Chapter 8

North Wales

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Carboniferous strata within this region occur in the broad eastern flank of the north-south axis of the Clwydian Range from Prestatyn to Oswestry, sections within the Vale of Clwyd and the outlying districts around Llandudno, Menai Straits and Anglesey (Fig. 8.1). In northeast Wales and the Welsh Borderlands the gently tilted Visean limestones are succeeded to the east by Namurian to Westphalian strata forming the Flint and Denbigh coalfields.

This region includes intermittent development of Tournaisian to Visean alluvial deposits ('Basement Beds'). These are overlain by Visean ramp-to-shelf carbonates, present along the northern margin of the Wales-Brabant High, extending across North Wales (Clwyd Limestone Group). Visean to Namurian basinal deposits (Craven Group) occur on the north coast of North Wales (Fig. 8.1), deposited on the southern margin of the Irish Sea Basin (see Chapter 16). During the Namurian and Westphalian this region is represented by thick fluvio-deltaic successions, including the Millstone Grit and Pennine Coal Measures groups, in turn overlain by alluvial deposits of the Warwickshire Group.

George (1958, 1974) was foremost in speculating on the role of tectonism during the accumulation of the Carboniferous rocks of North Wales, but this has been the focus of renewed attention following the application of 'sequence stratigraphy' methods (Gawthorpe *et al*. 1989). Somerville & Strank (1984a, 1989) recognised the influence of major structures such as the Bala and Menai Straits faults. Davies *et al.* (2004) sought to explain many of the major lateral facies and thickness changes as responses to movement on these fundamental fracture belts and linking structures such as the Nant-Figillt, Vale of Clwyd, Conwy Valley, Alyn Valley and Nercwys faults (Fig. 8.1).

Tournaisian –Visean

The 'Basement Beds' is an informal term used in North Wales to describe a number of isolated outcrops of alluvial deposits ('cuvettes') that record the infilling of an incised, possibly fault-influenced, topography. Formation names have been proposed for these alluvial deposits, namely Lligwy Sandstone, Menai Straits, Ffernant, Penbedw, Fron-fawr and Pant formations (Fig. 8.2. Cols. 1, 3, 5, 6, 8 & 9). The formations variably comprise reddened breccias, conglomerates, sandstones, siltstones and mudstones and common calcrete development. The formations show different ages of deposition and clast composition, derived from local upland areas that separated the cuvettes. The 'Basement Beds' are mostly unfossiliferous, although in the Menai Straits region (Fig. 8.2, Col. 3) miospores have been obtained from the Menai Straits Formation including *Raistrickia nigra, Waltzispora planiangulata* and *Dictyotriletes pactilis* (Hibbert & Lacey 1969), indicative of the NM Spore Zone [^1], of probable late Asbian age. However, east of the Vale of Clwyd, the local Ffernant and Penbedw formations are directly succeeded by early Visean (Chadian) limestones (Fig. 8.2, Col. 6), and thus the 'Basement Beds' here may be in part Tournaisian in age. Several miospore taxa diagnostic of the Tournaisian (e.g. *Vallatisporites vallatus*) are recorded as reworked elements from the 'Basement Beds' in the Menai Straits region (Hibbert & Lacey 1969).

Visean

The Clywd Limestone Group comprises dominantly shallow-marine ramp and platform carbonates, the margin of which was the site of localised mudmound ('reef') growth as part of a lateral transition into coeval basin margin facies of the Craven Group (Somerville *et al.* 1989; Davies *et al*. 2004). The Clwyd Limestone Group rests locally upon 'Basement Beds', or elsewhere with marked unconformity on deformed Silurian and older rocks.

The strata now included within the Clywd Limestone Group were thought to comprise only Asbian and Brigantian strata (George *et al.* 1976; Warren *et al.* 1984). However, earlier Chadian, Arundian and Holkerian strata have subsequently been discovered (Somerville & Strank 1984a, 1984b, 1984c; Davies *et al.* 1989, 2004). As the Mississippian transgression in North Wales proceeded, younger formations successively onlapped older units so that to the west and south it is these younger strata which rest on pre-Carboniferous rocks (Fig. 8.2). The group, up to 900 m thick, comprises, in ascending order, the Foel, Llanarmon Limestone, Leete Limestone, Loggerheads Limestone, Cefn Mawr Limestone, Minera Limestone and Red Wharf Limestone formations (Somerville 1979c; Davies *et al*. 1989, 2004; Waters *et al*. 2009).

The Foel Formation of Warren *et al.* (1984) is limited to the Clwyd area (Fig. 8.2, Col. 6). The succession comprises mainly porcellanous calcite mudstone and wackestone, argillaceous packstone, peloidal and locally ooidal grainstone, cryptalgal laminites and oncolitic floatstone. It appears to have accumulated in a lagoon or intertidal and supratidal mud flat, interdigitated with high-energy and open marine facies that record invasion of sediment derived from sheltering shoals or barriers (Davies *et al.* 1989; Somerville *et al.* 1989). It is entirely Chadian in age, containing the diagnostic basal Visean foraminifer *Eoparastaffella simplex* and in the Alyn Valley Borehole [SJ 1889 5744], south-west of Mold, mudstones contain a miospore assemblages of the *Lycospora pusilla* (Pu) Zone (Davies *et al.* 2004) $^{O\wedge1}$. The anomalous 88 m thickness of the formation encountered in this borehole was accommodated by synsedimentary movement on the adjacent Alyn Valley Fault (Davies *et al*. 2004). The brachiopod *Composita* cf. *ficoidea* dominates *in situ* shelly macrofossil assemblages (Neaverson 1930) along with the solitary coral *Axophyllum simplex* typical of Mitchell's (1989) Rugose Coral Assemblage B (Somerville *et al.* 1989).

The Llanarmon Limestone Formation comprises mainly pale, thick-bedded, peloidal and skeletal grainstone that accumulated under relatively high-energy, shallow marine conditions, the sharp base to the formation recording a major marine transgression. The lower part of the formation developed as an eastward-facing carbonate ramp, which by the late Arundian had evolved into a carbonate platform. The basal few metres of the formation in the Clwyd area (Fig. 8.2, Col. 6) contain Chadian foraminiferal assemblages ^{O2} (Davies *et al.* 1989). Higher strata contain the foraminifers *Glomodiscus miloni, G. oblongus*, *Uralodiscus settlensis* of the Cf4β-δ Subzones (Somerville & Strank 1984a; Davies *et al*. 2004) of Arundian age and a sparse coral assemblage assigned to Rugose Coral Assemblage D of Mitchell (1989) of late Arundian age (Somerville & Strank 1984a; Somerville *et al.* 1989) ^{O*3}. Miospore assemblages of the *Lycospora pusilla* (Pu) Zone (Chadian-Arundian) have been reported from the formation in Llanarmon Quarry (Somerville *et al.* 1989; Davies *et al*. 2004). In the Prestatyn area (Fig. 8.2, Col. 7) equivalent levels of the formation (the Moel Hiraddug Limestone Formation of Somerville *et al.* (1986)) contain a rich solitary coral fauna and the brachiopods *Delepinea carinata* and *D. destinezi* which can be assigned to Rugose Coral Assemblage D of Mitchell (1989), of late Arundian age ^{*1}. In the Vale of Clwyd (Fig. 8.2, Col. 5) the basal bed contains a low diversity archaediscid assemblage of possible Cf4β Subzone ^{O1}, but 0.7 m above the base is a diverse assemblage of the foraminifer Cf4γ Subzone (Davies *et al*. 2004). The upper levels of the formation north of Mold (Fig. 8.2, Cols 6 ^{O4} & 7 ^{O2}) contain Cf5 Zone to Cf6α-β subzones

foraminiferal assemblages, confirming the presence of both Holkerian to early Asbian strata (Somerville & Strank 1984a, c; Davies *et al.* 2004). At this time shoal facies progressively withdrew to the platform margin and these upper levels around Prestatyn (Fig. 8.2, Col. 7) include a dark, crinoidal facies (previously the Gop Hill Limestone Formation of Somerville *et al.* 1986,1989). The dolomitized sequence at Llandudno (Fig. 8.2, Col. 4) includes an unusual bryozoan build-up (Nichols 1965; Bancroft *et al.* 1988), the Nant-y-Gamar Limestone Member (Reef 1).

The Leete Limestone Formation comprises rhythmic units of dark, argillaceous skeletal packstone and paler grainstone, overlain by porcellaneous limestone (Somerville 1979b; Somerville & Gray 1984; Somerville & Strank 1984b; Davies *et al.* 1989). These deposits are known throughout the eastern Clwydian Range (Fig. 8.2, Cols. 5 & 6), the lower limestones of the Eglwyseg Rocks near Llangollen (Col. 8), quarries near Llanddulas (Col. 5), and in Tandinas Quarry, Penmon, Anglesey (Col. 2). The formation accumulated in hypersaline, lagoonal and peritidal environments landward of the shoals associated with the Llanarmon Limestone Formation. The formation includes the brachiopod *Daviesiella llangollensis*, indicative of a Holkerian to early Asbian age (Cope 1975; Somerville & Strank 1984c). The foraminifer *Holkeria* sp., indicative of the Cf5 Zone (Holkerian) is present at the base of the formation [O5] (Fig. 8.2, Col. 6). In its type area in the vicinity of Loggerheads (Fig. 8.2, Col. 6), the upper part of the formation and its northern tongues contain foraminifers of the Cf6α-β Subzones (early Asbian) including *Pojarkovella nibelis* and *Bibradya inflata* (Somerville & Strank 1984a, c; Davies *et al*. 2004).

The Loggerheads Limestone Formation consists mainly of pale, thick-bedded, skeletal and peloidal packstone, present in cycles typically topped by palaeokarstic surfaces, in turn overlain by mudstone palaeosols (Somerville 1979a; Davies *et al*. 2004), similar to the Urswick Limestone Formation of south Cumbria (see Chapter 12). Coeval, highly fossiliferous 'knoll-reef' facies, present on the Little Orme, Llandudno (Fig. 8.2, Col. 4, Reef 2) and at Graig Fawr near Prestatyn (Col. 7, Reef 1) are recognised as the Little Orme and Graig Fawr members respectively within the formation (Waters *et al*. 2009), though they occupy a transitional setting between this unit and laterally equivalent parts of the Craven Group (see below). The formation displays a sparse, but diverse coral assemblage (Somerville 1979a; Somerville & Strank, 1984b) typical of the Rugose Coral Assemblage G of Mitchell (1989) and brachiopod assemblages that include the taxon *Davidsonina septosa* (George *et al.* 1976), both consistent with a late Asbian age. The presence together of the foraminifers *Euxinita* sp. and *Pojarkovella* sp. from the lower part of the formation west of Mold (Fig. 8.2, Col. 6) suggests a horizon around the Cf6α-β/Cf6γ subzonal boundary [O7] (Davies *et al*. 2004). In the Corwen Outlier [SJ 052 427] (Fig. 8.1) the formation includes levels with abundant *Pojarkovella* sp. (Davies & Riley 2003). The appearance, at higher levels, of foraminifers in assemblages rich in the alga *Koninckopora inflata*, but devoid of *Pojarkovella*, confirm the Cf6γ Subzone, broadly indicating a late Asbian age (Somerville & Strank 1984a; Davies *et al*. 2004). The ammonoid *Goniatites crenistria* and *Bollandoceras micronotum* from Meliden Quarry, in the flank beds of Graig Fawr mud-mound (Fig. 8.2, Col. 7), have been taken to indicate a B_2 age (Neaverson 1930, 1943, 1965; Warren *et al*. 1984), but are more likely to be of P_{1a} Subzone (latest Asbian) age [+3] (see Riley 1993). However, Austin & Aldridge (1973) also recorded the conodonts *Gnathodus bilineatus* and *Mestognathus neddensis* (= *M. bipluti*) from the same locality, which would suggest a horizon above the Asbian/Brigantian boundary (see Riley 1993). Warren *et al*. (1984) also assigned a B_2 age to rich coral and diverse brachiopod faunas present in the Little Orme Limestone Member [*1] (Fig. 8.2, Col. 4).

The Cefn Mawr Limestone Formation comprises mainly dark, thin-bedded wackestone and packstone with thick beds of coarsely crinoidal grainstone (Somerville 1979c; Davies 1984). The formation near Mold and at Trefor Rocks, Llangollen (Fig. 8.2, Cols. 6 [*8] & 8 [*1]) include coral assemblages (Somerville 1979c; Somerville & Strank 1984b) typical of the Rugose Coral Assemblage H of Mitchell (1989) and consistent with a Brigantian age. *Orionastraea phillipsi* and *Corwenia rugosa*, typical of the Rugose Coral Assemblage I of Mitchell (1989), have been recorded in higher strata in Hendre Quarry [SJ 193 680] (Fig. 8.2, Col. 6 [*9]; Somerville 1979c) and the outlier at Corwen (Fig. 8.1). The ammonoids *Arnsbergites sphaericostriatus*, *Hibernicoceras carraunense* and *Paraglyphioceras bisati* found at Hope Mountain [SJ 286 559] (Fig. 8.2, Col. 6) are indicative of a comparable mid-Brigantian age, assigned to the P_{1c} Subzone [*9]. From near the top of the formation on Halkyn Mountain (Fig. 8.2, Col. 6), *Sudeticeras* sp. ex gr. *splendens/stolbergi*, is strongly suggestive of the P_{2b} Subzone [+10] (Davies *et al.* 2004).

The cyclic sequences of both the Loggerheads Limestone and Cefn Mawr Limestone formations represent shoaling-upwards rhythms developed as the product of consecutive glacio-eustatically driven marine inundations. Karstic surfaces, bentonitic soils and well-developed calcrete profiles demonstrate long emergent intervals in response to marine regressions and define the cycle boundaries. The thicker and typically finer-grained Cefn Mawr Limestone cycles are taken to indicate larger and more rapid transgressive events. Widespread coral and mudstone marker beds also facilitate cycle correlation (Somerville 1979c; Davies 1991; Davies *et al.* 2004). Such correlations reveal the influence, during deposition, of the Bala Lineament (Fig. 8.1); the cycles in both the Loggerheads Limestone and Cefn Mawr Limestone thicken, split and undergo lateral facies changes in the vicinity of the fault belt (Davies *et al*. 2004). The platform margin remained well defined during deposition of the Loggerheads Limestone and was the site of local 'knoll-reef' growth, but the more muddy Cefn Mawr Limestone facies promoted local instability and collapse.

Black, replacive chert nodules are common in the succeeding Red Wharf Limestone Formation, the topmost division of the Visean on Anglesey, along the Menai Straits and on the Great Orme, Llandudno (Fig. 8.2, Cols. 1, 3-4; BGS 1989). Distinctive sheet and channel sand bodies preserving fluvial, estuarine and transgressive barrier beach siliciclastic facies are a feature of the landward margin of the platform exposed on Anglesey (Walkden & Davies 1983; Davies 1991). There is a possible link with the laterally equivalent Minera Formation of the Mold and Llangollen areas (Fig. 8.2, Cols. 6 & 8; Davies *et al.* 2004), which comprises wackestone, packstone and grainstone arranged in cyclic sequences, with thick, calcareous sandstone commonly developed at the top. The cyclic sequences of the Red Wharf Limestone and Minera formations represent repeated shoaling-upwards sequences, the limestones ranging from storm wavebase to fair-weather wavebase. These two formations are considered to be entirely late Brigantian in age, yielding colonial rugose corals, including *Lonsdaleia duplicata*, and foraminifers, including *Asteroarchaediscus*, of the Cf6δ Subzone.

On the coast around Prestatyn (Fig. 8.2, Col. 7), Asbian and Brigantian strata belong to the Craven Group, introduced by Waters *et al*. (2007) to replace numerous geographically localised group names, including the essentially chronostratigraphical Dyserth and Gronant groups of Warren *et al.* (1984). The Craven Group in North Wales is up to 400 m thick and includes the Visean Prestatyn Limestone and Teilia formations, succeeded by the Namurian Pentre Chert and Bowland Shale formations (formerly Holywell Shales). The Prestatyn Limestone and Teilia formations are coeval with the Clwyd Limestone Group; both thicken northward.

The Prestatyn Limestone principally comprises dark grey, graded packstone and wackestone beds with mudstone partings. Aprons of limestone turbidites, limestone breccias and blocks developed basinal to 'knoll-reef' in the Loggerheads Limestone (see above). Aldridge *et al.* (1968) recorded a late Asbian conodont assemblage including *Gnathodus bilineatus* and *Gnathodus girtyi* from the formation (Fig. 8.2, Col. 7 [O4]). In the Gronant Borehole [SJ 0950 8279] Reynolds (1970) recorded the same taxa and *Mestognathus bipluti* from a horizon just below the top of the Prestatyn Limestone Formation. The presence of *Posidonia becheri* [~5] just above the contact indicates a P_{1b} (early Brigantian) age for the base of the Teilia Formation, which at higher levels contains a typical assemblage of *Dunbarella persimilis*, and *Arnsbergites sphaericostriatus* [+6], indicative of a Brigantian (P_{1c}) age (Warren *et al*. 1984). Dark argillaceous limestone and calcareous mudstone characterise the succeeding Teilia Formation (Warren *et al.* 1984), which accumulated predominantly from suspension in moderately deep water, largely below storm wave-base. Thin limestone beds were possibly introduced by storms and/or as turbidites. The formation onlaps the 'knoll reefs' of the Clwyd Limestone Group and passes laterally into the Cefn Mawr Limestone.

Namurian

The basal Namurian Pentre Chert Formation includes common sponge spicules and radiolaria. The formation represents continued suspension deposition in moderately deep water, largely below storm wave-base, and signals the end of large-scale carbonate deposition on the Visean platform. The Pentre Chert Formation onlaps the former carbonate platform succession thickening southwards with a locally disconformable base showing evidence of dissolution and collapse on Halkyn Mountain and the Little Orme (Davies *et al*. 2004; Warren *et al*. 1984). The sequence of bedded cherts which succeed the Visean carbonate succession at Red Wharf Bay on Anglesey (Fig. 8.2, Col. 1) may also represent this formation (Greenly 1919).

The succeeding Bowland Shale Formation is mudstone dominated with common marine fauna (marine bands), but also includes thin sandstone and limestone beds and rare thin coal seams and associated seatearth palaeosols. The formation reflects deposition across a range of settings from deep off-shore basinal environments to prodelta and periodically emergent interdistributary bay environments (Davies *et al*. 2004). Many of the key Namurian marine band faunas are recognised in the succession, especially in the Abbey Mills/Holywell area of the north of the Flint Coalfield (Fig. 8.2, Col. 6) (Ramsbottom 1974; Davies *et al*. 2004). The *Cravenoceras malhamense* ($E_{1c}1$) Marine Band [+11] occurs within the basal part of the formation in the Abbey Mills boreholes [SJ 194 775] (Ramsbottom 1974). Major flooding events are associated with the *Eumorphoceras ferrimontanum* ($E_{2a}2$) [+12], *Cravenoceratoides nititoides* ($E_{2b}3$) [+13], *Bilinguites gracilis* ($R_{2a}1$) [+14], *B. superbilinguis* ($R_{2c}1$) [+15], *Cancelloceras cancellatum* ($G_{1a}1$) [+16], and *C. cumbriense* ($G_{1b}1$) [+17] marine bands, with the latter two marine bands also found at the base and top of the formation, respectively [+2 & +3], near Wrexham in the north Denbigh Coalfield (Fig. 8.2, Col. 8) (Ramsbottom *et al.* 1978; Davies *et al*. 2004).

The Bowland Shale Formation of the Clwyd and Prestatyn areas (Fig. 8.2, Cols. 5 & 6) pass laterally southward into the Millstone Grit Group. In North Wales, this group comprises two distinct units, the quartzose sandstones of the Cefn-y-fedw Sandstone Formation and quartz-feldspathic sandstones of the Gwespyr Sandstone Member (Rossendale Formation). The Cefn-y-fedw Sandstone Formation records the northward progradation of fluvio-deltaic facies deposited along the northern margin of the Wales-Brabant High. South of the Bala Fault, the

Cefn-y-fedw Sandstone Formation occurs as a single, thick sandstone succession (Fig. 8.2, Col. 8 & 9) and conformably overlies the Visean Minera Formation. Immediately to the north of the fault, where the formation is thickest, it occurs as three separate sandstone intervals, interbedded with the Bowland Shale Formation (Fig. 8.2, Col. 6). Passing northwards the formation locally rests disconformably upon the Cefn Mawr Limestone Formation and interleaves with and onlaps the Pentre Chert Formation. Dating of the formation is based on faunas within the interleaving Bowland Shale succession (Davies *et al*. 2004). The lower sandstone is largely Pendleian, the middle sandstone mainly of Chokierian and Alportian age and the upper sandstone ranges from early Kinderscoutian to late Marsdenian in age (Fig. 8.2, Col. 6).

The quartz-feldspathic sandstone of the Gwespyr Sandstone Member, local representative of the Rossendale Formation of the Pennine area (Waters *et al*. 2009), are present in north-east Wales. In the Flint and Denbigh coalfields (Fig. 8.2, Cols. 6-8) the base of the member is diachronous and interleaves with the underlying formations. In the Flint Coalfield (Fig. 8.2, Col. 6) the lower levels of the Gwespyr Sandstone Member overlie the basal Yeadonian *Cancelloceras cancellatum* ($G_{1a}1$) Marine Band [+16], but succeeds the younger *C. cumbriense* ($G_{1b}1$) Marine Band further south in this coalfield [+17]and the Denbigh Coalfield (Fig. 8.2, Col. 8 [+3]).

Westphalian

The Pennine Coal Measures Group, containing fluvio-lacustrine (Coal Measures) facies, was deposited on the southwest margin of the broad Pennine Basin. Though subsequent tectonism has isolated the group into small coalfields (e.g. Flint and Denbigh coalfields) at outcrop (Fig. 8.1), an extensive subcrop exists beneath the Permo-Triassic of the Cheshire Basin and Welsh Borderlands (Ramsbottom *et al.* 1978). An isolated outlier occurs beneath Malltraeth Marsh on Anglesey (Fig. 8.2, Col. 1). The group has been divided regionally into three formations: Pennine Lower, Middle and Upper Coal Measures, as defined by Stubblefield & Trotter (1957), although the last is absent in North Wales.

The Pennine Coal Measures Group comprises cyclothems of alternating sandstone, siltstone and grey mudstone, with frequent coal seams, ironstone nodules or beds and seatearth (palaeosol) horizons. The base of the group is taken as the base of the Subcrenatum Marine Band, identified in sections and boreholes between the Point of Ayr and Flint, as well as in the River Dee, south-west of Wrexham (Fig. 8.2, Col. 8 [+4]; Fig. 8.3). Further to the east in the Milton Green Borehole [SJ 4374 5692], south of Chester, the Namurian/Wesphalian boundary was located immediately above the Aqueduct Coal (Earp & Taylor 1986). However, across much of the Flint Coalfield (Fig. 8.2, Col. 6) the upper parts of the Gwespyr Sandstone Member (see above) interleaves with mudstones containing the basal Westphalian Subcrenatum [+18] and Listeri marine bands and here the base of the group is taken at the base of the overlying, coal-bearing sequence (see Stubblefield & Trotter 1957; Davies *et al*. 2004). On Anglesey (Fig. 8.2, Col. 1; Fig. 8.3) a succession of sandstones probably equates with the Gwespyr Sandstone Member (see above), with what is interpreted as the Listeri Marine Band occurring in the middle of the succession (Fig. 8.3; Calver & Smith 1974), suggesting that most, if not all, of the member is Langsettian in age. The overlying Coal Measures facies is limited to the Pennine Lower Coal Measures Formation with non-marine bivalves of the Communis Chronozone [~1] found at the top (Greenly 1919; Calver & Smith 1974). Regionally, the base of the Pennine Middle Coal Measures Formation is taken at the base of the Vanderbeckei Marine Band, or, where this is absent or not recorded, at the top of the underlying Red Coal (Fig. 8.3).

Many of the marine horizons present in Lancashire (see Chapter 11) in the Pennine Lower Coal Measures are absent in North Wales, reflecting its marginal position (Ramsbottom *et al.* 1978). In addition to the Subcrenatum and Vanderbeckei marine bands, the Listeri, Maltby, Clown, Haughton, Aegiranum [+5] and Edmondia marine bands have been located principally in collieries in the Denbigh Coalfield (Fig. 8.2, Col. 8) and at Point of Ayr, but many appear to absent from the much of the Flint Coalfield (Fig. 8.3; Calver & Smith 1974). Faunas indicative of the Communis, Modiolaris and Lower Similis-Pulchra non-marine bivalve chronozones are also reported (Calver & Smith 1974; Davies *et al.* 2004). The Cambriense Marine Band fauna is not recorded in North Wales and, contrary to Ramsbottom *et al*. (1978), the Pennine Upper Coal Measures Formation is now thought not to be present (Davies *et al.* 2004).

The Pennine Coal Measures Group is generally overlain conformably by the predominantly red-bed strata Warwickshire Group (Powell *et al.* 2000). The group, c. 1400 m thick, includes the red-bed Etruria and Salop formations separated by the relatively coal-poor, grey Halesowen Formation. The Warwickshire Group succession in North Wales is only fully represented to the east of the Denbigh Coalfield (Fig. 8.2, Col. 8). Warwickshire Group strata, tentatively assigned to the Halesowen and Salop formations (Davies *et al*. 2004) are present in the Vale of Clwyd (Fig. 8.2, Col. 5) resting unconformably on the Visean Clwyd Limestone Group, as locally do red-beds present on Anglesey (Fig. 8.2, Col.1) and the Menai Straits. This reflects a period of intra-Westphalian uplift and erosion affecting areas to the west of the two main coalfields in North Wales and which may equate with development of the pre-Halesowen unconformity of the English Midlands (see Chapter 9).

The Etruria Formation comprises predominantly variegated, though commonly red–purple, mudstone with thin *Spirorbis* limestone beds in the upper part (Calver & Smith 1974). Subordinate, lenticular sandstones and conglomerates commonly consist mostly of volcanic and lithic clasts derived from erosion of the Wales-Brabant High. Thin coal seams are locally present. The formation was deposited within a well drained alluvial floodplain. The formation is entirely of Bolsovian age in the Denbigh Coalfield (Fig. 8.2, Cols. 7 & 8), but the onset of red-bed conditions was earlier (late Duckmantian) in the Flint Coalfield (Fig. 8.2, Col. 6), where it includes the former 'Buckley Fireclay'. Non-marine bivalve faunas of the *Anthraconauta phillipsii* Zone (late Bolsovian) have been recorded from the formation in both the Denbigh [~6] and Flint [~19] coalfields (Calver & Smith 1974).

The Halesowen Formation comprises grey-green, micaceous sandstone and grey-green, locally red and purple, mudstone. Also present are thin coals, beds of *Spirorbis* limestone, local intraformational conglomerate, and calcrete (Calver & Smith 1974). The sandstones are lithic arenites similar to the Pennant Sandstone Formation of south of the Wales-Brabant High (see Chapters 5 & 6) and indicative of a distant southerly source. The formation shows transitions from fluvial to floodplain deposition in association with relatively high water-tables. The formation has yielded miospores (Smith & Butterworth 1967; Butterworth & Smith 1976), plant micro- and macrofossils (Cleal 1984), and ostracods and non-marine bivalve faunas of the *Anthraconauta tenuis* Zone (Calver & Smith 1974) that indicate an early Asturian age (Fig. 8.2, Col. 8 [^~7]). A fauna including *Anomalonema reumauxi* from the St. Asaph Borehole [SJ 0366 7312] in the Vale of Clwyd, suggest a level near the Bolsovian – Asturian boundary (Calver & Smith 1974; Fig. 8.2, Col. 5 [~2]).

The Salop Formation comprises red and red-brown interbedded mudstone and sandstone, with beds of pebbly sandstone and conglomerate. Thin *Spirorbis* limestone beds, calcrete and sparse, thin coals are present in the lower part. The sandstones are mostly sublitharenite and

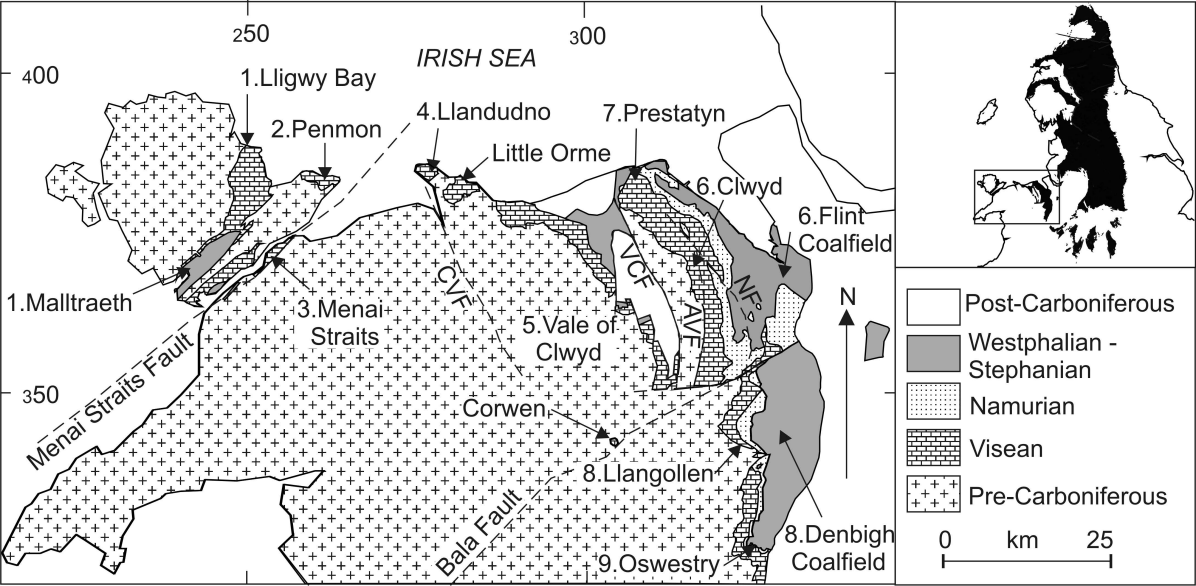
conglomerate clasts include Carboniferous Limestone and chert sourced by erosion of the Wales-Brabant High. The succession on Anglesey and along the Menai Straits (Fig. 8.2, Cols 1 & 3) includes basal breccias and conglomerates also with Visean chert clasts, but coals are also reported to be present in the overlying finer-grained facies (Ramsay 1881; Greenly 1919, 1938) suggesting an equivalence of some beds to the Halesowen Formation. The Salop Formation represents a return to well drained, proximal to distal alluvial-plain settings with localised shallow lake formation within semi-arid conditions. The formation is undated palaeontologically in North Wales, but is generally assumed to range from late Asturian to Stephanian or even Early Permian (Powell *et al.* 2000). The unconformable nature of the Anglesey and Menai Straits red-bed succession suggests this too is likely to be Asturian or younger in age.

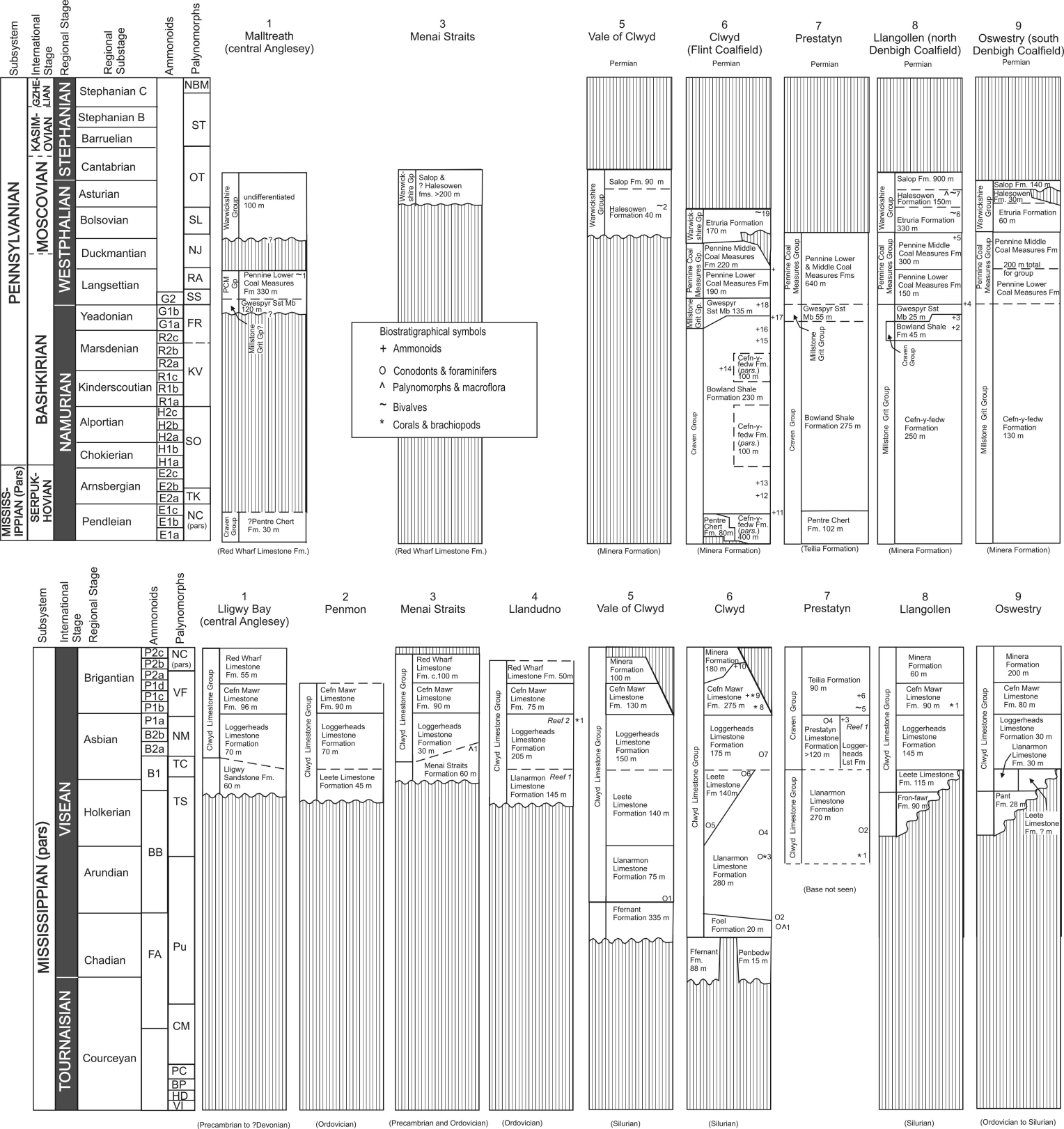
The unpublished recovery of the miospores *Dictyotrilites bireticulatus*, *Endosporites globiformis* and rare *Crassispora kosankei* from a low level within the Gloddaeth Purple Sandstone near Llandudno (D. G. Willmore *pers. com.* 1988, reported in Waters *et al*. 2009) suggests a late Langsettian to early Duckmantian age for a unit which has previously been viewed as either Mississippian (Warren *et al*. 1984) or Triassic (Williams & Eaton 1993). However, the unconformable nature of this unit (it rests on Asbian limestone), as well as its purple colour, suggest that the flora may be reworked within strata equivalent to the Salop Formation.

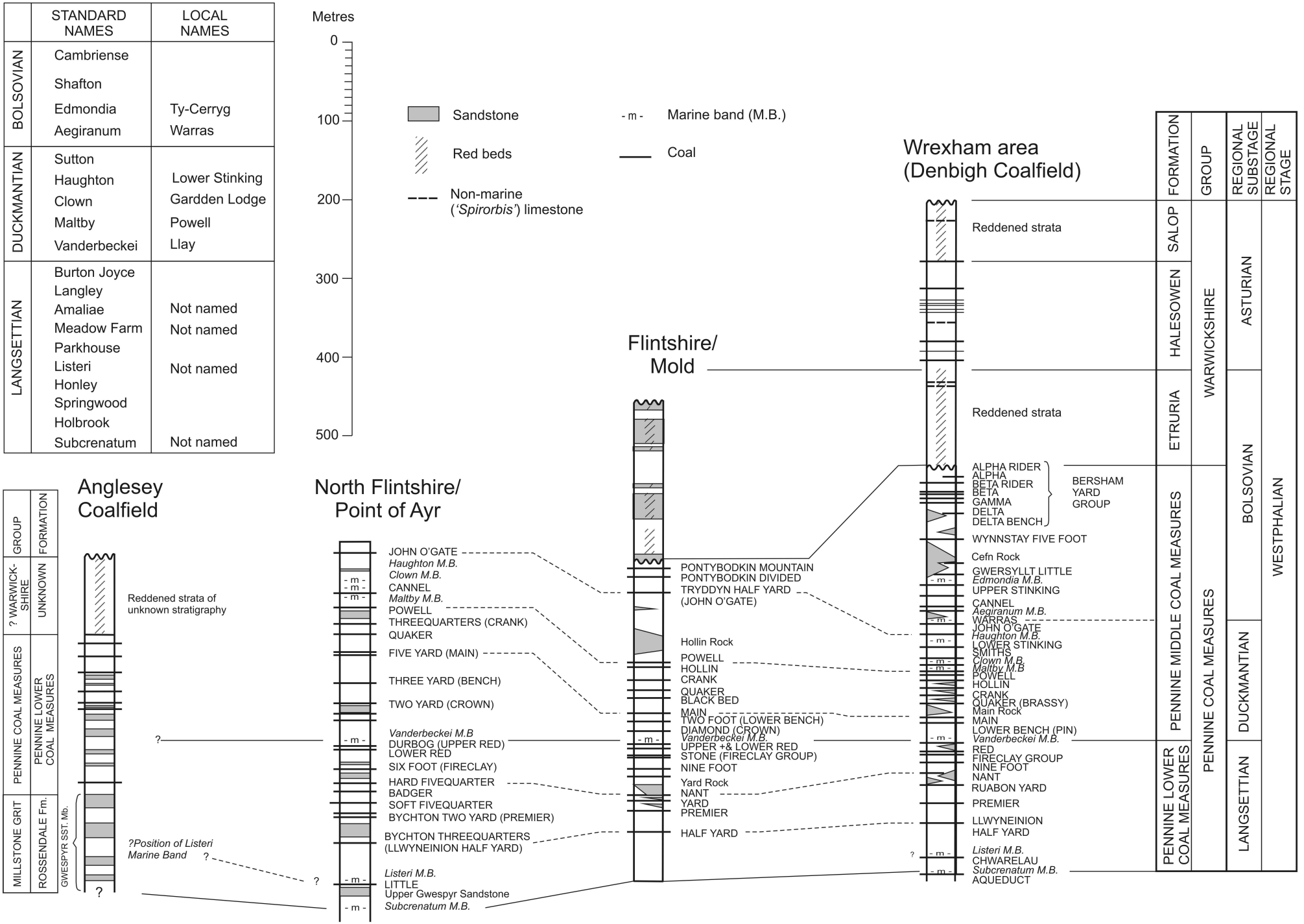
Fig. 8.1. Geological map showing the distribution of Carboniferous strata of North Wales, adapted from IGS (1979). AVF- Alyn Valley Fault; CVF- Conway Valley Fault; NF- Nercwys–Nant-Figillt Fault; VCF- Vale of Clwyd Fault.

Fig. 8.2. Correlation of Carboniferous successions in North Wales. The nomenclature is that of Waters *et al*. (2007; 2009), with details from the following publications: Col. 1 from BGS (1989), Walkden & Davies (1983), Davies (1991) and Calver & Smith (1974); Col. 2 from BGS (1989) and Davies (1991); Col. 3 from Greenly (1928) and Howells *et al*. (1991); Col. 4 from Warren *et al.* (1984), Bancroft *et al*. (1988) and BGS (1989); Col. 5 from Warren *et al.* (1984) and Davies *et al.* (2004); Col. 6 from Somerville (1979c) and Davies *et al.* (2004); Col. 7 from Warren *et al.* (1984) and Somerville *et al*. (1986); Col. 8 from Somerville (1979a, b) and Davies *et al.* (2004); Col. 9 from BGS (2000).

Fig. 8.3. Correlation of Westphalian successions in North Wales. The nomenclature is that of Waters *et al*. (2007; 2009), with details modified from the following publications: Anglesey Coalfield (Calver & Smith 1974); North Flintshire/Point of Ayr (Calver & Smith 1974); Flintshire/Mold (Calver & Smith 1974; Davies *et al.* 2004); Wrexham area (Calver & Smith 1974; Davies *et al.* 2004).


250
300
400
350
IRISH SEA
1.Lligwy Bay
2.Penmon
4.Llandudno
7.Prestatyn
Little Orme
6.Clwyd
6.Flint Coalfield
1.Malltraeth
3.Menai Straits
5.Vale of Clwyd
CVF
VCF
AVF
NF
Menai Straits Fault
Corwen
8.Llangollen
Bala Fault
9.Oswestry
8.Denbigh Coalfield
N
Post-Carboniferous
Westphalian - Stephanian
Namurian
Visean
Pre-Carboniferous
0
km
25


Subsystem
International Stage
Regional Stage
Regional Substage
Ammonoids
Palynomorphs
PENNSYLVANIAN
MISSISS-IPPIAN (Pars)
GZHE-LIAN
KASIM-OVIAN
MOSCOVIAN
BASHKIRIAN
SERPUK-HOVIAN
STEPHANIAN
WESTPHALIAN
NAMURIAN
Stephanian C
Stephanian B
Barruelian
Cantabrian
Asturian
Bolsovian
Duckmantian
Langsettian
Yeadonian
Marsdenian
Kinderscoutian
Alportian
Chokierian
Arnsbergian
Pendleian
G2
G1b
G1a
R2c
R2b
R2a
R1c
R1b
R1a
H2c
H2b
H2a
H1b
H1a
E2c
E2b
E2a
E1c
E1b
E1a
NBM
ST
OT
SL
NJ
RA
SS
FR
KV
SO
TK
NC (pars)
1
Malltreath (central Anglesey)
Warwickshire Group
undifferentiated 100 m
PCM Gp
Pennine Lower Coal Measures Fm 330 m
Gwespyr Sst Mb 120 m
Millstone Grit Gp?
Craven Group
?Pentre Chert Fm. 30 m
(Red Wharf Limestone Fm.)
3
Menai Straits
Warwick-shire Gp
Salop & ? Halesowen fms. >200 m
Biostratigraphical symbols
+ Ammonoids
O Conodonts & foraminifers
^ Palynomorphs & macroflora
~ Bivalves
* Corals & brachiopods
(Red Wharf Limestone Fm.)
5
Vale of Clwyd
Permian
Warwickshire Group
Salop Fm. 90 m
Halesowen Formation 40 m
~2
(Minera Formation)
6
Clwyd (Flint Coalfield)
Permian
Warwick-shire Gp
~19
Etruria Formation 170 m
Pennine Coal Measures Gp.
Pennine Middle Coal Measures Fm 220 m
Pennine Lower Coal Measures Fm 190 m
Millstone Grit Gp.
Gwespyr Sst Mb 135 m
+18
+17
+16
+15
+14
Cefn-y-fedw Fm. (pars.) 100 m
Bowland Shale Formation 230 m
Cefn-y-fedw Fm. (pars.) 100 m
+13
+12
+11
Craven Group
Pentre Chert Fm. 80m
Cefn-y-fedw Fm. (pars.) 400 m
(Minera Formation)
7
Prestatyn
Permian
Pennine Coal Measures Group
Pennine Lower & Middle Coal Measures Fms 640 m
Gwespyr Sst Mb 55 m
Millstone Grit Group
Craven Group
Bowland Shale Formation 275 m
Pentre Chert Fm. 102 m
(Teilia Formation)
8
Llangollen (north Denbigh Coalfield)
Permian
Warwickshire Group
Salop Fm. 900 m
Halesowen Formation 150m
~7
~6
Etruria Formation 330 m
+5
Pennine Coal Measures Group
Pennine Middle Coal Measures Fm 300 m
Pennine Lower Coal Measures Fm 150 m
+4
Gwespyr Sst Mb 25 m
+3
Bowland Shale Fm 45 m
+2
Craven Group
Millstone Grit Group
Cefn-y-fedw Formation 250 m
(Minera Formation)
9
Oswestry (south Denbigh Coalfield)
Permian
Warwickshire Group
Salop Fm. 140 m
Halesowen Fm. 30m
Etruria Formation 60 m
Pennine Coal Measures Group
Pennine Middle Coal Measures Fm
200 m total for group
Pennine Lower Coal Measures Fm
Millstone Grit Group
Cefn-y-fedw Formation 130 m
(Minera Formation)
Subsystem
International Stage
Regional Stage
Ammonoids
Palynomorphs
MISSISSIPPIAN (pars)
VISEAN
TOURNAISIAN
Brigantian
Asbian
Holkerian
Arundian
Chadian
Courceyan
P2c
P2b
P2a
P1d
P1c
P1b
P1a
B2b
B2a
B1
BB
FA
NC (pars)
VF
NM
TC
TS
Pu
CM
PC
BP
HD
VI
1
Lligwy Bay (central Anglesey)
Clwyd Limestone Group
Red Wharf Limestone Fm. 55 m
Cefn Mawr Limestone Fm. 96 m
Loggerheads Limestone Formation 70 m
Lligwy Sandstone Fm. 60 m
(Precambrian to ?Devonian)
2
Penmon
Clwyd Limestone Group
Cefn Mawr Limestone Fm. 90 m
Loggerheads Limestone Formation 70 m
Leete Limestone Formation 45 m
(Ordovician)
3
Menai Straits
Clwyd Limestone Group
Red Wharf Limestone Fm. c.100 m
Cefn Mawr Limestone Fm. 90 m
Loggerheads Limestone Formation 30 m
A1
Menai Straits Formation 60 m
(Precambrian and Ordovician)
4
Llandudno
Clwyd Limestone Group
Red Wharf Limestone Fm. 50m
Cefn Mawr Limestone Fm. 75 m
Reef 2
*1
Loggerheads Limestone Formation 205 m
Llanarmon Limestone Formation 145 m
Reef 1
(Ordovician)
5
Vale of Clwyd
Clwyd Limestone Group
Minera Formation 100 m
Cefn Mawr Limestone Fm. 130 m
Loggerheads Limestone Formation 150 m
Leete Limestone Formation 140 m
Llanarmon Limestone Formation 75 m
O1
Ffernant Formation 335 m
(Silurian)
6
Clwyd
Clwyd Limestone Group
Minera Formation 180 m
+10
Cefn Mawr Limestone Fm. 275 m
+*9
*8
Loggerheads Limestone Formation 175 m
O7
Leete Limestone Fm 140m
O6
O5
O4
Llanarmon Limestone Formation 280 m
O*3
O2
OA1
Foel Formation 20 m
Ffernant Fm. 88 m
Penbedw Fm 15 m
(Silurian)
7
Prestatyn
Craven Group
Teilia Formation 90 m
+6
~5
O4
+3
Reef 1
Prestatyn Limestone Formation >120 m
Logger-heads Lst Fm
Clwyd Limestone Group
Llanarmon Limestone Formation 270 m
O2
*1
(Base not seen)
8
Llangollen
Clwyd Limestone Group
Minera Formation 60 m
Cefn Mawr Limestone Fm. 90 m
*1
Loggerheads Limestone Formation 145 m
Leete Limestone Fm. 115 m
Fron-fawr Fm. 90 m
(Silurian)
9
Oswestry
Clwyd Limestone Group
Minera Formation 200 m
Cefn Mawr Limestone Fm. 80 m
Loggerheads Limestone Formation 30 m
Llanarmon Limestone Fm. 30 m
Pant Fm. 28 m
Leete Limestone Fm. ? m
(Ordovician to Silurian)


STANDARD NAMES
LOCAL NAMES
BOLSOVIAN
Cambriense
Shafton
Edmondia
Ty-Cerryg
Aegiranum
Warras
DUCKMANTIAN
Sutton
Haughton
Lower Stinking
Clown
Gardden Lodge
Maltby
Powell
Vanderbeckei
Llay
LANGSETTIAN
Burton Joyce
Langley
Amaliae
Not named
Meadow Farm
Not named
Parkhouse
Listeri
Not named
Honley
Springwood
Holbrook
Subcrenatum
Not named
Metres
0
100
200
300
400
500
Sandstone
Red beds
Non-marine ('Spirorbis') limestone
- m - Marine band (M.B.)
Coal
Anglesey Coalfield
GROUP
FORMATION
? WARWICK-SHIRE
UNKNOWN
PENNINE COAL MEASURES
PENNINE LOWER COAL MEASURES
MILLSTONE GRIT
ROSSENDALE Fm.
GWESPYR SST. Mb.
Reddened strata of unknown stratigraphy
?Position of Listeri Marine Band
North Flintshire/ Point of Ayr
JOHN O'GATE
Haughton M.B.
Clown M.B.
CANNEL
Maltby M.B.
POWELL
THREEQUARTERS (CRANK)
QUAKER
FIVE YARD (MAIN)
THREE YARD (BENCH)
TWO YARD (CROWN)
Vanderbeckei M.B
DURBOG (UPPER RED)
LOWER RED
SIX FOOT (FIRECLAY)
HARD FIVEQUARTER
BADGER
SOFT FIVEQUARTER
BYCHTON TWO YARD (PREMIER)
BYCHTON THREEQUARTERS (LLWYNEINION HALF YARD)
Listeri M.B.
LITTLE
Upper Gwespyr Sandstone
Subcrenatum M.B.
Flintshire/ Mold
PONTYBODKIN MOUNTAIN
PONTYBODKIN DIVIDED
TRYDDYN HALF YARD (JOHN O'GATE)
Hollin Rock
POWELL
HOLLIN
CRANK
QUAKER
BLACK BED
MAIN
TWO FOOT (LOWER BENCH)
DIAMOND (CROWN)
Vanderbeckei M.B.
UPPER +& LOWER RED
STONE (FIRECLAY GROUP)
NINE FOOT
Yard Rock
NANT
YARD
PREMIER
HALF YARD
Wrexham area (Denbigh Coalfield)
Reddened strata
Reddened strata
ALPHA RIDER
ALPHA
BETA RIDER
BETA
GAMMA
DELTA
DELTA BENCH
BERSHAM YARD GROUP
WYNNSTAY FIVE FOOT
Cefn Rock
GWERSYLLT LITTLE
Edmondia M.B.
UPPER STINKING
CANNEL
Aegiranum M.B.
WARRAS
JOHN O'GATE
Haughton M.B.
LOWER STINKING
SMITHS
Clown M.B.
Maltby M.B.
POWELL
HOLLIN
CRANK
QUAKER (BRASSY)
Main Rock
MAIN
LOWER BENCH (PIN)
Vanderbeckei M.B.
RED
FIRECLAY GROUP
NINE FOOT
NANT
RUABON YARD
PREMIER
LLWYNEINION
HALF YARD
Listeri M.B.
CHWARELAU
Subcrenatum M.B.
AQUEDUCT
FORMATION
SALOP
HALESOWEN
ETRURIA
PENNINE MIDDLE COAL MEASURES
PENNINE LOWER COAL MEASURES
GROUP
WARWICKSHIRE
PENNINE COAL MEASURES
REGIONAL SUBSTAGE
ASTURIAN
BOLSOVIAN
DUCKMANTIAN
LANGSETTIAN
REGIONAL STAGE
WESTPHALIAN