Chapter 4 Wales

Introduction — a structural perspective

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Most of Wales is underlain by a thick pile of sedimentary rocks, ranging in age from Cambrian to Devonian, together with volcanic and intrusive rocks which are exposed mainly in the north and south of the country. These rocks collectively constitute the fill of the Welsh Lower Palaeozoic Basin, a major region of prolonged subsidence which developed as a marginal basin on the southern continental flank of the Late Precambrian–Early Palaeozoic Iapetus Ocean. It was deformed and weakly metamorphosed, mainly in Early Devonian times, during the Caledonian Orogeny in response to plate collision processes.

The edges of the basin, at least, are floored by a Precambrian–earliest Cambrian basement, which is exposed in Anglesey, the northernmost Welsh mainland, the Welsh Borders, and in South Wales. Devonian, Carboniferous, and younger strata hide the eastern part of the basin, although the transition with the Midland Platform of England is exposed within the Welsh Border Fault System and the classic Shropshire sections. In South Wales, basin and platform sequences are largely buried by Devonian and Carboniferous rocks and, with them, are caught up in the northern part of the Late Carboniferous Variscan orogenic belt.

The Welsh Lower Palaeozoic Basin is one of the world's classic geological regions in the sense that many of the basic principles of geology were first formulated there in the last century and early part of this century. The earliest work in Wales, concerned with structural geology, is discussed and referenced by Bassett (1969) in his comprehensive essay on Early Palaeozoic major structures and requires no further comment here. The observations and interpretations made by O. T. Jones, R. M. Shackleton and others earlier this century, however, remain pertinent to modern research as the following pages reveal. Since Bassett's review, research into the tectonic evolution of the Welsh Basin has undergone a renaissance, particularly in the last decade, as new ideas about sedimentary basin dynamics and deformation have been applied.

To provide a context for the selected Geological Conservation Review sites in Wales, this chapter concentrates mainly on descriptions of the main structural characteristics of the Lower Palaeozoic succession in Wales. However, to appreciate fully the importance of these sites to the evolution of ideas and to ongoing research, it is also necessary to comment briefly on the tectonic models which have been applied to Wales. It is no longer realistic to explain the deformation patterns in terms of a single and simple end-Caledonian event; the basin was tectonically active throughout its Lower Palaeozoic extensional, subsidence history as well as during end-Caledonian compression. Most of the structural characteristics of the Welsh Basin can ultimately be attributed to reactivation of basement structures.

Folds

Folds in the Welsh Basin range in magnitude from those which can be identified on small-scale maps such as the 1:625 000 Geological Survey Ten Mile Map of Great Britain (BGS 1979) and the 1:1 584 000 Tectonic Map of Great Britain and Northern Ireland (BGS 1966), to those which are visible only under the microscope. The axial traces of the major folds are shown in (Figure 4.1).

The largest folds have wavelengths of several tens of kilometres and include the Snowdonia Synclinorium and Harlech Dome of North Wales, the Towy Anticline of south-east Wales and the Plynlimon Dome, central Wales Syncline, and the Berwyn Dome of mid-Wales. These structures are usually periclinal and thus commonly produce broadly ovoid outcrop patterns of rock units. Several of these largest-scale structures are not necessarily simple products of end-Caledonian horizontal shortening. Some of the domes may represent horsts which rose intermittently (or failed to subside) during the extensional stages of basin development, buoyed up perhaps by low-density basement or Lower Palaeozoic acid intrusions. Examples are the Derwen Anticline and Harlech Dome in the north (Fitches and Campbell, 1987; Kokelaar,

1988) and the Towy Anticline in the east (for example, Tyler and Woodcock; 1987). Similarly, the Snowdonia Synclinorium is probably nucleated on a major Ordovician caldera (Howells *et al.,* 1986).

Major folds have wavelengths of 1–5 km and amplitudes of 1–2 km. Examples are the Idwal and Hebog Synclines, and Tryfan and Capel Curig Anticlines (Wilkinson, 1988), components of the regional Snowdonia Synclinorium (Figure 4.2), the Llangollen Syncline of north-east Wales (Wedd *et al.,* 1927), and the Capel Cynon Anticline of West Wales (Anketell, 1987).

The Idwal Syncline is one of Britain's best-known structures and typifies these major folds. It is an open, almost symmetrical fold with upright NE–SW axial plane and gentle north-east plunge in Cwm Idwal. As with other major folds, however, it is non-cylindrical, non-plane, and its geometry changes markedly along its axial trace; to the north-east of the A5, in the slopes of the Carneddau, it becomes almost isoclinal and plunges steeply to the south-west. Less typically, the major folds are asymmetrical (and then usually close to tight) with one limb steep to overturned. Trum y Ddysgl is situated on the north-west overturned limb of the Idwal–Snowdon Syncline. The Hebog Syncline, the southern continuation of the same structure, also takes this form locally, where its axial plane shallows to about 60°NW from its usually vertical attitude, but the Dolwyddelan Syncline is reclined to strongly inclined along its entire length. Some major folds have an *en échelon* geometry, for example the Cwm Pennant Anticline described by Roberts (1979), Wilkinson and Smith (1988), and Smith (1988).

Smaller-scale folds, with wavelengths between 200 and 1500 m, are locally visible in hillsides and coastal cliffs, as on the coastline south of Aberystwyth (Price, 1962). Most are revealed only by detailed mapping, as in west Wales by Craig (1985, 1987) and Anketell (1987). Outcrop-scale folds, with amplitudes between a few centimetres and 10 m, are common in some areas (for example, Aberystwyth and its hinterland) but rare in others (much of Snowdonia, for instance). Because they mimic the morphology and orientation of the major folds, these small structures provide a ready source of information about fold geometries. Such folds are illustrated in Silurian rocks at Cwm Rheidol and in the Ordovician of Anglesey, for instance at Rhosneigr.

Cleavage

Almost all rocks in the Welsh Basin are cleaved to some extent. Exceptions are the more rigid volcanic rocks, such as the welded tuffs of Snowdonia, and most of the major igneous intrusions such as the Tan y Grisiau microgranite of North Wales.

Cleavage is most clearly seen in argillaceous rocks, where it is usually a spaced (up to 5 mm), disjunctive fabric (using Powell's (1979) classification). Cleavage domains, the sites of pressure solution and growth of new phyllosilicates (Craig *et al.,* 1982), anastomose about detrital grains and diagenetic pyrite. The cleavage is more widely spaced and ill-defined in siltstones, sandstones, and volcaniclastic rocks. Several of the sites described below illustrate these cleavage character -istics. In mudstones and shales containing a bedding-parallel compaction fabric, the cleavage is commonly a zonal crenulation type. Exceptionally, the cleavage in mudrocks is continuous, giving rocks which yield high-quality roofing slates as in the Slate Belt of North Wales, especially well seen at Moel Tryfan. The Welsh slates inspired much early work concerning the nature of cleavage (for example, Sharp, 1849; Sorby, 1853), and more recently on cleavage-forming mechanisms (see Wood and Oertel, 1980; Whalley, 1973; Knipe and White, 1977; White and Knipe, 1978).

The margins of minor intrusions, notably those of dolerite dykes in Snowdonia, are commonly cleaved, the fabric being defined by aligned deformed vesicles and new metamorphic minerals such as actinolite and chlorite. Some of the plutonic bodies, including the Mynydd Mawr Granite in North Wales, also have cleaved margins.

On small-scale maps, such as (Figure 4.1), the trace of cleavage usually appears to be parallel to fold axial traces. This congruence is because cleavage is approximately axial-planar to, or has a fanning relationship with, most folds. However, recent studies have revealed many examples of cleavage transecting folds. Craig (1987) showed that in parts of West Wales the cleavage is anticlockwise with respect to small folds, axial planar to larger folds, and clockwise to major folds. Cave and Haim (1986) reported, numerous examples of clockwise transection from the Aberystwyth area and, in earlier unpublished work, were the first to record this phenomenon in Wales. The transection of folds by cleavage is widely recognized in the Caledonides of South Britain, where it has been interpreted as the consequence of transpressional deformation produced by oblique collision (for example, Soper *et al.,* 1987; Woodcock *et al.,* 1988).

Other complex fold–cleavage relationships are to be found in southern Snowdonia where, in the outer arcs of some folds, cleavage refracts so strongly that it becomes virtually parallel with bedding (Smith, 1988). Locally, as on the coast north of Aberystwyth, cleavage appears to have various time relationships to folding: it cuts across some folds, is axial planar to others, or is itself folded (Fitches and Johnson, 1978).

Strain

Strain markers are widely, although patchily, distributed throughout the Welsh Basin. Until recently, few attempts have been made to use them for strain analysis, despite the recognition of their potential use, over a century ago, by Sorby (1853). The now classical work on strain analysis in Wales, which had international significance, was carried out by Wood (1971, 1974), mainly in the Cambrian rocks of the Slate Belt in North Wales. He used as strain markers the centimetric, green reduction spots found widely in the grey and purple slates of that region. These spots, of diagenetic origin, were originally nearly spherical, but have been deformed into triaxial ellipsoids which have short axes normal to cleavage and long axes down the dip of that fabric. Wood calculated that up to 67% horizontal shortening and up to 157% vertical extension took place during cleavage development in the Slate Belt.

Siddans (1971) used accretionary lapilli to measure strains around the Capel Curig (or Mymbyr) periclinal anticline. Roberts and Siddans (1971) studied the shapes of various volcanic fragments in the Llwyd Mawr ignimbrite of Snowdonia, attempting to separate the volcanic compaction and tectonic strains. The strain data, obtained from some 50 sites by various workers throughout North Wales, were used by Coward and Siddans (1979) to calculate that the part of Anglesey between the Carmel Head Thrust and the Menai Straits has been shortened by 12 km during the end-Caledonian deformation, while the section from the Menai Straits to the Welsh Borders has been shortened by 43 km.

More recently, Wilkinson (1987, 1988) has made a major strain study of central Snowdonia, obtaining data from 250 sites by using a variety of strain markers, mainly in Caradoc volcaniclastic units: volcanic clasts, accretionary lapilli and siliceous concretions. Similarly, Smith (1988), working in southern Snowdonia, has used as markers ferruginous ooliths and, in the aureole of the Tan y Grisiau Granite, contact metamorphic spots. Further south, Craig (1985) measured the low strains in parts of west Wales from deformed concretions, following on studies made by Lisle (1977) on the Aberystwyth Grits.

The more recent strain studies have revealed that, although deformation in the Welsh Basin almost invariably involves nearly horizontal shortening and vertical extension, the strain magnitudes and shapes of finite strain ellipsoids are highly variable, even within small areas. Wilkinson (1987, 1988), Smith (1988), and Wilkinson and Smith (1988) attributed this heterogeneity partly to variations in lithology and positions of sites in major folds. However, the main cause, in their view, is the location with respect to reactivated basement fracture zones; anomalously high strains are found in cover rocks above basement fractures, whereas lower and more homogeneous strains characterize the cover to blocks between fractures. This topic is further discussed below.

Faults

As information has accrued on sedimentation and volcanism in the Welsh Basin, it has become increasingly apparent that the basin was intermittently tectonically active throughout its extensional history; subsidence and sediment accumulation were accomplished to a large extent by faulting. According to some authors, notably Wilkinson and Smith (1988), these basin faults were nucleated on reactivated basement faults. Many faults were repeatedly active, particularly those comprising the Menai Straits (Gibbons, 1983) and Welsh Borders (Woodcock, 1984a, 1984b) lineaments. Most of these early faults have a Caledonoid (NE–SW) or nearly N–S strike (Fitches and Campbell, 1987).

Fault-control on sedimentary facies and thicknesses in the Lower Palaeozoic succession is now widely documented, for example: in the Ordovician of Anglesey (Bates, 1974); along the Bala Fault lineament (Fitches and Campbell, 1987) and in the Llandovery area (Woodcock, 1987a). Most of the syndepositional faulting is consistent with an extensional or transtensional regime. Similarly, the accumulation of volcaniclastic deposits and the location of intrusions (notably plugs and dykes) were governed to a large extent by contemporary faulting. This control has been closely studied in central Snowdonia by the British Geological Survey's Snowdonia Unit, which has demarcated the Ordovician Snowdon caldera fractures and apical graben (Reedman *et at,* 1985), for example, and identified a failed rift system from dyke distributions (Campbell *et al.,* 1988), while Orton (1988) has analysed the interaction between sedimentation and faulting in central Snowdonia.

Woodcock (1984b, 1988; see Llanelwedd and Dolyhir Quarries) has shown that several lineaments in the Welsh Borders comprise complex systems of dip-slip and strike-slip faults, with folds in places, which can be interpreted as strike-slip 'duplexes'. Woodcock (1984b) and Lynas (1988) described the Clun Forest Disturbance, a NNE–SSW linear zone of anastomosing faults and folds in the Welsh Borders, as a flower structure. This structure comprises upward divergent reverse faults in a linear zone of uplift, and was caused by strike-slip displacement. The Glandyfi vergence divide in west Wales (Cave, 1984; Cave and Haim, 1986) has been interpreted as another example of a flower structure by Craig (1985, 1987), who takes this to be an end-Caledonian structure probably nucleated on a long-lived basement fracture.

Thrust faults occur on a small scale in various parts of the basin (Price, 1958, 1962). The only large-scale example, however, is the Carmel Head Thrust on Anglesey, which carries rocks of the Mona Complex over Ordovician strata (Greenly, 1919; Bates and Davies 1981). The Tremadoc 'Thrust Zone', identified by Fearnsides (1910) and Fearnsides and Davies (1944) on the basis of repetition of strata and various small-scale structures, is reinterpreted by Smith (1987, 1988) as a Caradoc olistostrome which probably slid northwards off the Harlech Dome. In mid-Wales, Jones and Pugh (1915) identified the NNE-striking, west-dipping Brwyno–Gelli Goch and Cascade–Forge Thrusts; the throw on these structures is not known (Cave and Haim, 1986).

Much of Central Wales is cut by ENE faults which displace folds and other faults, including the mid-Wales thrusts, and hence are late structures. Those mapped by Cave and Haim (1986) have dominantly dip-slip displacement. Faults with this trend are mineralized in places (Phillips, 1972; Raybould, 1976) and are perhaps manifestations of early Variscan, rather than end-Caledonian deformation (Fitches, 1987). The Bala Fault, one of the major faults of the Welsh Basin (Figure 4.1), is considered by Fitches and Campbell (1987) to have moved by strike-slip displacement also mainly during Variscan events, although parts of that structure were active as dip-slip faults during the early Palaeozoic.

Bedding planes in many parts of the Welsh Basin have been used as detachment surfaces, which are usually marked by striated thin veins of quartz, carbonate, and other minerals. Particularly outstanding examples, which first attracted the attention of researchers (for example, Nettle, 1964 and Nicholson, 1966, 1978), are found near Llangollen (Ca'er-hafod). Others, with genetically associated vein breccias, bedding-normal veins and folds, are seen at various places along the west Wales coast (Fitches *et al.,* 1986). Nicholson (1966) showed that the Llangollen veins preceded end-Caledonian deformation, although Davies and Cave (1976) ascribed those in west Wales to pre-lithification gravity sliding which accompanied fold and cleavage development. More recently, Craig (1985) and Fitches *et al.* (1986) interpreted the association of veining, bedding-plane detachment, small-scale thrust and normal faulting as the product of post-lithification hydraulic jacking followed by gravity sliding before the end-Caledonian deformation. These intriguing structures remain of topical research interest — see Traeth Penbryn and Allt Wen.

Deformation sequence

Most parts of the Welsh Basin are characterized by a single set of folds on upright, mainly NE–SW axial planes which are accompanied by cleavage. These structures are commonly described as the 'regional' or 'main' structures. They are usually attributed to end-Caledonian or Late Silurian–Early Devonian deformation (Dewey, 1969), although the current trend is to use the North American term 'Acadian' (for instance, Soper *et al.,* 1987). Woodcock (1987a) supported Jones' (1955) view that the main cleavage-forming event, in south-east Wales at least, continued into, or was confined within, late early Devonian to mid-Devonian times. Ongoing isotopic work in central and North Wales, by J. Evans (BGS), M. Dodson and P. Bishop (Leeds University), is likely to shed light on the timing of deformation in those parts of the basin, and on whether or not the 'main' structures are contemporaneous across the basin. Particularly relevant in providing time constraints on the deformation is the Lligwy Bay section on Anglesey (Greenly, 1919; Bates and Davies, 1981) where presumed Devonian red-beds are folded, cleaved and thrust: usually, elsewhere in Britain south of the Southern Uplands Fault Devonian rocks were only strongly deformed by Variscan events.

It has become clear that deformation of the basin cannot be regarded simply as a single, climactic event; several regions were tectonically active at various times during basin evolution, and even the main, end-Caledonian deformation was polyphase.

Along the N–S Rhobell Fracture Zone on the eastern flank of the Harlech Dome, Kokelaar (1977, 1979) demonstrated an early Tremadoc set of folds with steep N–S axial planes, which preceded eruption of the Rhobell Fawr Volcanic Group and, similarly oriented, end-Tremadoc folds which deform those volcanics. An end-Tremadoc regional deformation event has been recognized over much of north-west Wales on the evidence that the basal Arenig deposits are usually unconformable on older rocks (Shackleton, 1953, 1954; George, 1961; Roberts, 1979; Allen and Jackson, 1985a, 1985b). The magnitude of the sub-Arenig unconformity increases, irregularly, to the north and west of the Harlech Dome until some 5000 m of mainly Cambrian strata are cut out on LlSrn. Roberts (1979) suggested that this tectonic event involved block uplift on major faults. It is not yet clear whether this end-Tremadoc event caused widespread folding and cleavage or produced these compressional structures only along fault zones.

Allen and Jackson (1985a, 1985b) tentatively attributed localized NW-trending folds in the Harlech Dome to a late Ordovician–Silurian deformation, but structures of this age within the basin are not widespread. There is evidence, however, (Woodcock, 1984b) for strike-slip faulting along the south-east margin of the basin, of probable Ashgill age. Lynas (1970a) considered evidence for a mid-Caradoc event producing a flat-lying cleavage around the northern and eastern flanks of the Harlech Dome, perhaps in response to incipient uplift of the dome associated with volcanism. Coward and Siddans (1979) attributed this fabric to deformation in the Tremadoc Thrust zone. However, this 'early' cleavage is now interpreted as the regional, end-Caledonian cleavage, which has an unusually shallow dip because host rocks were ramped southward over the Tan y Grisiau Granite and Harlech Dome during the regional deformation (Bromley, 1971; Campbell *et al.,* 1985; Smith, 1987, 1988). The lineation on the low-angle cleavage, which earlier workers had ascribed to intersection with the upright, regional cleavage, is usually a grain shape fabric in the cleavage, generally the effect of elongate grains in the cleavage, probably caused by strong down-dip extension.

Several sets of end-Caledonian structures have been identified in various parts of Wales. Roberts (1967, 1979) recorded three deformations in North Wales. According to him, the main fold architecture, represented by the mainly NE–SW upright cleavage and folds such as the Idwal Syncline, developed first, during a D_1 event. Rare, recumbent folds with axial-planar crenulation cleavage were then imposed (D_2), and followed in turn by upright NW–SE to N–S folds and crenulation cleavage (D_3). Helm *et al.* (1963) considered that the D3 deformation was responsible for the major arcuation of the main structures through North Wales. However, Roberts (1979) assigned the late structures to localized deformation (along zones above basement fractures according to Wilkinson, 1988); Coward and Siddans (1979) argued against this refolding model on the grounds of fold geometry.

Polyphase deformation structures are also known in mid-Wales. Fitches (1972) described, from the Aberystwyth area, a sequence of structures, closely similar to that described by Roberts (1969) in North Wales. Other examples from northern Mid-Wales were described by Martin *et al.* (1981). Tremlett (1982) and Craig (1985) suggested that the D_2 and D_3 structures probably denote localized movement near faults, rather than regionally correlatable events. Their view is supported by the close spatial association of kinks and crenulations of the regional cleavage with the Tal y Ll■n section of the Bala Fault system (Bracegirdle, 1974; Fitches and Campbell, 1987). On these grounds, the structures deforming the regional cleavage in Mid-Wales, and perhaps also Snowdonia, are Variscan rather than Caledonian — see above. In summary, the main D_1 deformation occurred in the late Silurian to early Devonian but not necessarily as a single climactic event. Earlier movements, often related to faulting and volcanic activity, caused local folding and tilting, but there is no evidence of earlier cleavage. Similarly, deformation later than D_1 is of local development and it may often be attributed to fault movement which may be Variscan.

Tectonic models

It has been shown that the main end-Caledonian folds throughout the Welsh Basin, are typically upright and non-cylindrical structures, irrespective of scale; and the main cleavage usually has an axial planar, fanning or transecting relationship with the folds. Despite this uniformity of morphology, however, the orientations of these structures are highly variable (Figure 4.1). Particularly conspicuous in North Wales is the arcuation of axial planes and cleavage from N–S in the Harlech Dome and southern Snowdonia, through NE–SW (Caledonoid) in central Snowdonia, to E–W in north-east Wales. A similar, but smaller scale, arcuation occurs about the north-western flank of the Berwyn Dome, where the NNE–SSW Central Wales Syncline turns abruptly into the E–W Llangollen Syncline. In much of central and west Wales the structures strike approximately NNE–SSW, but in the southern part of the basin they arc to ENE–WSW and then E–W. The cause of these arcuations has been extensively debated in the past and, in conjunction with the more recently recognized allied enigma of transecting cleavages, is again a topical research subject. An interrelated problem is whether or not deformation is 'thin-skinned', whether the structures flatten downward to merge with one or more detachment zones deep in the cover, or upper part of the basement, or is 'thick-skinned', that is the cover structures link with, and are partly controlled by, those deep in the basement.

Jones (1912) was the first to address the problem of arcuation in the southern part of the basin, concluding that it is a primary Caledonian feature and not a product of deflection of Caledonoid structures by a younger event. Anketell (1987) supported this view and contradicted Pringle and George's (1948) explanation which postulated subsequent warping. Shackleton (1954), concerned with northern Wales, considered that cover structures were strongly guided by fracture systems in the basement. He pointed out that on Anglesey, for example, at Ogof Gynfor, there is no detachment along the exposed cover–basement boundary and that there are small-scale examples of faults in the basement passing up into faults and folds in the cover (earlier recorded by Greenly, 1919). These and other observations -led him to suggest that the structural arcuations in the cover in northern Wales are responses to moulding of structures against and above the sides and corners of basement fault-blocks.

By contrast, Helm *et al.* (1963) explained the North Wales arcuation in terms of regional refolding of Caledonoid structures about later NW–SE axial planes. Their interpretation was countered by Coward and Siddans (1979) on the grounds that there are no structures in the region which are consistent with the inner-arc compression and outer-arc extension required by the refolding model.

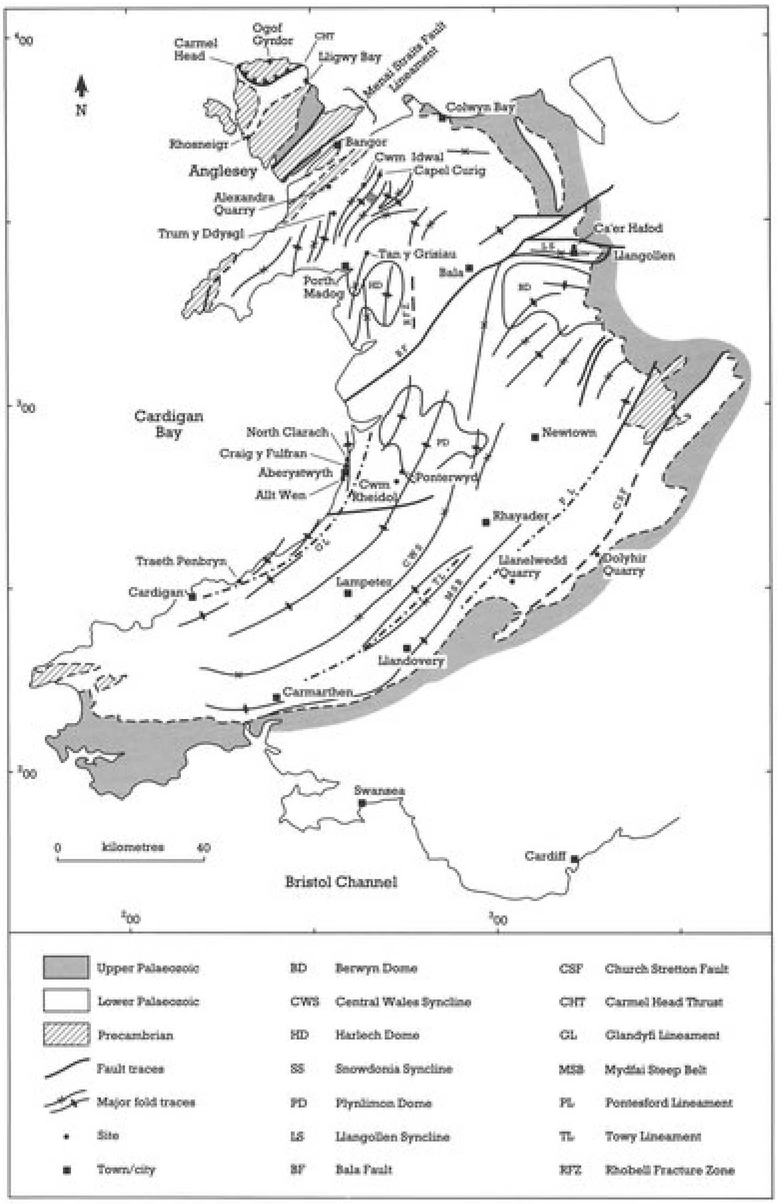
Coward and Siddans (1979) went on to erect a 'thin-skinned' interpretation of northern Wales, based largely on their strain study, deducing that the cover and upper part of the basement lie on a deep detachment. They explained the structural arcuation as the result of compression of Snowdonia against a rigid block situated beneath the Berwyn Dome. Campbell *et al.* (1985) modified this indenter model, considering that the rigid block comprised the Caradoc Tan y Grisiau granite and basement rocks beneath the northern flank of the Harlech Dome.

In a radical departure from previous interpretations of deformation in Wales, Woodcock (1984a, 1984b) introduced the concept of strike-slip and transpressional tectonics to explain the end-Caledonian, and perhaps earlier, tectonic events in the south-eastern part of the basin. These views, together with an assessment of possible Variscan and younger reactivation of Caledonian structures, are developed in Woodcock (1987b, 1988) and Woodcock *et al.* (1988).

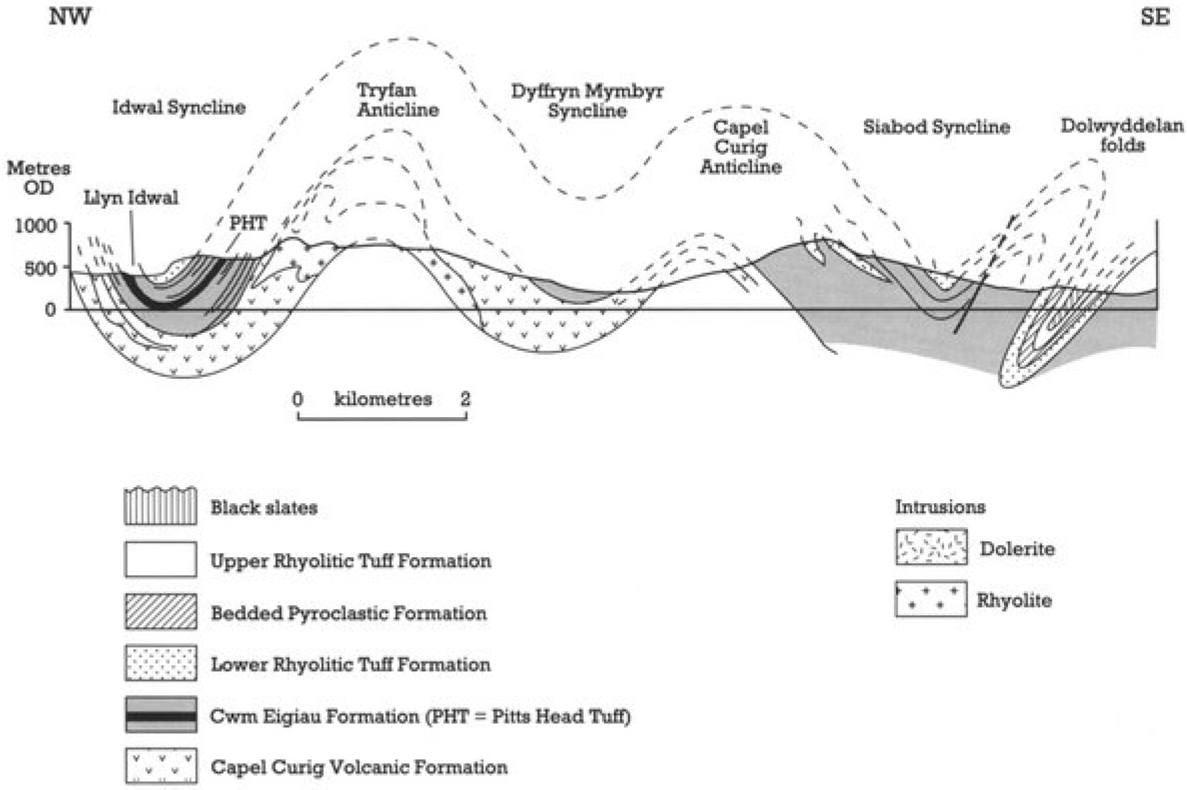
The various interpretations reviewed above have recently been elaborated upon and revised by Smith (1988), Wilkinson (1988) and Wilkinson and Smith (1988), as a result of their comprehensive strain studies in Snowdonia, and by Kokelaar (1988) from an analysis of igneous activity in northern Wales.

Based on Gibbons' (1987) conclusion that the Precambrian rocks of Anglesey and Ll■n represent an amalgamation of terranes, accreted in latest Precambrian to earliest Cambrian times by docking along NE–SW strike-slip zones, it is considered that much of northern Wales is underlain by a similarly heterogeneous basement dissected by steep NE–SW, and probably N–S, shear zones. These shear zones were reactivated, largely as brittle structures, during early Palaeozoic extension and transtension of the basin, and separated fault blocks which could move vertically and laterally independently of one another. In this way, the basement structures strongly governed Cambrian and Ordovician sedimentation patterns and igneous activity. Intermittent differential block movements during basin subsidence, some causing inversion, may have been responsible for local folding, warping, and tilting, during end-Tremadoc times for example. Subsequently, as a result of the end-Caledonian closure of the Iapetus Ocean (Soper and Hutton, 1984; Soper *et at,* 1987) the blocks were jostled due to approximately NW–SE compression, again reactivating older faults. Block margin faults which were aligned normal to compression allowed dip-slip displacement, and induced Caledonoid folds and cleavage at and above their tips. On the other hand, faults aligned at an angle with respect to regional compression were reactivated as strike-slip faults, generating transpressive structures in the cover; *en echelon* folds, transecting cleavage and complex patterns of minor faults (Woodcock *et al.,* 1988). This model has therefore combined, modified, and developed the basement control model of Shackleton (1954) and the trans-pressional models of the Welsh end-Caledonian deformation.

[**References**](#)



(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.



(Figure 4.2) Section through the major folds of Snowdonia (after Wilkinson, 1988).