Alexandra Quarry

[SH 518 561]

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Highlights

Alexandra Quarry provides outstanding exposures illustrating Caledonian crustal deformation in the Welsh Cambrian Slate Belt. The Slate Belt of Wales is renowned internationally for its elliptical strain markers, the so-called reduction spots. Small strain markers such as the reduction spots were used in classic early studies of strain measurement. These features can be used to interpret the structure of the Slate Belt, which suffered the highest intensity of Caledonian deformation in North Wales.

Introduction

The overall structure exposed in the quarry is a NE–SW-trending, tight, upright anticline containing the Purple Slate Group in its core, flanked by Dorothea Grit and the overlying Striped Blue Slate Group. This broad structure is complicated by attenuation of the fold limbs and the presence of strike faults.

The geology of the Slate Belt has been investigated from an early stage in the study of Welsh geology because of the wealth of interesting structures exposed in the slate quarries. Sorby (1853, 1856, 1908) interpreted the green spots which characterize some of the slates, as the products of reduction in the sedimentary environment. He used them to estimate shortening perpendicular to cleavage of 75%, combined with 10% volume reduction: this was the first quantitative estimate of strain undertaken. The detailed account of the regional geology is that of Morris and Fearnsides (1926). More recent accounts of regional geology and theoretical structural studies are those of Wood (1969, 1971, 1974), Cattermole and Jones (1970), Tullis and Wood (1975), Wood *et al.* (1976), Roberts (1979), and Wood and Oertel (1980). The Slate Belt has featured prominently in the regional interpretations of Shackleton (1953), Dewey (1969), and Coward and Siddans (1979).

Alexandra Quarry, south-east of Moel Tryfan, was described in detail by Morris and Fearnsides (1926) and lies within the area depicted on the geological map of Cattermole and Jones (1970). The quarry provided a sample locality in the study of Wood and Oertel (1980) in their measurement of strain in the Welsh Slate Belt; and it also appears as a locality in the field guides of Roberts (1979) and Howells *et al.* (1981).

Description

Alexandra Quarry (see (Figure 4.3)A and B) has been excavated on a variety of levels, the lowest of which are now flooded. Exposure is excellent, although not always accessible. The structure is described at a number of sites within the quarry which are well illustrated by line drawings in Roberts (1979).

Towards the centre of the quarry around [SH 5181 5613], a large screen of rock separates the north-east end from the lower levels to the southwest (Locality A, (Figure 4.3)A). When viewed from a position on the lowest part of the track, the southwest face of this rock screen provides a cross-section of the structure perpendicular to the strike. An anticlinal hinge in the Purple Slate is flanked by NW-dipping Dorothea Grit forming the north-west wall of the quarry, and by SE-dipping, tectonically thinned, Dorothea Grit on the southeast side, with Striped Blue Slate above. A prominent greywacke bed showing boudinage occurs on the south-east limb. The screen also contains a vertical dolerite dyke. Like other presumed Ordovician dykes in the Slate Belt it is boudinaged and shows cleavage in its margins.

Although the overall structure displayed in the quarry is anticlinal, strike faults complicate the picture and, unfortunately, the presence of a large flooded pit immediately in front of the screen means that several of the interesting structures cannot be directly examined. This can be achieved at the south-west end of the quarry.

On the north-west side of the quarry at [SH 5161 5599] an anticline can be observed in the Dorothea Grit with the south-east limb faulted out against NW-dipping Purple Slate (Locality B, (Figure 4.3)A and B). Greywacke beds show quartz-filled tension cracks indicating extension in the outer arc during folding. A few *en échelon* quartz veins and prominent slickensides on bedding surfaces indicate that flexural slip was an important deformation mechanism in the greywackes.

On the south-east side of the quarry at [SH 5165 5590] south-easterly-dipping Purple Slate forming the face displays a variety of structural features (Locality C, (Figure 4.3)A). The subvertical, NE–SW striking cleavage forms the main face of the quarry at this location. Grit horizons (<0.05 m thick) in the slate are frequently graded and have load casts. Small-scale folding of these sandstone units is occasionally visible and this mimics the style of the large Slate Belt folds, with their strongly attenuated limbs.

The Purple Slate Group contains green spots of probable diagenetic origin. They have traditionally been termed reduction spots, but the colour of the spots has since been attributed to iron depletion, not reduction (Wood *et al.,* 1976). Sorby (1853) and subsequent workers considered them to be pre-deformation; a conclusion proved by the fact that they are affected by the contact metamorphism of dolerite dykes which have themselves been deformed (Wood, 1973; Wood *et al.,* 1976). During regional deformation, these spots were deformed into ellipsoids whose long (*x*)axes came to be generally <0.03 m in length. For the Slate Belt as a whole, long axis dimensions in the range 0.010.10 m are quoted (Tullis and Wood, 1975).

For initially spherical spots, the long (*x*) and intermediate (*y*) direction are contained within the cleavage, and the short axis (*z*) is perpendicular to the cleavage. This is the case for the majority of isolated spots in Alexandra Quarry, with x-axes plunging steeply to the south-west; indicative of the near-vertical extension recorded throughout the Slate Belt. On joint surfaces which cut the cleavage, the strong flattening of the spots in the plane of cleavage can be observed. Wood and Oertel (1980) recorded ordinary strains (E) (based on 67 measurements) from this quarry, of (1.00):(0.38):(–0.63); that is, the original radii of the sphere have doubled in *x,* increased by 38% in y and shortened perpendicular to the cleavage by 63%. The *x* and y dimensions of spots lie oblique to cleavage in cases where the initial shape was irregular. Examples of irregular, and occasional bedding-parallel iron depletion zones can also be observed at this locality.

Interpretation

Alexandra Quarry has been chosen to represent the principal structural features of the Cambrian Slate Belt which suffered the highest intensity of deformation in North Wales. This deformation produced a structural style in sharp contrast to the style exhibited by the volcanics of Snowdonia. Cattermole and Jones (1970) noted the sub-cylindrical nature of large folds in the Slate Belt which differs from the periclinal folds observed in Snowdonia.

Morris and Fearnsides (1926) outlined the main features of the Slate Belt. The NE–SW-oriented belt is separated by boundary faults from the Precambrian and basal Cambrian volcanics to the north-west and the Ordovician slates to the southeast. Internally, the Slate Belt contains numerous fold hinges (dominantly anticlinal) whose attenuated limbs are frequently replaced by strike faults. These essential features are well displayed in Alexandra Quarry. Morris and Fearnsides (1926) described in detail the compressive features of the belt, in which category they placed the folds, cleavage, and two types of strike fault. Their type 1 'slide' type of strike fault is in essence an extreme continuation of the process of flexural slip, whereas the second type is later and post-dates, to some extent, the folding and imposition of cleavage. They estimated horizontal shortening in the belt as >40%, on the basis of evidence provided by a folded bed. They did not, however, recognize the significance of reduction spots, but did indicate that the principal movement of material during deformation was vertically upwards (based on the predominance of anticlinal hinges). Wood (1971, 1974) made a detailed analysis of strain in the Slate Belt; he estimated the tectonic thickness of the succession in the Arfon Anticline to be about double (Wood *in* Rast, 1969).

Cattermole and Jones (1970), although generally following the interpretation of Morris and Fearnsides (1926), described the structural history of the Slate Belt in terms of the deformation phases identified by Roberts (1967). In this scheme, F_1

is the main deformation phase with fold interlimb angles of 65–80° and different fold profiles dependent on lithology. The strike faults were interpreted as high-angle reverse faults.

Morris and Fearnsides (1926) interpreted the development of the Slate Belt using a model involving its compression between the rigid crystalline rocks of Anglesey and the low-lying volcanics of Snowdonia. They suggested that as Snowdonia was progressively driven to the northwest toward Anglesey during the late Silurian, folding, sliding, and cleavage formation were induced in the belt.

Roberts (1979) concluded that the similar folds of the Slate Belt were 'flattened buckle folds which are essentially the result of initial pure shear upon which later simple shearing has occurred'. The interpretation of the deformation was compatible with early suggestions that 'severe flattening was coupled with an essentially upward distention of the sedimentary pile'. The structure of the Slate Belt emphasizes the inhomogeneous nature of deformation in North Wales for which large-scale strain variation, structural position, and lithological control are all likely determining factors.

The present state of research at the site does not allow much advance on the nature of the main deformation other than to confirm the observations of Morris and Fearnsides (1926) and Cattermole and Jones (1970) that the cleavage-parallel movements have been important in the modification of the fold belt. More needs to be known about the relative age and displacement sense of these movements. However, there is no evidence to suggest (cf. Roberts, 1979) that simple shear modification rather than homogeneous flattening of the initial buckle folds has been responsible for the 'similar' folding. The upright cleavage in the context of the other Snowdonia and Anglesey sites, and of other regional research on cleavage in North Wales (Coward and Siddans, 1979; Wilkinson, 1988), does not support the concept of Morris and Fearnsides (1926) that Snowdonia was driven towards Anglesey.

Studies along the length of the Slate Belt have shown the inhomogeneous nature of deformation with tectonic thickening ranging from 50–180%. Maximum extension is coincident with plunge culminations of major folds (and vice versa) (Wood, 1974). Where spots are absent, fabric anisotropy has been used to estimate strain, based on calibration with localities where spots are present (Tullis and Wood, 1972, 1975). The strong agreement between strain, fabric anisotropy and magnetic susceptibility anisotropy has established that slaty cleavage can be accounted for purely by physical rotation (Tullis and Wood, 1972, 1975; Oertel and Wood, 1974; Wood *et al.,* 1976).

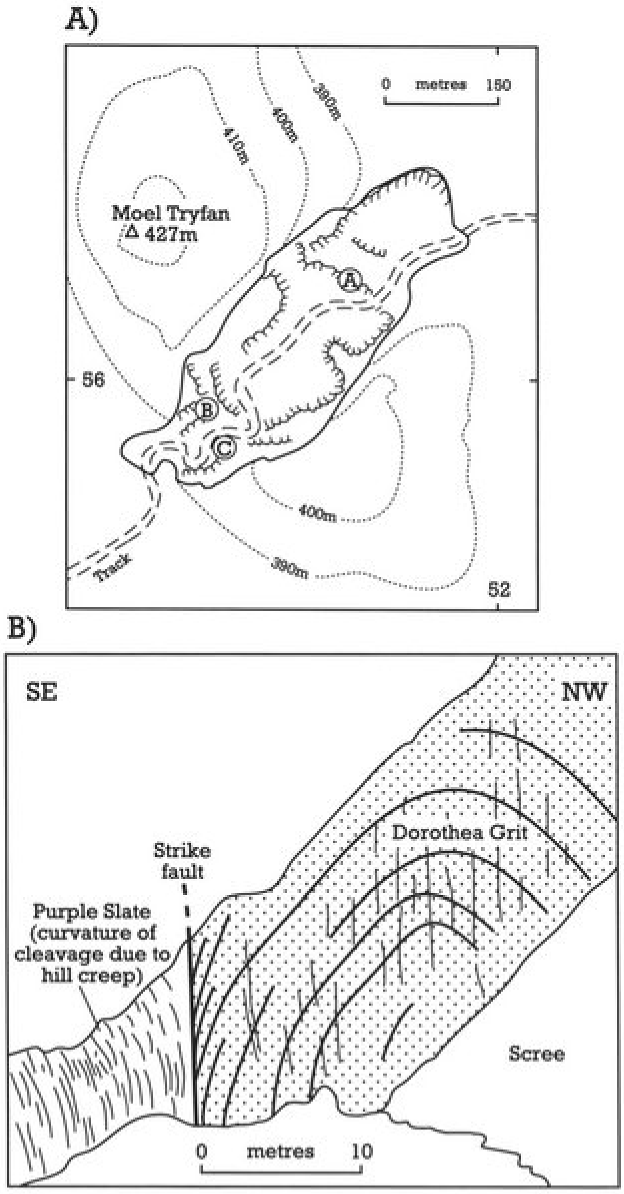
Alexandra Quarry is important as the best and most accessible locality for examining the structural features of the Welsh Slate Belt. The quarry faces, provide excellent exposures of characteristic tight anticlinal folds whose limbs are replaced by strike faults. Small-scale strain markers and minor structures enable the intensity and mechanisms of deformation to be established.

The quality of strain data has allowed a detailed understanding of deformation in the Slate Belt: not only of interest in regional terms, but also from a theoretical viewpoint. These perfect triaxial ellipsoids have provided a means to quantitatively evaluate strain during the generation of slaty cleavage since the classic work of Sorby in the nineteenth century, and will remain a data source of international importance. This work has fuelled an international debate (Tullis and Wood, 1972, 1975; Oertel and Wood, 1974; Wood *et al,* 1976) on the origin of cleavage, of considerable significance in studies of orogenic processes worldwide. The site illustrates high strain-levels typical of the Slate Belt, which suffered the highest Caledonian strains in North Wales. This is an important factor in ongoing studies of the significance of regional strain variations in the Caledonian Orogenic Belt.

Conclusions

The Slate Belt of North Wales is famous for its deformed rocks of Cambrian age. These have been compressed and folded and now take the form of cleaved slates. The area is well known for the studies which have been carried out on these rocks in relation to the extreme compression suffered by Britain during the Caledonian mountain-building phase, around 400 million years ago. Originally-spherical green spots in the muds (so-called reduction spots) are now perfect ellipsoids and have been used in classic studies to quantify the deformation. It has been shown that the sedimentary sequence has been laterally shortened by up to 63% in a north-west to south-east direction, and elongated to become up to double their original thickness. The perfect cleavage planes that characterize these roofing slates are perpendicular to the shortening and are parallel to the upward elongation. This is a classic locality for the study of folds, cleavage and strain related to the Caledonian Orogeny in Wales.

[References](#)



(Figure 4.3) Alexandra Quarry. (A) Site map, showing Localities A–C described in the text. (B) Sketch illustrating anticline in Dorothea Grit with a faulted south-east limb. See text for explanation. Locality B of Figure 4.3A.