The section at Ogof Ddû thus shows a rapid environmental change, from high-energy shallow near-shore conditions for the Ffestiniog Flags Formation, to quiet, restricted and sediment-starved environments with low oxygen levels for the Dolgellau Formation. The development of Palaeozoic black mudstones such as the Dolgellau Formation has been related to periods of sea-level rise (e.g. Leggett, 1980; Leggett *et al.,* 1981), and the abrupt fades change from Ffestiniog to Dolgellau certainly suggests a relative rise in sea level at this time, though whether eustatic or caused by regional subsidence is not yet clear.

Ogof Ddû is much the best section through the Dolgellau Formation; however, the succession differs from the thicker correlative beds on the south and east of the Harlech Dome (e.g. Foel Gron) in evincing more current activity and bioturbation and in yielding certain non-olenid trilobites (*Maladioidella, Richardsonella?*).This may reflect stronger current activity and oxygenation in relative proximity to the Irish Sea positive area. The volcaniclastic sandstone in the *scarabaeoides* Zone has given the best radiometric date for late Merioneth rocks and currently (1999) provides the best available constraint on the base of the Ordovician anywhere in the world (Davidek *et al.,* 1998).

The transition from black to dark-grey mudstones across the Dolgellau to Dol-cyn-afon formational boundary, better exposed at Ogof Ddû than elsewhere, is due to the reduced preservation of organic carbon in Tremadoc rocks and is correlated with the upward trend towards increased oxygenation and more rapid sedimentation through the Tremadoc succession. The transition differs from that on the south and east of the Harlech Dome (see the Dol-cyn-afon and Bryn-llin-fawr site reports) in showing a relatively condensed succession at a phosphate-rich bed, with a possible non-sequence above or below it and a much reduced development of the *Acerocare* Zone. The well-laminated mudstones at the base of the Lower Mudstone Member presumably remained largely anoxic, with the gradual upward increase in disruption and bioturhation indicating increased oxygenation, leading to the development of structureless and thoroughly bioturbated mudstones by mid-Tremadoc times, when normal well-oxygenated conditions existed at the sea floor. The Dolgellau to Dol-cyn-afon boundary at Ogof Ddû is recognized at the appearance of abundant phosphate nodules such as characterize Tremadoc sequences throughout the Harlech Dome. Current theory for precipitation of phosphate as nodules (Smith, 1988) requires that some thickness of sediment must have been oxic (although oxygen levels were low at times, judging from the record of bioturbation). It is considered that the increase of waning-flow events introduced sufficient oxygenation to provide a mechanism for the precipitation of phosphate nodules (see discussion in Prigmore, 1994).

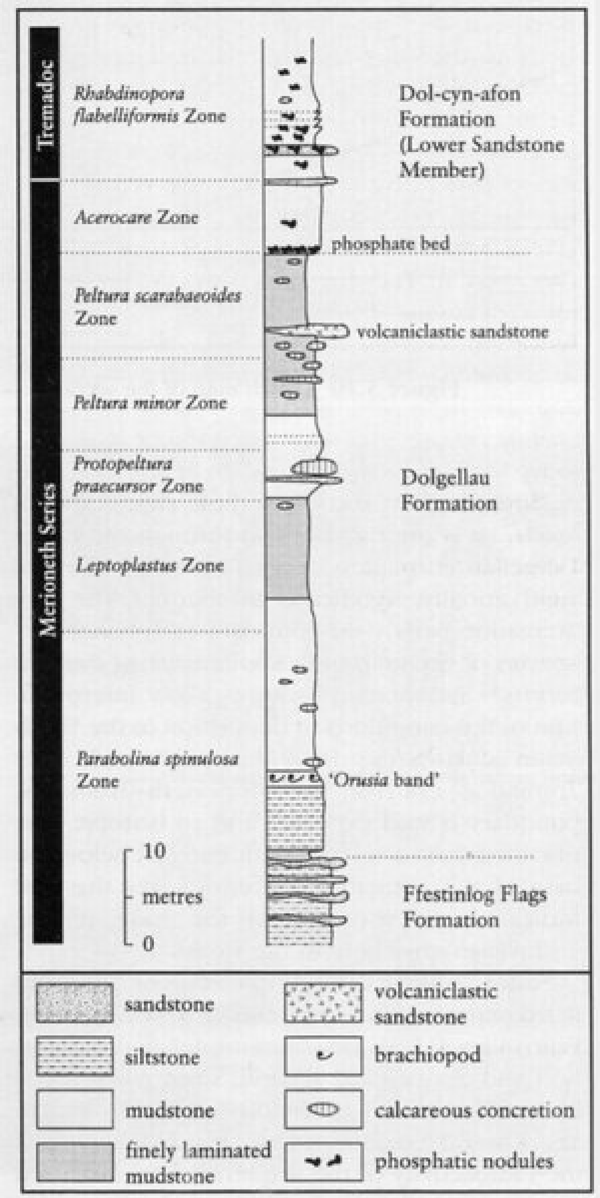
The majority of Dol-cyn-afon lithologies indicate deposition from waning-flow events, such as turbidite or storm events. The laminated and mottled mudstones characteristic of the Lower Mudstone and Lower Sandstone members formed from low-concentration turbidity currents or bottom currents, along with pelagic fallout of organic material. The thick- to medium-bedded sandstones high in the Lower Sandstone Member were presumably produced by high-concentration turbidity currents, whilst the numerous rhyolitic clasts imply a strong volcanic component. Thinner but otherwise similar sandstones occur elsewhere in the Harlech Dome (Prigmore, 1994), but the absence of thick volcanogenic sandstones in those areas suggests that Ogof Ddû lay in a more proximal position, indicating a possible volcanic source to the west or north-west.

The Ogof Ddû section gives the best exposure of the lithological and sedimentological succession through the Lower Sandstone Member of the Dol-cyn-afon Formation, though because of the strong cleavage the faunas are better seen at Tyn-llan and Wern Road (see site reports, Chapter 7).

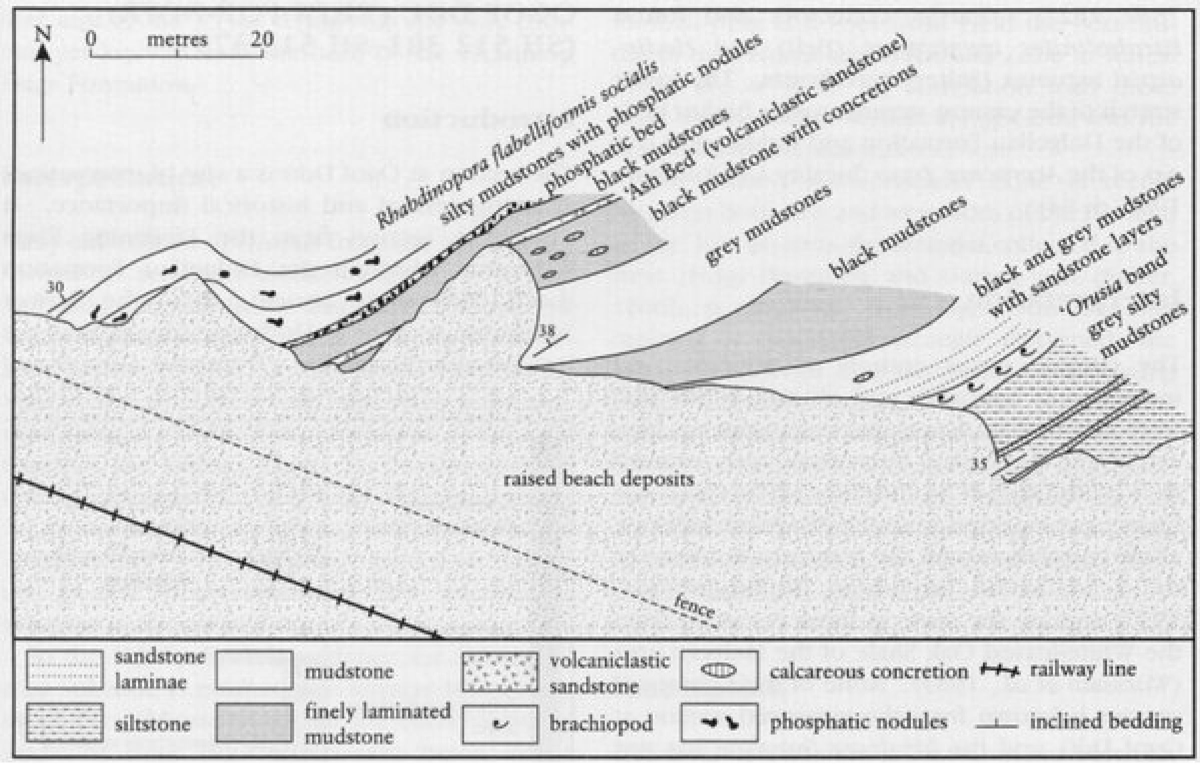
Conclusions

The section at Ogof Ddû is of international importance, both stratigraphically and historically. It shows better than elsewhere a full sequence of higher Upper Cambrian rocks and is the type locality for several species of trilobite. The rocks show evidence for changes in marine environments, from sandstones deposited in a shallow sea to black muds deposited in quiet waters away from the influence of land areas; this change may be due to rapid foundering of the sea floor. The succession of faunas enables correlation across Britain to other parts of the world. Around the Cambrian—Ordovician boundary the black mudstones pass upwards into grey mudstones, the colour change being related to increasing levels of oxygenation in the water and possibly to a global sea-level rise. A volcanic bed just below the boundary is 491 million years old and gives the best available indication of the age of the Cambrian—Ordovician Boundary.

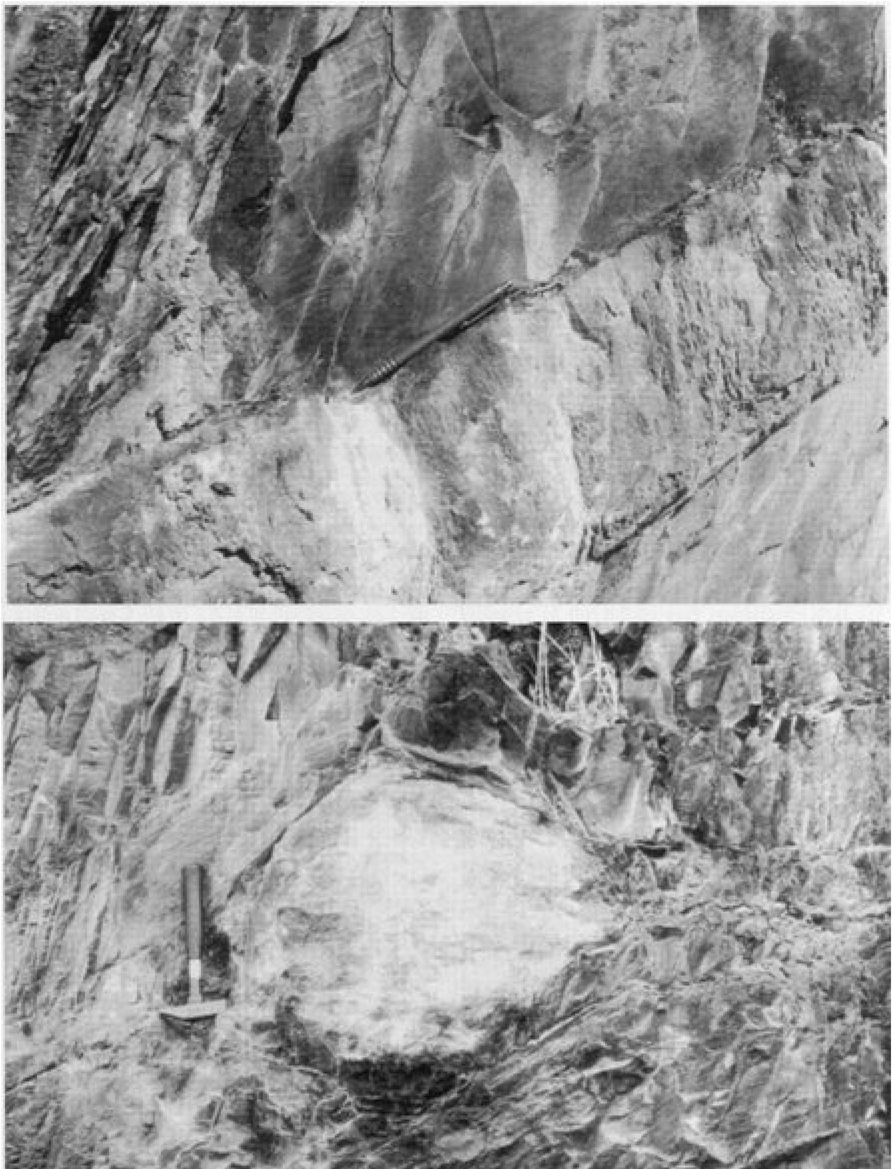
References



(Figure 3.9) Stratigraphical succession east of Ogof Criccieth, measured by D.R.A. Ponsford (unpublished), with zonal stratigraphy from Howells and Smith (1997, fig. 5).



(Figure 3.10) Sketch map of the section east of Ogof Ddû, after Ponsford (unpublished).



(Figure 3.11) The Dolgellau Formation exposed at Ogof Ddû. (a) The thickest of the beds of volcaniclastic sandstone in the scarabaeoides Zone. Zircon crystals from this bed yielded an age of 491±1 Ma. (b) A large calcareous concretion in the scarabaeoides Zone, lying about 1 m below the sandstone in (a). Bedding lamination is visible dipping to the left just above the hammer handle; cleavage dips more steeply to the left. (Photos: J.K. Prigmore.)