Ca'er-Hafod Quarry, Llangollen

[SJ 215 476]

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Highlights

Carbonate veins here are platy and lineated. They lie along bedding and record movements, apparently tectonic, prior to the main Caledonian phase. These phenomena appear to be restricted to rocks of mid- to late-Silurian age.

Introduction

The Ca'er-hafod Quarry provides rare outcrops of a very distinctive suite of laminated carbonate veins, apparently lying along bedding, and inscribed with a very pronounced rectilinear, ridge-and-groove lineation. Both the mineral fabric of the veins and this lineation are older than the deformation episode which folded the Wenlock Series country rocks. The veins (spar beds or 'rhesog') here had their macroscopic features first described by Wedd *et al.* (1927), in the Geological Survey Memoir dealing with the Wrexham district.

Wedd *et al.* noted the bedding-parallel nature of the veins, that they are affected by folding, the presence of a groove-like lineation on the veins, and the likelihood that there had been considerable amounts of movement along them. These authors also made clear the apparent restriction of the veins, in the Wrexham district, to the Wenlock Pen-y-glog Formation.

This slate formation, once worked on both north and south limbs of the gently easterly plunging Llangollen Syncline, has its subcrop marked by a string of disused quarries. They provide the only access to these carbonate veins, which were unknown in natural outcrops. The quarries also provide the most convenient areas in which to examine the regional cleavage; this has a moderate dip to the north, atypical of Caledonian North Wales. The Ca'er-hafod Quarry is on the north limb of the Llangollen Syncline (Figure 4.17).

The microscopic character of the veins was first described by Nettle (1964). Veins with the same mineralogy, fabric, and structure as those of the Llangollen Syncline, are found in the Middle Wenlock to Lower Ludlow rocks of areas east of Llanwrst, in northern Clwyd (Warren *et al.,* 1970). These authors, however, broadly link formation and deformation of the veins, with formation of the regional cleavage.

Description

Cleavage and bedding here have the characteristic E–W trend of this north-eastern section of the Welsh Basin. The disused quarry situated near Ca'er-hafod (Wedd *et al.,* 1927, p. 97; Nicholson, 1966, 1970, 1978) was referred to by Fitches *et al.* (1986, Figure 7D) by the name of the nearest house, Pont Glas. The 180 m-long working, opens to the east, is nowhere wider than 40 m, and is driven into the silty mudstones of the Pen-y-glog Formation. Its steep north and south walls are parallel to the strike of bedding (Figure 4.18).

Situated in the complexely folded, north limb of the Llangollen Syncline, bedding surfaces dip steeply to the south (e.g. 105/62°S). The accompanying cleavage dips moderately to the north (e.g. 093/55°N), bedding and cleavage here being about perpendicular to one another, suggesting that the rocks of the quarry lie near a fold hinge. Although the Llangollen Syncline, like many of the subsidiary folds of its north limb, plunges gently to the east, the folds affecting the three veins, and the bedding–cleavage intersections in the enclosing slate, all plunge gently westwards. The moderate northerly dip of the cleavage, is typical of the syncline as a whole.

Three principal laminated veins occur in the quarry (Nicholson, 1978). All of them have a well-developed ridge-and-groove lineation on the calcite laminae of which they are made. The bottom vein, forming the north wall of the quarry, shows how this lineation may change substantially in pitch, even from the surface of one-millimetre-thick lamina to the next. The top vein, which lies at the base of the south wall of the quarry, is approximately 0.10 m thick, the thickest of the three. The central vein is the thinnest and most thoroughly laminated. As a result, it shows more regular and intensively developed folds than the other veins (Figure 4.17).

The bottom vein is partly composed of a cemented breccia. Both in this and other respects, it closely resembles that exposed in the north wall of the easternmost of the quarries of Moel y Faen ([SJ 1887 4772]; Wedd *et al.,* 1927). The other two veins of the Ca'er-hafod Quarry do not contain breccia zones.

The central vein, about 10 mm thick, is exposed for tens of metres on a mesoscopic, folded bedding surface (Figure 4.18). The published description of the modifying effects of this deformation on the primary fabric of generally vein-parallel, single-crystal plates of calcite is based on material from this central vein (Nicholson, 1978; microprobe data on calcite composition, Hamdi Lemnouar, 1988). The very numerous, small folds are periclinal in form, each having a hinge length of some 0.20 m. These hinges lie parallel to those of the larger folds. They all plunge parallel to the bedding–cleavage intersection on the folded surface and have their axial surfaces parallel to the cleavage of the slate in which they are embedded. All these field relationships confirm the interpretation based on microscopic evidence, that folding was part of the regional deformation, taking place after the veins were already fully formed.

The slates of the Ca'er-hafod Quarry also contain discordant calcite–quartz veins, apparently linked in origin with the laminated, bed-parallel veins. Instead of being folded during regional deformation, they were boudined. The early formation of these discordant fractures may be used as an indication that the cleavage here is not a structure formed during burial and related compaction and water loss (Davies and Cave, 1976). This has importance for the assessment of proposals made concerning the place of vein systems in the regional tectonics of Caledonian Wales. Fitches *et al.* (1986), for example, making passing reference to the Silurian rocks of the Wrexham district, suggest that such veins may have formed as water driven from sediments during burial was injected along chosen bedding horizons. It is supposed that such injection allows the detachment of upper levels of the sediment column, freeing them for the lateral movement that the formation of the lineation on the veins requires.

The wide, folded, bedding surface on which the central vein is exposed, also reveals the way in which a number of highly discordant veins are joined to the central vein, in a direction subparallel to the bedding–cleavage intersection. These sheets, at most 10 mm in thickness, dip more steeply to the north than cleavage, and have been extended in their plane, boudined, during the regional deformation. The evidence of extension is found in the repeated quartz-filled zones, less than a millimetre thick, that cross discordant sheets, in directions sub-perpendicular to them. The patterns of fractured calcite crystals on either side of these zones match, although they are separated by the fibrous quartz that now fills the zones (Nicholson, 1966). The formation of these extension structures, developed in planar bodies lying at low angles to cleavage when they were deformed, is consistent with the simultaneous formation of folds in the veins, lying about at right-angles to cleavage.

In all three veins, the laminae are made up of vein-parallel, single-crystal, calcite plates, which have their crystallographic c-axes at right angles to their planar surfaces. Plates very commonly have thickness to lateral extent ratios of at least 100. Their thicknesses range from 0.1 mm to over 10 mm. The amplitude of the folds later imposed on the fabric varies in direct proportion to the vein thicknesses. Deformed plates are distinguished by complex developments of *e*-lamellae (Nicholson, 1966). The calcite crystals of the discordant, boudined veins, are also plate-like in shape, although arranged in various orientations, oblique to vein walls. These plates are separated from one another by relatively coarse-grained quartz.

Nettle (1964) attributed the unusual laminated structure of the veins to the modification of earlier fabrics during regional deformation and metamorphism. This interpretation was challenged by Nicholson (1966), who emphasized the primary nature of their laminated structure, and the way that it was affected distinctively by the succeeding episode of deformation, common to veins and country rock. He later analysed the small-scale folds produced by regional deformation in the laminated veins (Nicholson, 1978), suggesting that laminae formed in repeated acts of precipitation, separated by intervals of shear. He showed that interlaminar slip in early stages of folding was accommodated through the crystal–plastic behaviour of the single-crystal, calcite plates of which laminae are made. Work hardening, however, evidently raised the resistance of the plates, so that later slip was facilitated by pressure solution instead. Both this pressure solution, and the slip accompanying it, were concentrated where the surfaces between calcite plates lay at high angles to the principal shortening strain. Consequently, the through-going stylolites that gradually evolved were sited in fold limbs, eventually extending across the vein to isolate one hinge from another.

Plates and laminae show much greater continuity in cross-sections of microfolds than in sections parallel to fold axes. This condition, appears to be primarily related not to folding, however, but to the earlier-formed lineation, which in this vein lies approximately at right-angles to fold axes. In effect, calcite plates are elongated parallel to the lineation, which is so well developed on inter-laminar surfaces through these veins.

Calcite laminae are separated from one another by thin seams composed of muscovite and fine-grained quartz. The grain size of the latter may be a product of recrystallization, rather than being primary. It may be significant that this material coats the grooves and ridges cut into the calcite plates. As far as is known, however, this recrystalliz-ation may have occurred during folding, rather than at the time of formation of the lineation. Muscovite flakes, for the most part, lie parallel to the seams.

Interpretation

The interest at this site relates principally to the laminated calcite veins. The platy and lineated nature of these is itself unusual, and the veins record deformation which pre-dates the main Caledonian phase.

Both the development of the primary fabrics of the laminated veins, and the nature of the folds later developing in them, are phenomena of interest in their own right. This interest is heightened by the apparent rarity of platy, calcite fabrics like those here, even in laminated veins. Investigation of the primary character of the veins also provides an opportunity to investigate structural development at times before the regional folds and cleavage had formed. The swing of the cleavage and folds to the ESE trend at this site is of considerable regional interest.

Veins composed of primary, platy, calcite crystals, and their distinctive folds, in Britain appear to be restricted to rocks of Wenlock or Ludlow age. Nicholson (1966) has pointed out the existence of veins with platy calcite in Ribblesdale and the southern Lake District, in country rocks of similar age and sedimentary facies to those of the Llangollen Syncline. Warren *et al.* (1970) have made similar observations on the Silurian rocks of northern Clwyd. The veins of western Caledonian Wales (Fitches *et al.,* 1986), in older host rocks, although laminated and lineated like those of the Llangollen Syncline are not composed of calcite but ferroan dolomite, in which the platy morphology is unknown.

Laminated and lineated veins also apparently made up of calcite plates have been reported, however, from slates of the Appalachian fold belt of Pennsylvania (Beutner *et al.,* 1977). This occurrence resembles in several ways that of Ca'er-hafod. The country rocks, for instance, are of similar mid- to late-Silurian age. The principal veins are similarly parallel to bedding and strongly folded. At the same time, fold hinges are separated from one another by stylolites cutting across veins, as at Ca'er-hafod. There is also a set of associated, discordant and boudined calcite–quartz veins. Although vein carbonate is described as calcite, nothing is said of its morphology. But the appearance of the folded veins, in the only figure. showing the folded fabric in any detail, is quite compatible with a platy form for the calcites. Two points made by Beutner *et al.* (1977) are of special interest. Firstly, it is said that the Pennsylvanian bed-parallel veins lie along faults with only small displacement; however, no evidence is given. Secondly, the Pennsylvanian laminated veins apparently occur only in the gently dipping limbs of overturned folds. This is a contrast with Ca'er-hafod, where bedding–cleavage relationships suggest that veins are exposed in the region of a fold hinge.

Accepting the evidence of the discordant veins at Ca'er-hafod, the platy shape of the calcites may be described as a habit. The plates do not seem to be bounded, that is, by the compromise surfaces developed between adjacent crystals in competitive growth (Grigor'ev, 1965; Dickson, 1983). Such a habit has been described from crystal cavities in the New Jersey zeolite region of the USA (Schaller, 1932). The habit has been described as being indicative of high-temperature growth. This is of interest as the veins of the Llangollen Syncline are accompanied by well-crystallized muscovite (see

Hamdi Lemnouar, 1988 for analysis). This proposal does not fit, however, with a source of mineralizing fluids in water drawn from the sediment body itself (Fitches *et al.,* 1986), at a time before even low-temperature metamorphism had begun.

Questions are raised by the lamination of the veins, but detailed explanations have yet to appear. However, using published analyses, some proposals may be outlined. The laminated veins, for instance, may be complex examples of the crack–seal veins of Ramsay (1980); that is, veins formed by successive development of microcracks followed by successive mineral infilling. The modified version of this hypothesis proposed by Cox (1987), seems to be particularly apt, designed as it was to explain veins forming when large displacements were occurring parallel to vein margins.

The formation of the lineation offers particular difficulties. The lineation is cut deep into the surfaces of only very thin calcite plates. If the incision of the lineation were mechanical, it is difficult to understand how the mechanically anisotropic and weak calcite plates were not at the same time deformed plastically and even broken into pieces. However, there is no sign of such disruption. The process, therefore, seems more likely to have occurred through sculpting by diffusion-based processes, rather than abrasion. The lineation, in effect, may have been formed through pressure solution, the surfaces representing an unusual variety of stylolite (Ramsay and Huber, 1987, p. 655).

The site lies at the eastern end of the fold cleavage arc that characterizes the Caledonian tectonic trend in North Wales (Shackleton, 1969). As (Figure 4.1) shows, the trend of folds and cleavage at this end of the arc is slightly south of east; in Snowdonia (for example, Alexandra Quarry to Capel Curig, above) it swings to the NE–SW 'Caledonoid' trend, whereas to the south (Tan y Grisiau) it becomes almost N–S and then returns through NNE–SSW (Rheidol and Ponterwyd) to NE–SW (at Traeth Penbryn). This swing has been attributed by Shackleton (1969) to moulding against basement fault blocks, by Helm *et al.* (1963) to late (post-main-phase) Caledonian deformation, and most recently by Soper *et al.* (1987) to, once again, control by the basement during the main-Caledonian (early-Devonian) phase of closure of Iapetus.

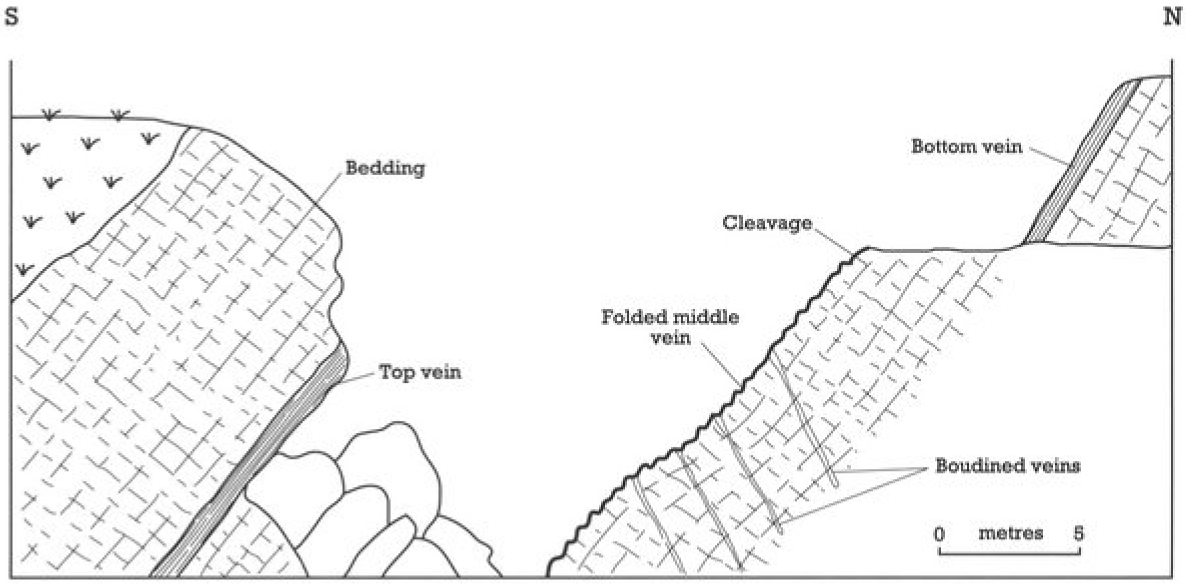
Conclusions

This site is important from two points of view. Firstly, it provides an example of the Caledonian structural trend in north-eastern Wales, where it swings to a trend slightly south of east. This trend, which contrasts with other areas in Wales, has been explained as being a result of how the Palaeozoic rocks (at this locality of Silurian age) were compressed above and against the rigid basement of older (Precambrian) rocks.

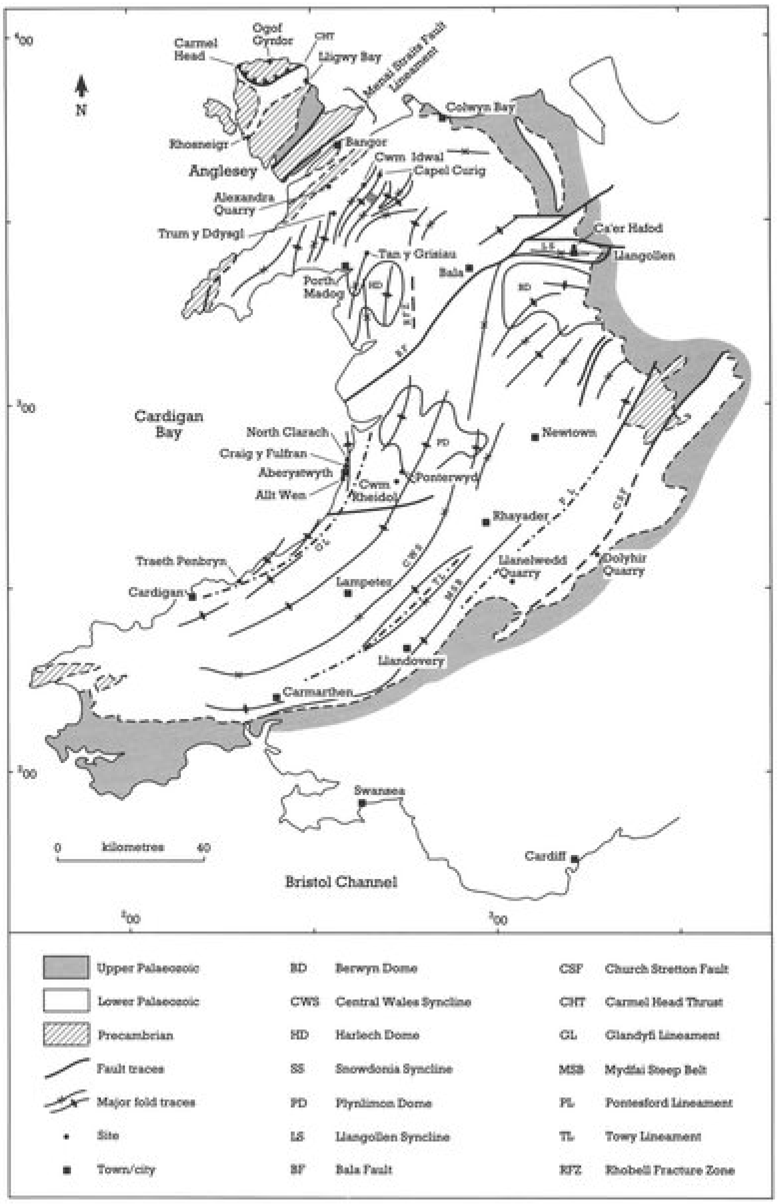
The laminated and lineated calcite veins, that are extensively developed parallel to bedding, indicate an early stage of tectonic movement in the late Silurian. Their growth requires vertical opening along bedding, but other features suggest horizontal displacements. Although the growth of these unusual platy calcite veins is not fully understood, currently they are the subject of considerable interest. It is quite clear, however, that these veins were deformed in the (post-Ludlow) main phase Caledonian deformation of the Welsh Basin, when regional folding and cleavage were developed.

References

(Figure 4.17) Ca'er-hafod. Part of the quarry showing bedding dipping steeply south, and cleavage gently north. The outcrop of the central vein (top left to centre) shows minor folds plunging towards the observer, and ridge-and-groove lineation almost at right-angles to this. View looking east. (Photo: R. Nicholson.)



(Figure 4.18) View looking west at Ca'er-hafod Quarry (Llangollen) showing steeply dipping Wenlock country rocks and spar beds (veins).



(Figure 4.1) Map showing the traces of the principal folds and faults of Caledonian age in Wales. The localities described in the text are also shown.