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Geology of the Dinantian Outlier near Corwen, North Wales

A report for the Countryside Council for Wales
assessing the case for inclusion of Hafod-y-calch quarry
in the Geological Conservation Review

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Executive summary

- Exposures in the Hafod-y-calch quarry, sited within the isolated outlier of Dinantian rocks near Corwen, provide a critical constraint on Dinantian tectonic and palaeogeographical understanding.

- The presence of two of the main marker beds within the Dinantian succession in North Wales – the Main Shale and Coral Bed – permits precise correlation with sequences in Flintshire and at Llangollen, and allows lateral thickness and facies variations to be quantified.

- The boundaries of cyclic sequences exposed in the quarry are marked by features that testify to synsedimentary emergence, karstic dissolution and soil forming processes, and can be correlated with comparable levels in outcrops further east.

- The section demonstrates the early onset of Minera Formation facies deposition within a region of enhanced subsidence to the north of the Bala lineament.

- Within the context of the outlier, the section provides evidence to show that late Dinantian (Brigantian) carbonate platform facies were deposited in narrow gulfs located along the major tectonic lineaments of North Wales, and which extended far into the contemporary hinterland of older rocks.

- The section provides critical evidence to show that Dinantian rocks were deposited across a much wider area of North Wales than hitherto suggested.

- It is recommended that the northern Hafod-y-calch quarry site is included within the GCR site and that remedial work is undertaken to re-expose and improve access to critical parts of the section.

- The southern Hafod-y-calch quarry is very overgrown and further work is required to clear and re-expose the rock section present. However, the southern quarry has significant potential to provide lithological and stratigraphical information to underpin further the palaeogeographical importance of the outlier sequence; accordingly it is recommended that it too should be included within the GCR site.

- Urgent consideration should also be given to the conservation of the only exposures in the lower part of the outlier sequence, at both Plas-isaf and Plas-uchaf. It is recommended that these exposures should also be included within the GCR site.

CONTENTS

1. Background

The tiny Dinantian outlier near Corwen, sited some 10 km to the southwest of the nearest main outcrops of Dinantian rocks in North Wales provides a critical and unique constraint on Dinantian palaeogeographical reconstructions for the region. When compared with more easterly outcrops, the outlier should provide an insight into the changes in limestone facies and biota, which occurred as the contemporary Dinantian coastline was approached. However, with the exception of a nineteenth century paper by Morton, the rocks of the outlier have not been examined in detail. In the absence of more recent work, the scientific importance of the principal quarry section in the outlier, at Hafod-y-calch, and its need to be included in the Geological Conservation Review (GCR) process has been questioned.

In discussions with CCW staff, BGS sought to highlight the national scientific importance of the Hafod-y-calch site. The position of the outlier sequence within modern chrono- and biostratigraphical schemes for the Dinantian has not been rigorously tested. However, it was argued that this did not reduce its importance, but in fact underlined the need for the site to be conserved so that such investigations could take place, and its critical palaeogeographical significance fully appreciated.

Subsequently Dr Raymond Roberts of CCW asked for an indication of BGS charges to undertake a site visit and to provide a robust report assessing the case for inclusion of the Hafod-y-calch section in the GCR process. Recognising that such a visit would provide an opportunity for BGS to survey the outlier in detail for the first time, and to examine its main sections and obtain important stratigraphical information, BGS offered to jointly fund a more thorough investigation of the outlier including a detailed biostratigraphical and petrological analysis of the sequence.

2. Notes

In the following account of the outlier sequence, the limestones are classified according to the textural scheme of Dunham (1962). The whole of the study area lies within 100km square SJ and the letter prefixes for grid references are omitted.

3. Introduction

The outlier of Dinantian (Lower Carboniferous) limestones at Hafod-y-calch is situated 2km WSW of Corwen, immediately to the west of the confluence of the Afon Alwen and River Dee (Figure 1). At its highest point [0535 4266], south of Plas-uchaf, the outlier attains an elevation of 180m AOD. The Dinantian rocks rest unconformably on deformed Lower Palaeozoic rocks depicted on the published BGS 1:50 000 scale Sheet 120 (Corwen) as Nantglyn Flags Formation, of mid Silurian age. The outlier is bounded to the south-east by the Bryn Eglwys Fault, one of series of linked fractures which make up the long-lived and influential Bala Lineament (Fitches and Campbell, 1987). It is situated 10km to the southeast of the next nearest Dinantian outcrop in the southern Vale of Clwyd (Figure 1).

The sequence at Corwen, in common with Dinantian successions throughout North Wales, records the pulsed transgression of the northern flank of the Wales-Brabant Massif (St. Georges Land). In detail, pre-existing, basement fracture belts exercised a major influence on the development, distribution and thickness of Dinantian facies. The Bala, Menai Straits and Welsh Borderland lineaments, together with their linking fractures created a rifted topography of down-faulted embayments separated by up-faulted ridges across which the Dinantian transgression progressed (Davies et al., in press). The embayments were sites of the thickest Dinantian deposition, with thickness and facies patterns testifying to discrete intervals of renewed rifting and rapid subsidence in step with Dinantian successions elsewhere in the UK (Frazer and Gawthorpe, 1990).

Situated adjacent to the Bala Lineament and separated by many kilometres from the next nearest outcrop of Dinantian rocks, the Corwen sequence provides a critical restraint on Lower Carboniferous facies and palaeogeographical reconstructions for North Wales.

4. Previous research

The most recent detailed account of the Corwen sequence, by Morton (1878), provides a comprehensive summary of earlier studies most notably those by Sharpe (1846), Jukes (1865a,b), Davies (1865) and Ricketts (1866). Morton's examination formed part of a broader study of the Carboniferous Limestone Series in the Llangollen region, and in the key exposures in the outlier he recognised elements of his Llangollen succession. He assigned the beds exposed in quarries at Plas-uchaf and Plas-isaf to his 'Lower White Limestone', a division which he subsequently subsumed within his regional 'Middle White Limestone' (e.g. Morton, 1886; 1897). Morton included the higher strata worked in the extensive quarry complex at Hafod y Calch in his 'Upper Grey Limestone', but stated that the presence of strata equivalent to the 'Sandy Limestone' of Llangollen was unlikely. In the Llangollen area, all these subdivisions were subsequently shown to lie within the *Dibunophyllum* Biozone of the Vaughanian scheme (Hind and Stobbs, 1906; Wedd et al., 1927). Morton estimated the thickness of the Corwen sequence to be about 750ft (c. 230m).

Following the published debate between Jukes (1865a,b) and Davies (1865), Morton (1878) was alert to the palaeogeographical significance of the Corwen outlier commenting that 'there can be little doubt that the limestone of Hafod was deposited on the same open Carboniferous sea as that at Llangollen'. He also observed that the basal division of his Llangollen sequence, the 'Lower Grey and Brown Limestone', appeared to be absent at Corwen. The inference, that this reflected a westwards onlap between Llangollen and Corwen, against a sloping floor of pre-Carboniferous rocks, was elucidated by George (1958) who concluded that the Corwen outlier lay 'high in the *Dibunophyllum* Zone' close to the 'ultimate Viséan shoreline'. Curiously, he stated subsequently (George, 1974) that the Corwen outlier 'appears to carry a full formational sequence, the Lower Brown Limestone not being overlapped despite its location far into the massif'. Yet in erecting and defining chronostratigraphical stages for the Dinantian of the UK, George et al. (1976) show the outlier sequence as including strata of both the Brigantian and preceding Asbian stages, but with the Lower Brown Limestone absent.

5. Results of the BGS survey

The new BGS geological map of the Hafod-y-calch outlier is shown in Figure 1. Much of the outlier is concealed beneath glacial drift deposits which have been omitted from the figure. The principal exposures remain those cited by Morton including quarries and adjacent crags at Plas-isaf [0517 4297] and Plas-uchaf [0530 4272], as well as the extensive complex of quarries at Hafod-y-calch. The latter comprises a large southern quarry [0547 4283 to 0565 4255], over 350m in length, sited immediately to the west of Hafod-y-calch farmhouse; and a 200m-long northern quarry [0537 4300 to 0546 4285] sited some 400m to the north-east of the farm (Figure 1). The southern Hafod-y-calch quarry has been long abandoned and is largely overgrown, but the northern quarry has been worked and enlarged more recently and provides the most extensive section in the outlier sequence. The various quarries were worked for building stone and lime.

The limestone sequence dips steeply to the north-east by up to 51°. The exposures at Plas-isaf and Plas-uchaf are thought to lie at or close to the base of the outlier sequence. Morton reported that excavations during the construction of Plas-isaf farmhouse failed to encounter limestone suggesting that the western boundary of the outlier lies between the house and the quarry. The contact with underlying Lower Palaeozoic rocks is nowhere exposed, but the presence of dolomitised limestones with quartz sand grains and pebbles, at the base of the Plas-isaf quarry section, is consistent with a position closely overlying a basal unconformity. Abrupt terminations in the limestone features suggest that splays of the Bryn Eglwys Fault limit the outlier on both its northern and southern sides and there is little doubt that the Bryn Eglwys Fault itself defines the outlier's south-eastern boundary (Figure 1).

The BGS survey of the outlier sequence has demonstrated the presence of three Dinantian formations that can be matched with divisions recognised in the main Dinantian outcrops of Flintshire and Llangollen (BGS, 1994 and 1997). These comprise, in ascending order, the Loggerheads Limestone, Cefn Mawr Limestone and Minera Formation. The pale massive limestones exposed at Plas-isaf and Plas-uchaf are typical of the Loggerheads Limestone. The contact between the Cefn Mawr Limestone and the basal sandstone of the Minera Formation is exposed in the northern Hafod-y-calch quarry and the north-eastern most exposures in the outlier are in this latter division. Between the base of the outlier succession, on the west, and the limits of exposure to the east, an estimated 210m of strata are traversed much of it concealed beneath gravely glacial drift deposits. How far the outlier extends north-eastwards, beneath the alluvium of the River Dee, can only be speculated up on. However, if no fault or folding intervenes, it is possible that a considerable thickness of younger Carboniferous strata is preserved between the Bryn Eglwys and Plas-isaf faults. Comparisons with the Flintshire and Llangollen outcrops suggest that, if present, such strata are likely to include upper levels of the Minera Formation and a considerable thickness of the overlying Cefn y fedw Sandstone of Namurian age (Figure 1). Alternatively, Upper Carboniferous (Silesian) strata may rest with marked disconformity on the Dinantian sequence as in the Vale of Clwyd (BGS, 1997).

As part of the BGS study, the Dinantian sequence has been dated using foraminifera and calcareous algae. A total of 49 samples were collected and sectioned, and details of the microfossil assemblages present in each sample are given in Appendix 1. The biostratigraphical scheme used is the Belgian one developed by Conil et al. (1980) and refined by Paprothe et al (1983), based on the type Dinantian (Lower Carboniferous) for western Europe. The scheme was adapted for the UK by Riley (1993) and was first rigorously applied in North Wales by Davies et al., (1989 and in press).

6. Description of the Dinantian sequence

6.1 Loggerheads Limestone Formation

The lower 55m of the outlier sequence are assigned to the Loggerheads Limestone. The type section for the formation is in the Leete Country Park, west of Mold (Somerville, 1979; Davies et al., in press) in which area it is broadly equivalent to the Middle White Limestone of Morton (1886). The formation comprises pale grey or white, massive and pseudobrecciated packstones and grainstones. The limestones are arranged in upward shoaling cycles the tops of which are commonly defined by palaeokarstic features and calcrete textures providing clear evidence of subaerial exposure (Davies, 1991).

Evidence for an unconformable base to the formation at Plas-isaf has been alluded to above. Purple sandy packstone/grainstones (Plate 1) at the base of 6.5m-thick sequence, are overlain by mottled red and grey clay and beds of dolomitised limestone with scattered quartz pebbles. Upper parts of the section comprise massive white and pink-stained skeletal and pelloidal packstones and grainstones locally rich in the dasycladacean alga *Koninkopora inflata* and *K. minuta* (Plates 2 and 3). The cyclic nature of the formation is well seen in the section at Plas-uchaf where up to five cycles are present in a 23m-thick sequence (Figure 2). The lower parts of the cycles typically comprise poorly sorted skeletal packstones composed of micritised tests of foraminifera, and plates and fragments of echinoderm, brachiopod and calcareous algae (Plate 4). Anastomising stylolites with associated mudstone films commonly give rise to a distinctive pseudobrecciated appearance. Upper parts of the cycles comprise well-sorted grainstones composed of rounded micritic pelloids and skeletal grains including abundant abraded plates of dasycladacean algae.

Brown, ramifying tubular structures, 1-3mm in diameter, present at the top of at least two of the cycles exposed at Plas-uchaf, are interpreted as calcified fossil rootlets known as rhizoliths. One of these rhizolith-bearing levels underlies a discontinuous veneer of dark brown and black laminated micrite identical to modern laminar calcrete crusts (Plate 5).

Intact macrofossils noted in the Loggerheads Limestone during the BGS survey comprised productid brachiopods and a single colony of the tabulate coral *Syringopora* observed in the basal bed at Plas-isaf. Diverse assemblages of foraminifera and calcareous algae recorded at both Plas-isaf and Plas-uchaf confirm an Asbian age for these strata (Appendix 1). However, they include samples with abundant *Pojarkovella nibelis*, a taxon normally regarded as diagnostic of the early Asbian CF6α-β subzonal interval. In the Flintshire Dinantian succession, these assemblages characterise the Leete Limestone Formation, however, Davies et al. (in press) have shown that lower parts of the overlying Loggerheads Limestone also contain assemblages with abundant *P. nibelis* associated with diagnostic Cf6γ Subzone markers such as *Euxinita* sp. Since lithologies suggestive of the Leete Limestone are absent from the Corwen outlier, the evidence suggests that the limestones at Plas-isaf and Plas-uchaf are equivalent to these lower levels of the Loggerheads Limestone in its type area.

6.2 Cefn Mawr Limestone Formation

The thickness of the Cefn Mawr Limestone sequence in the Hafod-y-calch outlier is estimated to be around 105m. However, the contact with the underlying Loggerheads Limestone is nowhere exposed and the mapped boundary is entirely conjectural. The type section for the formation is Cefn Mawr Quarry, west of Mold (Somerville, 1979; Davies et al., in press) where it broadly equates with the Upper Grey Limestone of Morton (1886; see also Strahan, 1890). In its type area the formation comprises cyclic sequences of dark grey, argillaceous wackestones and pale grey packstones and grainstones. Palaeokarstic features and calcretes are again present at the tops of many of the cycles. Important marker beds recognised in the Flintshire and Llangollen outcrops include the ‘Main Shale’ and the ‘Coral Bed’ (Davies et al., in press).

The northern Hafod-y-calch quarry provides a section through the upper 25m of the formation with evidence for at least three shoaling upwards cycles (Figure 3). The lowest 2.3m of the quarry section comprise a complex sequence of peritidal and pedogenic carbonates and mudstones developed at the top of the lowest cycle. A basal 1m-thick unit composed of irregular nodules of fine-grained recrystalised limestone (microsparite) set in a green mudstone matrix is overlain by a 1.5m thick composite mudstone bed which includes a lower fissile, dark grey part and a blocky, green coloured upper part. At the top of the cycle, nodular beds of calcite mudstone with spar-filled fenestrae are associated with rootlet-bearing green mudstones and thin beds of calcareous siltstone.

At the base of the middle cycle, and welded to the underlying unit, is a 0.1m bed of coarse crinoidal packstone with disarticulated and inverted productid valves. The distinctive swirling ridges of the trace fossil *Zoophycus* are well seen on the top of this basal bed. The overlying 2-m thick mudstone with nodules of argillaceous limestone in its upper part is thought to be the local equivalent of the Main Shale. Shell pavements composed entirely of the crushed valves of rhynconellid, spiriferid and spiny productid brachiopod valves are present in the lower 0.5m of the mudstone. The overlying 5-m thick sequence of thinly interbedded limestones and dark grey mudstones is a characteristic facies of the Cefn Mawr Limestone. The tabular and nodular limestone beds, ranging up 0.3m in thickness, comprise dark grey, foetid, highly argillaceous wackestones and packstones. Graded packstone beds are present in the fossiliferous upper part of this thin-bedded sequence, which is capped by a metre-thick unit of coral bafflestone containing abundant well preserved colonies of both fasciculate and massive rugose coral genera, together with solitary corals, brachiopods and bryozoa. This is clearly the fossiliferous horizon cited by earlier workers at Hafod-y-calch (e.g. Morton, 1878; Neaverson, 1946; George, 1958) and comparison with Cefn Mawr Limestone sequences of eastern outcrops strongly suggest that it represents the Coral Bed of Flintshire and Llangollen. The 3-4 metres of strata immediately above the Coral Bed are currently unexposed in the quarry, but the succeeding massive bed of pelloidal and skeletal packstone/grainstone is though to occur at the top of the middle cycle (Figure 3). Anastomosing, black, carbonaceous filaments interpreted as rootlets are present in the upper part of the bed below an irregular pitted surface. The complete middle cycle is estimated to be 13.5m-thick in the quarry.

The upper 8m of the Cefn Mawr Limestone in the northern Hafod-y-calch quarry comprises a sequence of massive, locally sandy, pelloidal and skeletal grainstones with coated grains (Plates 6 and 7). This forms the bulk of a third cycle. The overlying oolitic sandstones, which form the uppermost part of this cycle, are included in the succeeding Minera Formation.

The Cefn Mawr Limestone contains a diverse coral and brachiopod macrofauna. The diagnostic Brigantian colonial rugose corals *Actinocyathus floriformis, Lonsdalea duplicata, Palaeosmilia regia, Corwenia rugosa* and *Orionastrea phillipsi*, together with longer ranging species of *Lithostrotion, Siphonodendron* and *Diphyphylum,* and the tabulate *Syringopora ramulosa*, are all recorded from the Coral Bed. Amongst the solitary forms is the Brigantian taxon *Dibunophyllum bipartitum*. A Brigantian age is confirmed by the presence of microfossil assemblages containing *Koskinobigenerina* sp., *Asterarchaediscus* spp. and *Neoarchaediscus* spp. which are diagnostic of the Cf6δ subzone.

6.3 Minera Formation

The upper 17m of the section in the northern Hafod-y-calch quarry are assigned to the Minera Formation (Figure 3). As much as 50m may be present in the degraded southern quarry complex. The type section for the formation is at Minera, north-west of Wrexham (Davies et al., in press), where it is equivalent to the Sandy or Arenaceous Limestone of earlier workers (Morton, 1878; Wedd et al., 1927). The formation is characterised by an alternation of limestones and calcareous sandstones arranged in cyclic sequences. Palaeokarstic and pedogenic features may again be present at the tops of the cycles, but where sandstones form the upper beds such features are normally poorly developed and cycle boundaries are consequently more difficult to recognise. The base of the formation is taken at the base of the lowest mappable sandstone unit. This typically includes strata that form the upper part of a sedimentary cycle, the lower components of which are included in the Cefn Mawr Limestone and this is the case at Corwen (Figure 3).

The 10m-thick unit mapped as the basal sandstone of the Corwen sequence is fully exposed in the northern Hafod-y-calch quarry section where it forms the prominent buttress separating the western part of the quarry from an eastern extension. Indeed the form of the quarry possibly reflects the avoidance of this sandstone unit when the site was being worked for lime production (Davies, 1865). The same sandstone appears to occupy a similar unworked ridge in the southern Hafod-y-calch quarry.

In detail, the basal sandstone is composite in character and may itself include elements of 3 separate shoaling upwards cycles (Figure 3). Two beds of oolitic sandstone with scattered granules and pebbles of quartz, each capped by an irregular, pitted palaeokarstic surface and overlain by purple and green mudstone palaeosols, occupy the lower 4m. The individual radial-fibrous ooids within these sandstones are typically cored by fine, quartz sand grains and set in calcite cement (Plate 8). In fresh sections these beds form pale, massive units not unlike the underlying Cefn Mawr limestones, but weathering reveals their sandy nature producing a honeycombed crust of friable red and brown sandstone. Identical rocks are present in the Minera Formation at Llangollen and in Flintshire (Wedd et al., 1927; Davies et al., in press). The 1.15m-thick palaeosol overlying the upper oolitic unit is capped by 0.3m-thick limestone bed in which jig-saw brecciation, floating sand grains and stringers of purple clay provide clear evidence of syndepositional pedogenesis (Plate 9) (Davies, 1991). The succeeding sequence of purple and grey brachiopod-bearing mudstones and thin-bedded sandy packstones occupies a position within the middle of the basal sandstone, and underlies an upper 3m composed of fine-grained white, brown and red quartz sandstones (Plate 10); these siliceous beds possibly forming the upper units of a third cycle.

Overlying the basal sandstone of the Minera Formation in the northern Hafod-y-calch quarry, and forming the uppermost 7m of the exposed section, is a sequence of massive, pale grey skeletal and pelloidal packstones and grainstones with scattered, fine, quartz sand grains (Plates 11 and 12). Prominent bedding surfaces overlain by red mudstone partings may mark the position of incipient cycle boundaries within this upper limestone sequence, but no definitive pedogenic or palaeokarstic features have been observed.

Few macrofaunal remains were noted in the Mineral Formation sequence at Hafod-y-calch. Crushed productid and rhynconellid brachiopod valves are present in the mudstones in the middle of the basal sandstone unit, and a single fasciculate coral colony was observed 3m below the top of the exposed section. Microfossil assemblages observed in the Minera Formation are of lower diversity than those in the underlying formations, but the presence of *Asterarchaediscus* spp. and *Neoarchaediscus* spp. in a sample from southern Hafod-y-calch quarry (VK49) confirms a Brigantian, Cf6δ subzone, age.

7. Interpretation of the sequence

In their account of the Flintshire Dinantian succession, Davies et al. (in press) provide detailed environmental interpretations of the facies and faunas that characterise the three formations identified within the Corwen outlier. The sedimentary cycles from which they are constructed represent transgressive/regressive couplets generated by contemporary movements of marine base level. In the Loggerheads Limestone and Cefn Mawr Limestone, the body of each cycle records shallow marine deposition on a carbonate platform. During accumulation of the Minera Formation, the platform was also receiving significant volumes of siliciclastic detritus. The presence of palaeokarstic and pedogenic features demonstrates that the tops of many of the cycles were subjected to subaerial exposure, vadose dissolution and soil forming processes. These features confirm that the regressive phases of the cycles were not the product of simple progradations, but record the repeated lowering of sea level (forced regressions) leading to widespread emergence of the platform surface (Davies, 1991).

The Asbian and Brigantian stages coincided with the initiation and growth of an extensive ice cap on the southern super continent of Gondwana (Veevers and Powell, 1987). Analysis of the style of cyclicity displayed by Asbian and Brigantian limestone formations throughout the UK, persuaded Walkden and Walkden (1990) that small-scale glacio-eustatic movements in sea level, associated with the developing glaciation, were the likely cause.

There is a marked contrast in the style and average thickness of the cycles in the Loggerheads Limestone, during the Asbian, compared with Cefn Mawr Limestone, during the Brigantian. The former is constructed from relatively thin cycles dominated by massive packstones and grainstones. These grain-supported facies were deposited in shallow water depths where there was effective winnowing of fines. In contrast, the Cefn Mawr Limestone comprises cycles which are on average twice as thick as those in the underlying formation, and which are characterised by thick sequence of thinly interbedded mudstones and wackestones which accumulated at depths below the zone of effective winnowing (Davies, 1984; Davies et al., in press). This contrast shows that the transgressive rises in sea level recorded by cycles in the Cefn Mawr Limestone were, on average, of greater magnitude, and drowned the platform to greater depths, than those in Loggerheads Limestone. This has led to the suggestion that, during the Brigantian, the effects of glacio-eustatic sea-level rises were enhanced by regional down warping of the crust at a time when rift-related tectonism was giving way to the post-rifting, thermal subsidence regime which dominated northern Britain during the ensuing Silesian period (Frazer and Gawthorpe, 1990; Corefield et al., 1996).

The marked increase in the volume and grade of siliciclastic detritus being supplied to the carbonate platform during the deposition of the Minera Formation may relate to the onset of more humid climatic leading to greater fluvial supply to coastal areas (cf. Walkden, 1987). Uplift along the northern flank of the Wales-Brabant Massif has been proposed as an alternative or additional cause (Leeder, 1982).

8. Regional comparisons and palaeogeography

The BGS survey of the outlier confirms Morton's (1878) assertion that strata equivalent to his 'Lower Brown Limestone' of Llangollen are absent. In Flintshire and Llangollen, these strata are now included within the lithologically distinctive Leete Limestone Formation (Somerville, 1979; BGS, 1994; Davies et al., in press) and recognised as Holkerian to early Asbian in age. Their absence from the Corwen succession, and of older Dinantian divisions present in Flintshire, is consistent with south-westwards onlap against the sloping flank of the Wales-Brabant Massif (Figure 4). The presence of abundant *Pojarkovella nibelis* within the Loggerheads Limestone at the base of the Corwen sequence is significant in confirming that the Dinantian transgression of North Wales inundated this area around the early-late Asbian boundary, close to the onset of the cyclical phase of platformal deposition.

Within the Flintshire and Llangollen Dinantian successions, significant lateral thickness and facies changes occur in the vicinity of the Bala Lineament. George (1974) viewed this as evidence for sinistral strike-slip displacement along the fracture belt, suggesting a cumulative movement of as much as 20km. However, detailed work by BGS on the Flintshire succession has shown that cycles in the Loggerheads Limestone, Cefn Mawr Limestone and Minera Formation expand and split as the fault belt is approached from the north (Davies et al., in press). This contrasts with attenuated sequences of all three formations present to the south at Minera (Figure 4). These changes provide clear evidence that syndepositional movement along the lineament and its associated fractures created a region of enhanced subsidence and sediment accumulation to the north, and of condensed deposition to the south. Contemporary strike slip movement along the Bala Lineament is still viewed as an important causative factor, but the overall amount of lateral displacement required is considerably less. The observed Corwen succession is a minimum of 210m thick, and even a conservative estimate for the portion of Minera Formation concealed beneath the Dee alluvium, would suggest a total thickness for the Carboniferous Limestone sequence in excess of 250m. This is notably thicker than the c.190m preserved on the south side of the lineament at Minera, over 20km to the east, suggesting that the zone of subsidence along the north side of the Bala Fault extended into the Corwen area.

A comparison of the Cefn Mawr Limestone and Minera Formation sequence exposed in the northern Hafod-y-calch quarry with sections in the main Flintshire crop provides an insight into the lateral changes in facies and thickness between the two areas (Figure 4). Key to this comparison is the possible presence of two of the principal marker beds within the Cefn Mawr Limestone sequence, i.e. the Main Shale and Coral Bed. There is no absolute biostratigraphical proof that the units identified at Hafod-y-calch are the same as those recognised in the east. A simplistic correlation of the two successions using the base of the Minera Formation as a datum suggests that there is no such correlation. At Pen Rhrw Quarry [284 560], on Hope Mountain, the Coral Bed lies almost 40m below the mapped base of the Minera Formation; at Hafod-y-calch it lies just 14m below the oolitic sandstone which marks the contact. However, a closer inspection of the motifs reveals the presence at Pen Rhrw of an oolitic grainstone bed, the only oolitic horizon within the section, just 13m above the Coral Bed with the first recognisably sandy lithologies noted immediately above. If, as seems probable, the oolite of Pen Rhrw represents the sand depleted equivalent of the oolitic sandstone at Hafod, then the Coral Bed and Main Shale correlation is confirmed. It is clear from this correlation that the base of the Minera Formation is diachronous and that the supply of siliciclastic sediment to the Dinantian platform, in volumes sufficient to form mappable sandstone units, commenced earlier at Corwen than to the east.

Even so, the lack of significant, sand grade contamination in the underlying limestone succession, aside from the basal beds at Plas-isaf, does little to suggest that the sequence as whole accumulated close to the final limit of Dinantian inundation as suggested by George (1958). In his paper, George (fig. 19) shows the Corwen sequence sited landward of the 500ft (c. 152m) isopach for the whole Dinantian sequence. The conservative 250m total-thickness suggested by the BGS study shows this to have been a serious under-valuation. These new figures imply that, as it reached its maximum extent, a far greater portion of North Wales was submerged by the transgressive Dinantian sea than previously supposed. In detail, the zones of enhanced subsidence located along the Bala and other major tectonic lineaments may have promoted the formation of narrow carbonate gulfs that extended far into the Wales-Brabant hinterland (Figure 5). With the climatic deterioration of the late Brigantian, these embayments would have become the focus for fluvially supplied sand input. This may account for the earlier onset of Minera Formation facies at Corwen, and the presence of sandy limestones at Pen Rhrw in parts of the Cefn Mawr Limestone sequence which, away from the Bala Lineament, are free of sand contamination.

9. Conclusions

The BGS survey of the Dinantian outlier near Corwen has identified the presence of formations recognised in more eastern outcrops including the Loggerheads Limestone, Cefn Mawr Limestone and Minera Formation. Microfossil assemblages of foraminifera and calcareous algae contained in these units confirm that the succession spans parts of the Asbian and Brigantian stages. Earlier Dinantian formations, including strata equivalent to the early Asbian Leete Limestone, are absent due to regional onlap. The exposed sequence is estimated to be 210m-thick, and a conservative estimate for the part concealed to the north east, beneath the alluvial belt of the River Dee and Afon Alwen, suggests a total thickness for the Dinantian succession at Corwen of no less than 250m.

The sequence exposed in the northern of two large quarries at Hafod-y-calch, includes two of the key marker beds recognised in the Cefn Mawr Limestone of the Flintshire and Llangollen outcrops, viz. the Main Shale and Coral Bed. It also exposes the local contact between the Cefn Mawr Limestone and Minera Formation. This section underpins regional comparisons which confirm that the outlier succession accumulated within a zone of enhanced subsidence sited on the north side of the Bala Lineament. During the period of climatic changes in the late Brigantian, this zone acted as a focus for terrigenous sand supply and deposition.

10. Recommendations

The BGS study of the isolated Dinantian outlier near Corwen, and of the northern Hafod-y-calch quarry site in particular, has confirmed their national importance in the context of Dinantian palaeogeographical reconstruction. They provide evidence critical to a fuller understanding of both the distribution and evolution of Dinantian facies in North Wales, and the controlling influence of intra-Dinantian movements along major basement fracture belts. Accordingly, BGS recommends that the Hafod-y-calch quarry site should be included in the GCR and that measures are taken to ‘repair’ the section and to re-expose parts recently concealed by the dumping of waste material over the quarry faces. The current limited exposure in the Coral Bed needs to be developed, and action should also be taken to stabilise the landslippage affecting the lower part of the section which includes the Main Shale.

The importance of the southern Hafod-y-calch quarry site is difficult to gauge in its present overgrown and degraded state. However, the southern quarry has the potential to provide information to further underpin the palaeogeographical importance of the outlier and, therefore, it too should be included within the GCR site. To reveal the potential of these exposures consideration should be given to clearing the site and re-exposing the rock section.

The limestone quarries at Plas-isaf and Plas-uchaf currently provide the only exposures in the lower part of the outlier succession, in the Loggerheads Limestone. In order to include a representative section through as much of the outlier as possible, these exposures should also be included in the GCR site.

Acknowledgements
BGS gratefully acknowledges the co-operation of all landowners during the geological survey of the outlier, and in particular Rûg Estate for allowing access to the northern Hafod-y-calch quarry. Ron Domain is thanked for his excellent work drafting the figures.

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FIGURES 1 to 5

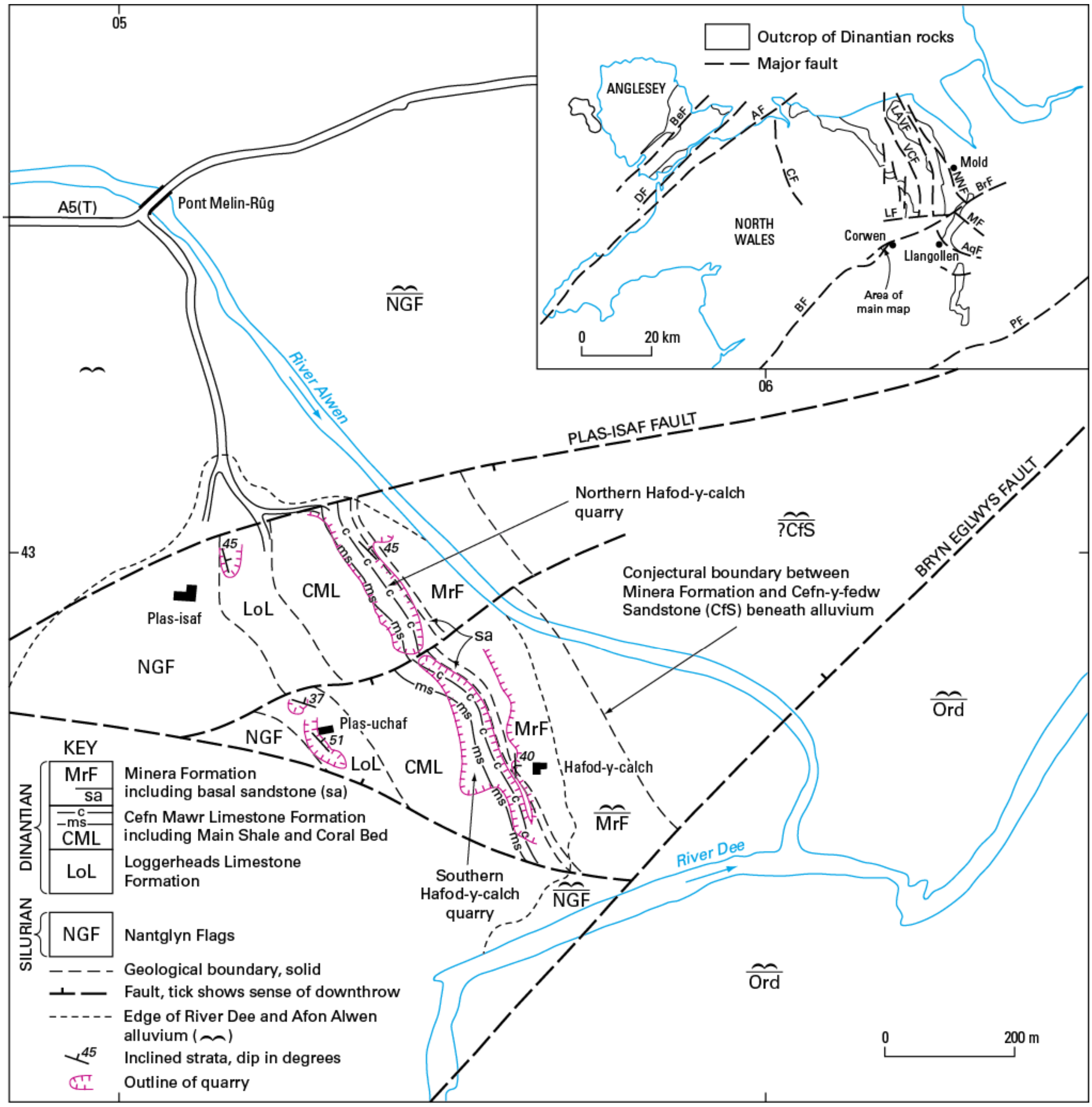

Figure 1 Geological map of the Dinantian outlier near Corwen (glacial drift deposits omitted), showing its relationship to the principal outcrops of Dinantian rocks in North Wales and the structures which affect them. (Abbreviations: AF-Aberdinlle Fault, AqF-Aqueduct Fault, AVF-Alyn Valley Fault, BF-Bala Fault, BeF-Berw Fault, BrF-Bryn Eglwys Fault, CF- Conwy Valley Fault, DF-Dinorwic Fault, LF-Llanelidan Fault, MF-Minera Fault, NNF-Nercwys-Nant-figillt Fault Zone, PF-Prees Fault, VCF-Vale of Clwyd Fault, CfS-Cefn-y-fedw Sandstone, Ord-undivided Ordovician Rocks).

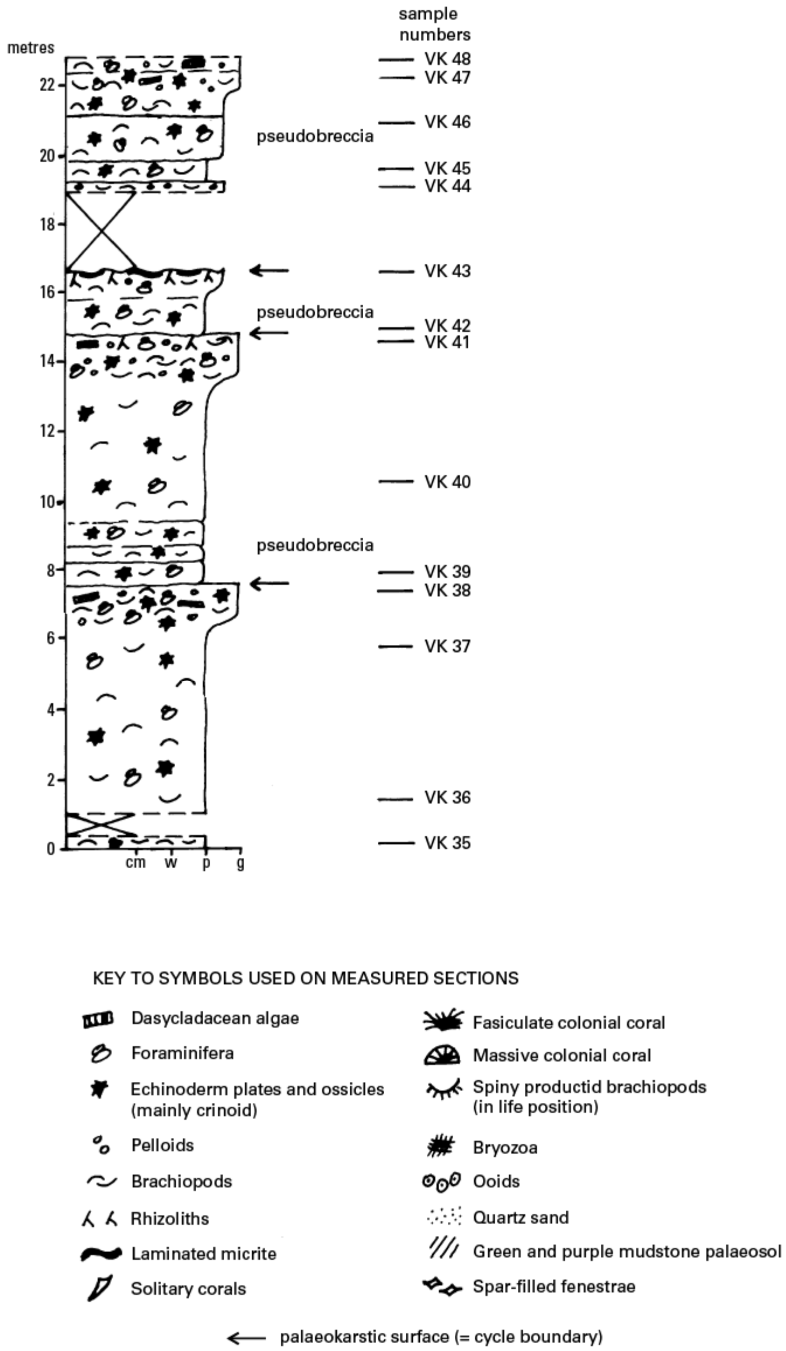

Figure 2 Log of the section exposed in the quarry and crags at Plas-uchaf

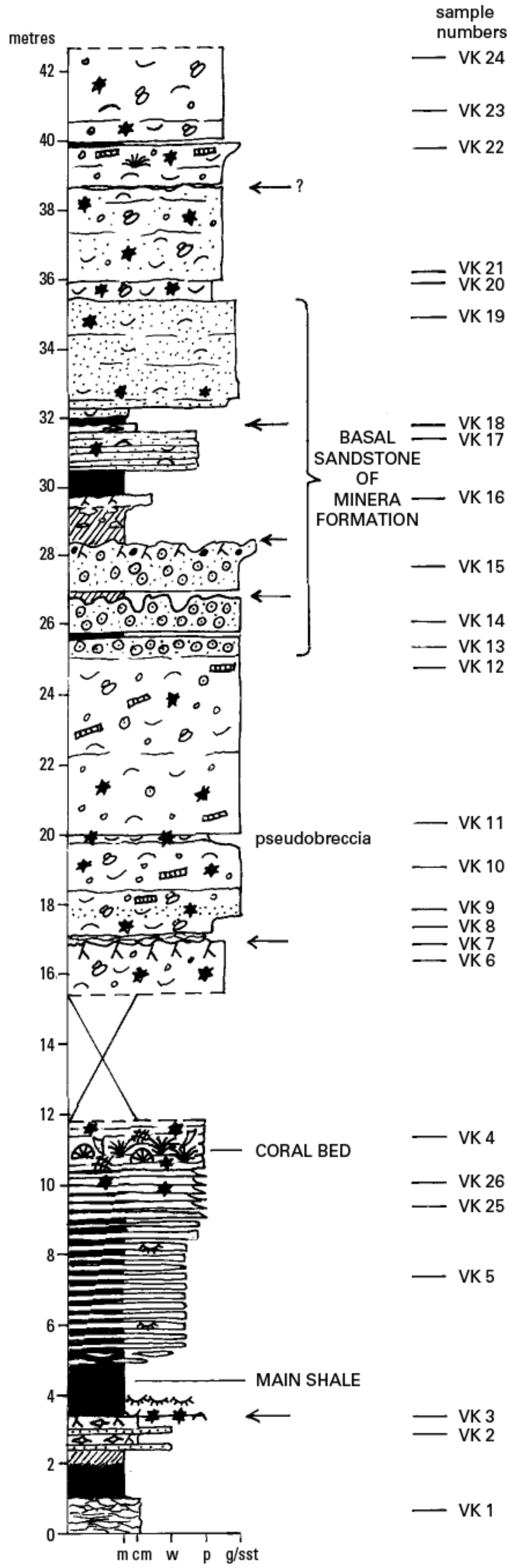

Figure 3 Log of the section exposed in the northern Hafod-y-calch quarry (for key to symbols see Figure 2)

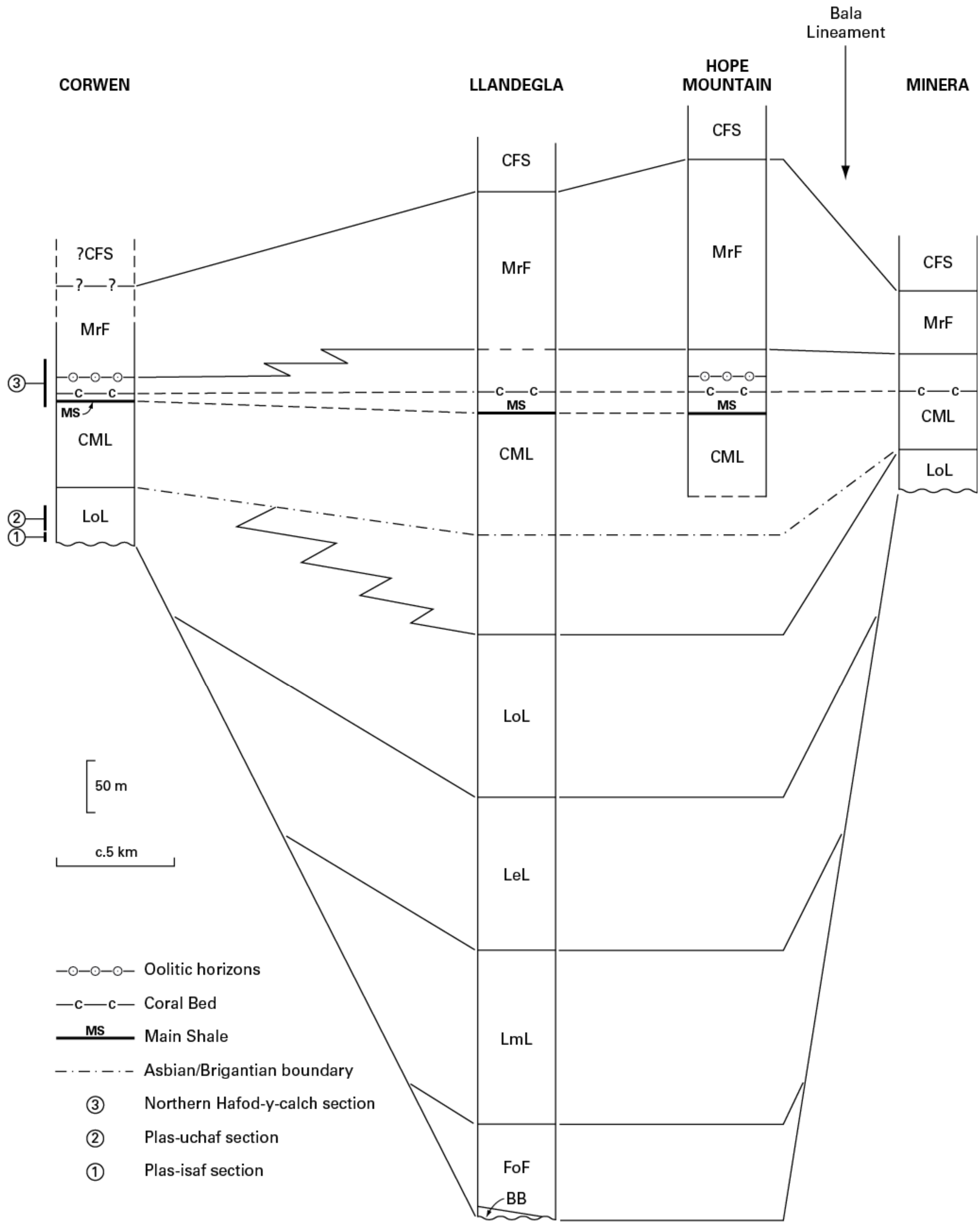

Figure 4 Regional relationships of the Corwen Dinantian succession.
(Abbreviations: BB-Basement Beds, CfS-Cefn-y-fedw Sandstone, CML-Cefn Mawr Limestone, FoF-Foel Formation, LeL-Leete Limestone, LmL-Llanarmon Limestone, LoL-Loggerheads Limestone

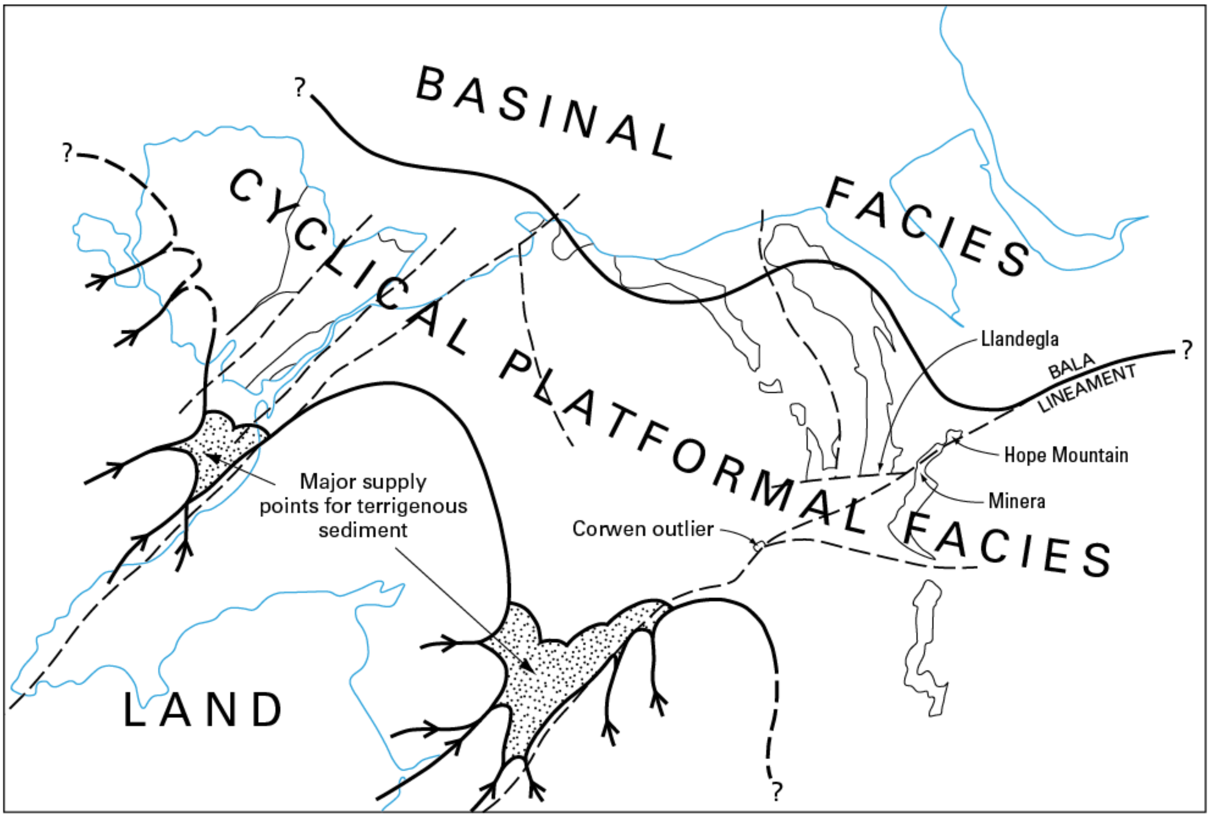

Figure 5 Dinantian palaeogeography of North Wales during the Brigantian Stage (Dinantian outcrops and major faults as in Figure 1)

APPENDIX 1. Foraminiferal and algal biostratigraphy

General remarks:
The distribution of foraminifera and alga in samples from the sections at Plas-isaf (sample numbers VK27-34), Plas-uchaf (sample numbers VK 35-48) and the northern Hafod-y-calch quarry (sample numbers VK 1-24), in addition to a single sample (VK49) from the southern Hafod-y-calach quarry, are given on tables 1 to 3. The biostratigraphic scheme used is the Belgian one of Paprothe et al. (1983), based on the type Dinantian (Lower Carboniferous) for W. Europe, adapted for the UK by Riley (1993). Since that work Riley (unpublished) has re-examined the type Brigantian section; including the original material procured by Strank (1981), and demonstrated that a non-sequence occurs at the base of that stratotype. Furthermore, the range of *Koninckopora*, hitherto claimed by Strank (1981) to be absent in the Brigantian strata of the type section (but see Somerville & Strank, 1984), can be shown to range at least 7m above the base of the Brigantian at the stratotype, and is present in abundance in at least 30% of Strank's original samples. Hence, in this report, the Cf6γ-δ subzonal boundary is now drawn within the early Brigantian (within the Hawes Limestone equivalent). All the samples from Corwen appear to lie in the Asbian and Brigantian stages.

The spreadsheets show a 'X' for each identifiable component. Blank columns represent samples with no identifiable components. Significant biomarkers (providing resolution to within 2 biozones) are colour coded red. Blue colours represent identifiable reworking of material from an underlying zone. At the base of each spreadsheet maximum zonal ranges (e.g. Cf5-6) of the sample are given. Where no zonal data are given, the resolution is low and greater than 2 biozones. Green coding represents a precise dating of a sample to a single subzone.

The microfacies shows a range of depositional settings including open platform bioclastic carbonate sands, oolite shoals and inner platform calcite mudstone and marine sandstones. Some marine facies are overprinted with pedogenic microfabrics, demonstrating emergence after deposition. The marine biofacies are interesting in that there are no foraminiferal elements (e.g. visarriotaxids, howchiniids, valvullinellids and *Planoarchaediscus* are all absent) which typify the deepest platform facies (found at maximum flooding surfaces) and outer platform/slope settings (found during low stands) seen elsewhere in N. Wales (e.g. Llandudno-Prestatyn district) and other regions adjacent to the Irish Sea (Southern Lake District, Craven and Dublin basins, Isle of Man). This tends to corroborate the view that the Corwen area occupied an inner to mid-platform setting during Asbian and Brigantian marine flooding events.

Note: In tables 1-3, all the samples lie within the Cf6 Biozone, and letters a, b, g, and d represent the consecutive α, β, γ and δ subzones respectively.

Table 1. Microfossil assemblages from Plas-isaf quarry and crags

BGS samples (pre-fix KV)	27	28	29	30	31	32	33	34
Brunsia spirillinoides	X				X	X		
Brunsia spp.	X							
calcisphaeres	X	X			X			
Endothyra spp.	X	X	X	X	X	X	X	X
Eostaffella sp.	X	X		X		X	X	X
Koninckopora inflata	X		X	X	X	X	X	X
Koninckopora minuta	X	X	X	X		X		X
Mediocris mediocris	X					X		
palaeotextulariid (bilam.)	X	X			X	X	X	
Paraarchaediscus spp.	X		X					
Paraarchaediscus stilus	X							
Pojarkovella nibelis	X		?	?		X		
Priscella prisca	X							
Earlandia sp.		X		X	X			
kamaeniids		X	X	X			X	X
palaeotextulariids indet.		X		X				
Septabrunsiina sp.		X						
Climacammina sp.			X					
Endothyranopsis ex. gr. crassa			X			X	X	
Gigasbia sp.			X	X	X			
Omphalotis sp.			X					
Spinobrunsiina sp.				X				
stacheiinids				X				
Archaediscus spp.					X			
Bibradya inflata					X	X		
Endostaffella sp.					X			
Koskinotextularia sp.					X			
Foram Zones Cf	6a-b	6	6b-g	6a-d	6a-d	6a-b	6a-g	

Table 2. Microfossil assemblages from Plas-uchaf quarry and crags

BGS samples (pre-fix KV)	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Brunsia spirillinoides	X			X		X			X	X		X	X	
calcisphaeres	X			X	X		X		X	X	X	X		X
Earlandia sp.	X	X	X		X	X	X	X	X		X	X		X
Endothyra spp.	X			X	X	X		X	X	X				
Gigasbia sp.	X				X		X				X	X		X
Globoendothyra sp.	X				X			X					X	X
kamaenids	X	X	X		X					X		X	X	X
Koninckopora minuta	X	X	X	X	X	X	X	X	X		X	X	X	X
palaeotextulariids	X			X	X			X				X		
Paraarchaediscus sp.	X				X			X		X	X			
Plectogyranopsis sp.	X			X	X		X		X	X	X	X		
Spinobrunsiina sp.	X													
Archaediscus spp.		X		X		X			X				X	X
Brunsia sp.		X	X					X						
Endothyranopsis crassa		X				X	X							
Eostaffella sp.		X	X	X	X	X		X	X		X	X	X	
Koninckopora inflata		X			X	X	X	X		X	X			X
Priscella prisca		X					X	X		X			X	X
Tetrataxis sp.		X		X						X	X			
Cribrospira sp.			X											
Pojarkovella nibelis			X	X	X	X	X	X	X	X	?	X	?	
Septabrunsiina sp.			X											
Pseudoammodiscus sp.				X			X	X						
stacheiinids				X										
Bibradya inflata					X			?		X	?	X		
Endostaffella sp					X					X				
Koskinotextularia sp					X									
Mediocris mediocris					X		X	X	X	X		X		X
Millerella sp.					X									
Omphalotis sp.					X			X						
Plectostaffella sp.					X	X								
palaeotextulariids (bilam.)						X			X		?	X	X	X
Palaeospiroplectammina sp.							X							
Dainella holkeriana								X					X	
Endospiroplectammina sp.									X		X		X	
lituotubellid												X		
Nannopora anglica														X
Foram Zones Cf	5-6d	5-6d	5-6b	5-6b	6a-b	6a-b	5-6b	5-6b	6a-b	6a-b		6a-b	6a-b	6a-g

Table 3 Microfossil assemblages from the northern Hafod-y-calch quarry and Sample 49 from the southern Hafod-y-calch quarry

BGS Samples (pre-fix VK)	1	2	3	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	49
calcisphaeres	X		X		X		X									X	X		X		X				X	
Earlandia sp.	X		X			X			X	X										X				X	X	
Pseudotaxis micra	X			X	X					X					X	X					X					X
Archaediscus sp.			X	X	X	X	X	X	X	X	X		X						X				X		X	X
Coelosporella sp.			X		X	X				X	X	X		X												
Eostaffella sp.			X		X	X			X		X			X							X					
palaeotextulariid indet.			X												X				X	X	X		X		X	
Endothyra spp.				X		X	X	X	X	X		X	X						X	X	X	X	X	X	X	X
Tournayellina aff. beata				X	X		X													X						
Brunsia sp.					X																					
Koskinobigenerina sp.					X		X	X			X								X	X						
Mediocris mediocris					X				X			X							X	X	X	X			X	
Paraarchaediscus stilus					X																				X	
Pseudoammodiscus sp.					X		X	X	X	X										X						X
stacheiinids					X	X			X		X					X										X
Tetrataxis sp.					X		X	X	X		X			X					X	X	X	X	X			X
Endostaffella sp.						X													X		X				X	X
Paraarchaediscus spp.						X																				
Asterarchaediscus spp.							X				X			X												X
Earlandia trs. Gigasbia.							X	X																		X
Endothyranopsis crassa							X	X											X	X						
Nannopora anglica							X		X					X												
Neoarchaediscus spp.							X	X	X		X			X												X
Plectostaffella sp.							X	X																		
Priscella prisca							X	X	X				X	X					X			X		X		X
Cribrospira panderi								X																		
Palaeotextulariid (bilam).								X		X															X	X
Gigasbia sp.									X	X										X						X
Globoendothyra sp.									X		X															X
Omphalotis sp.									X	X																
Pseudolituotubella sp.									X																	
Biseriella parva										X																
Koninckopora inflata (clast)											X	X							?							
lituotubellid											X														X	
Endospiroplectammina sp.												X														
Girvanella sp.																X									X	
Saccaminopsis sp.																				?						
aoujgaliids																								X		
Euxinita sp.																									X	
Foram Zones Cf			5-6	5-6	6g-d	5-6	6d	g-d	6	5-6	6d		5-6	6d	5-6				6g-d	6g-d	5-6		5-6		6d-g	6d

PLATES 1 to 12

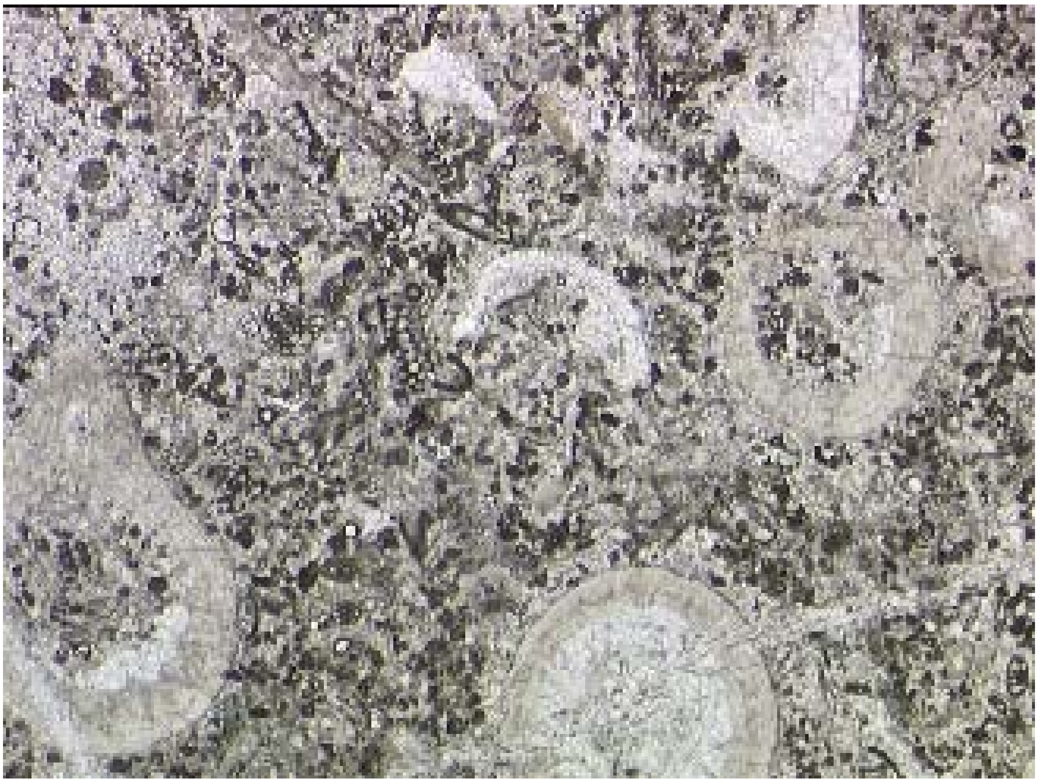

Plate 1. Foraminiferal calcisphaer packstone with subordinate allochems of coral, brachiopod and the dasycladacean alga Koninkopora, Loggerheads Limestone, Plas-isaf quarry (VK27). Maximum field of view 8mm.

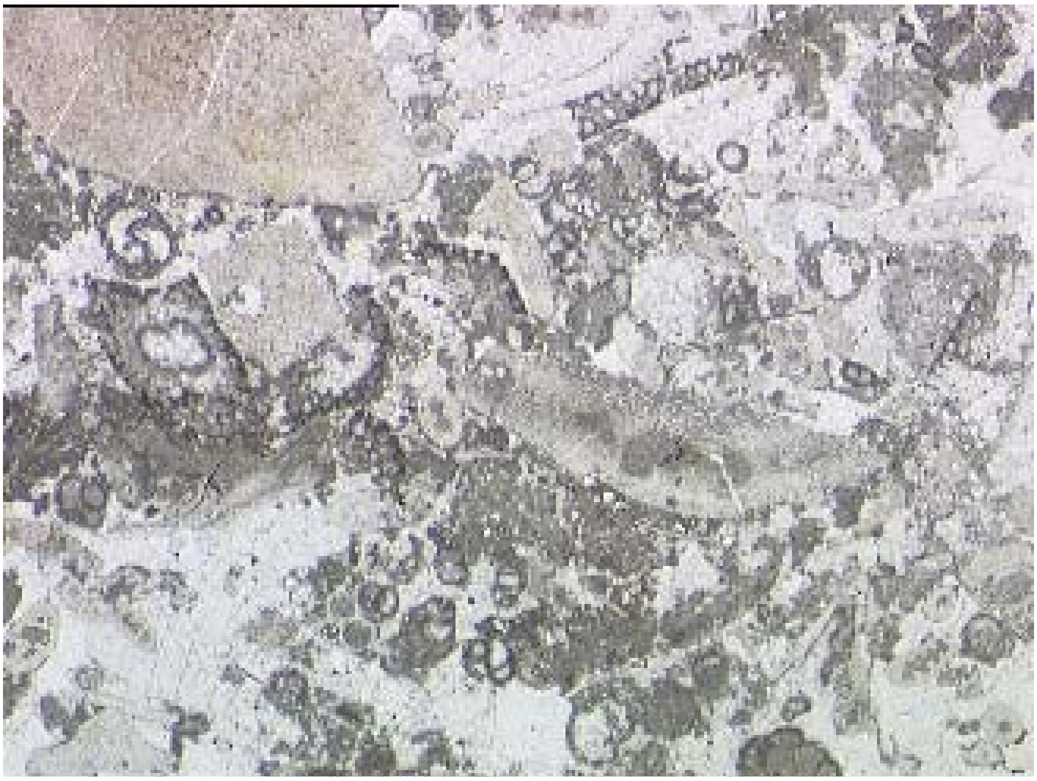

Plate 2. Koninkopora foraminiferal grainstone with subordinate allochems of brachiopod and echinoderm, Loggerheads Limestone, Plas-isaf quarry (VK29). Maximum field of view 8mm.

Plate 3. Algal foraminiferal packstone with micritesed skeletal grains (pelloids), Loggerheads Limestone, crags above Plas-isaf quarry (VK33). Maximum field of view 8mm.

Plate 4. Partially micritised skeletal wackestone/packestone with allochems of Koninkopora, foraminifera, calcispaeres, brachiopod and angular quartz sand grains, Loggerheads Limestone, Plas-uchaf quarry (VK35). Maximum field of view 8mm.

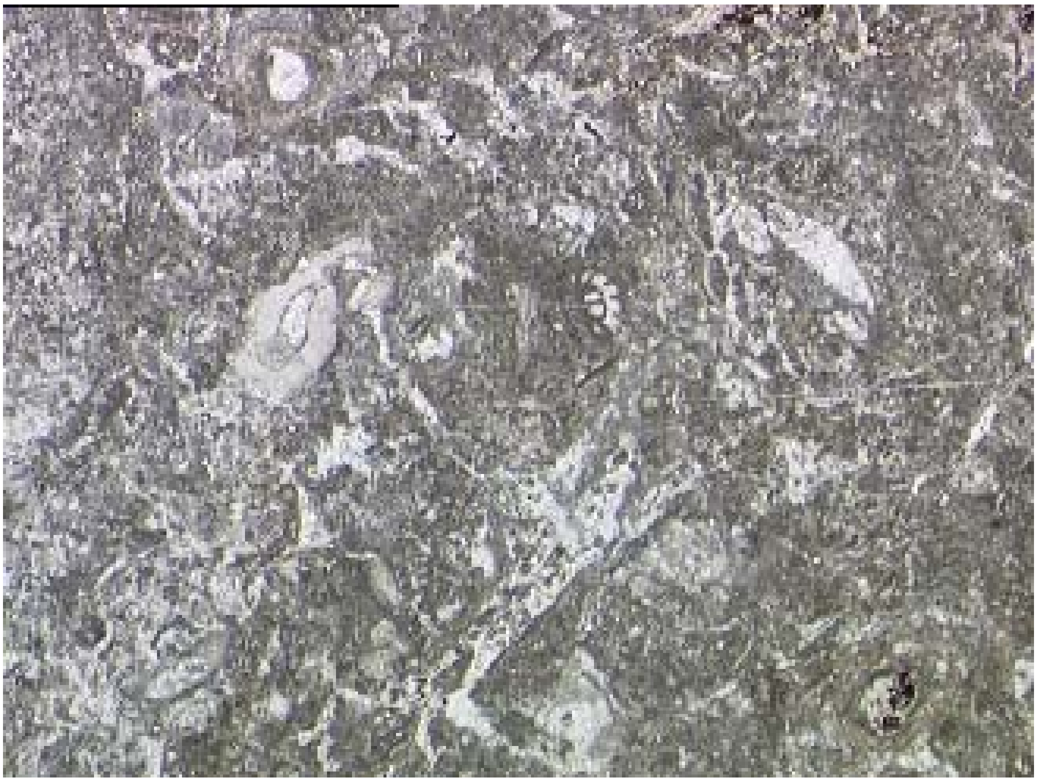

Plate 5. Dense laminated micrite (calcrete) with irregular, spar-filled fractures, circular and elliptical cross-sections through tubular rhizoliths, and relict skeletal allochems, Loggerheads Limestone, Plas-uchaf quarry (VK43). Maximum field of view 8mm.

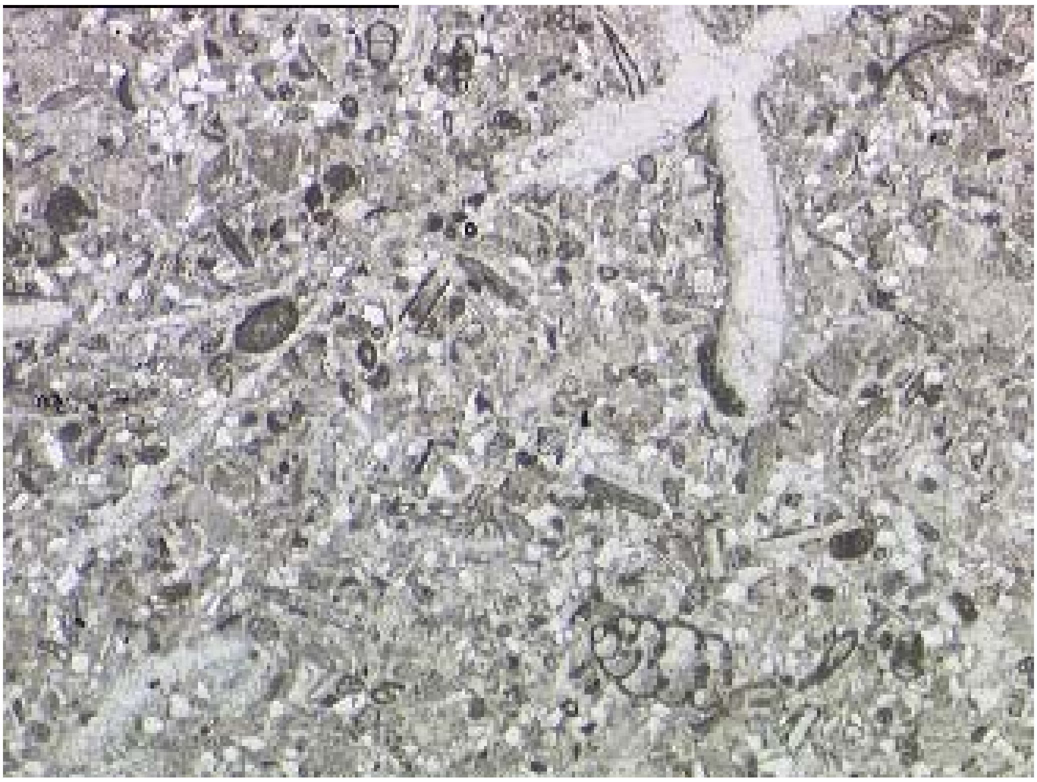

Plate 6. Sandy skeletal packstone with allochems of foraminifera, brachiopod, echinoderm and abundant angular to sub-rounded quartz sand grains, Cefn Mawr Limestone, northern Hafod-y-calch quarry (VK8). Maximum field of view 8mm.

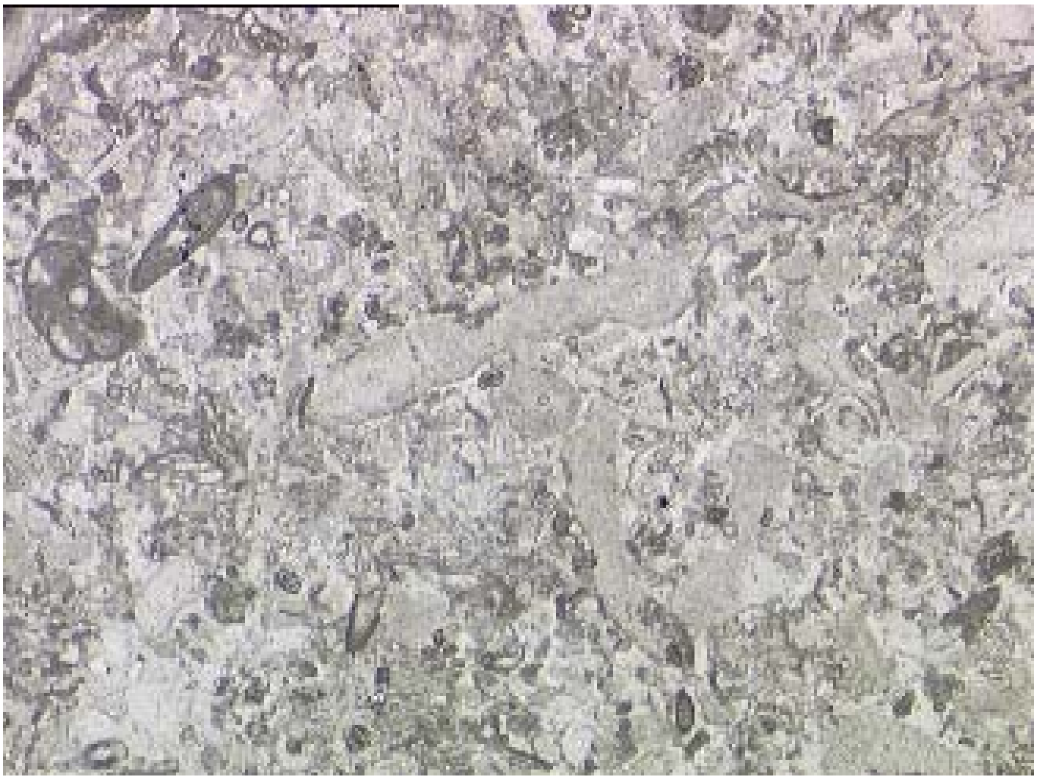

Plate 7. Skeletal pelloidal grainstone with allochems of foraminifera, brachiopod, echinoderm and calcareous algae, Cefn Mawr Limestone, northern Hafod-y-calch quarry (VK10). Maximum field of view 8mm.

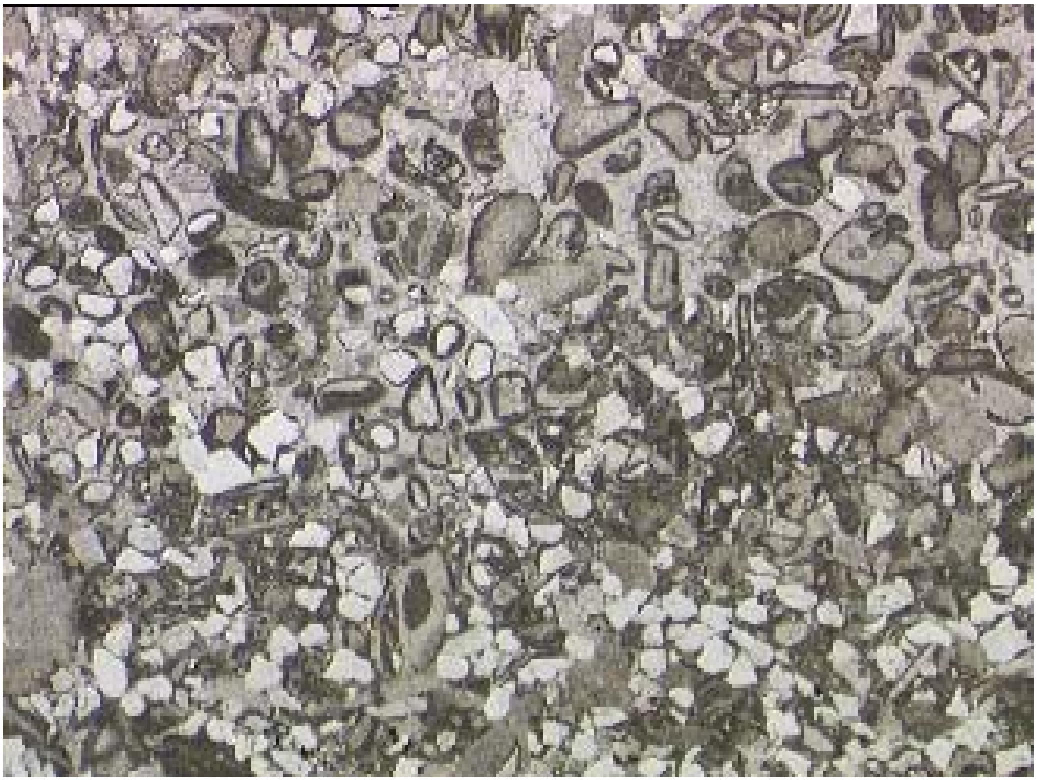

Plate 8. Calcite cemented, oolitic sandstone with quartz sand-cored ooids and subordinate allochems of brachiopd, echinoderm, foraminifera and calcareous algae, basal bed of Minera Formation, northern Hafod-y-calch quarry (VK13). Maximum field of view 8mm.

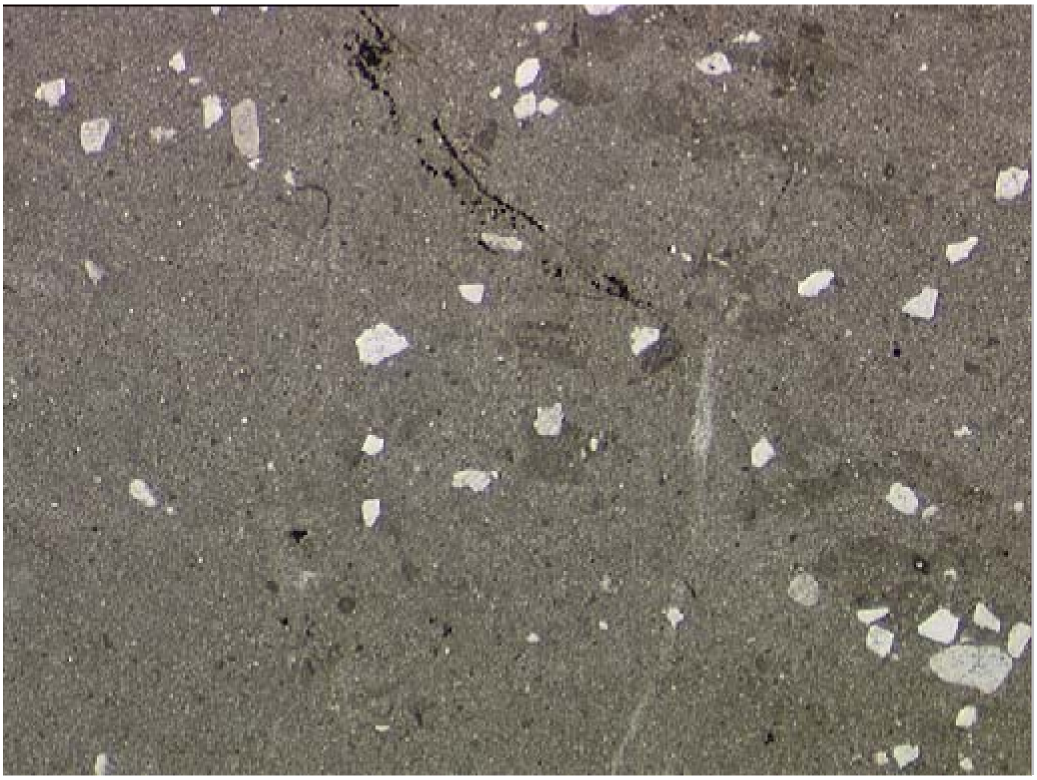

Plate 9. Pedogenic calcite mudstone with clots of denser micrite, 'floating' quartz sand grains and ghosts of altered skeletal allochems, Minera Formation, northern Hafod-y-calch quarry (VK16). Maximum field of view 8mm.

Plate 10. Calcite cemented quartz sandstone with subordinate allochems of foraminifera and echinoderm, Minera Formation, northern Hafod-y-calch quarry (VK19). Maximum field of view 8mm.

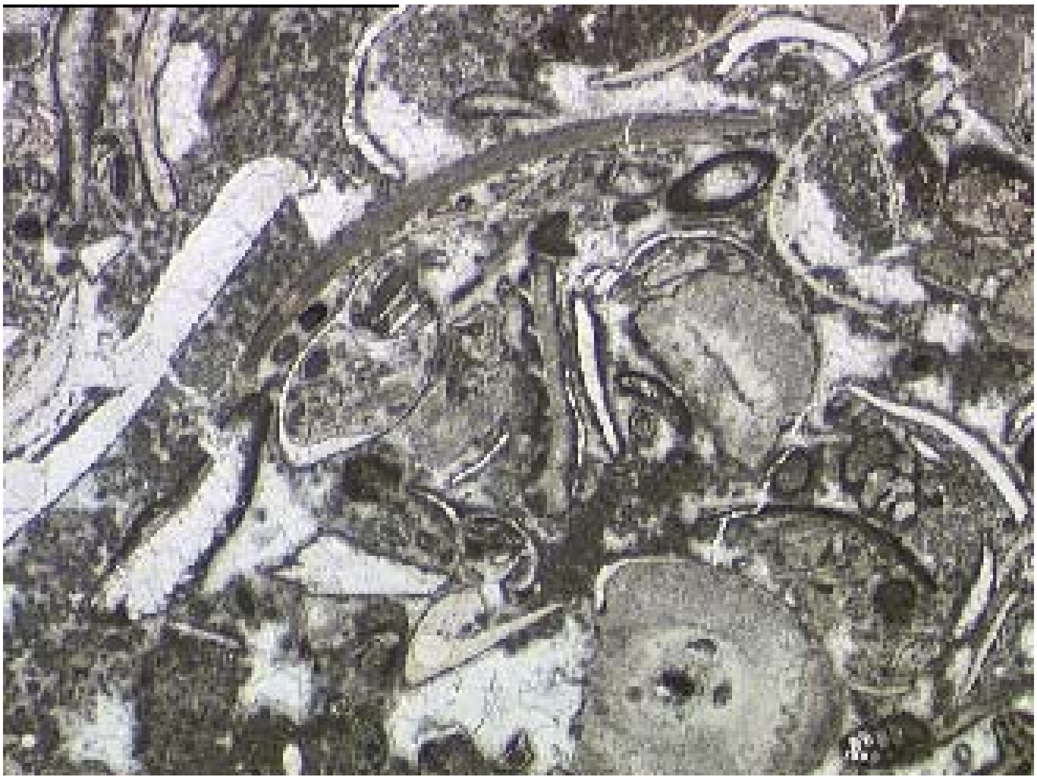

Plate 11. Ill sorted skeletal packstone with allochems of brachiopd, foraminifera, echinoderm, and micritised grains (pelloids), Minera Formation, northern Hafod-y-calch quarry (VK20). Maximum field of view 8mm.

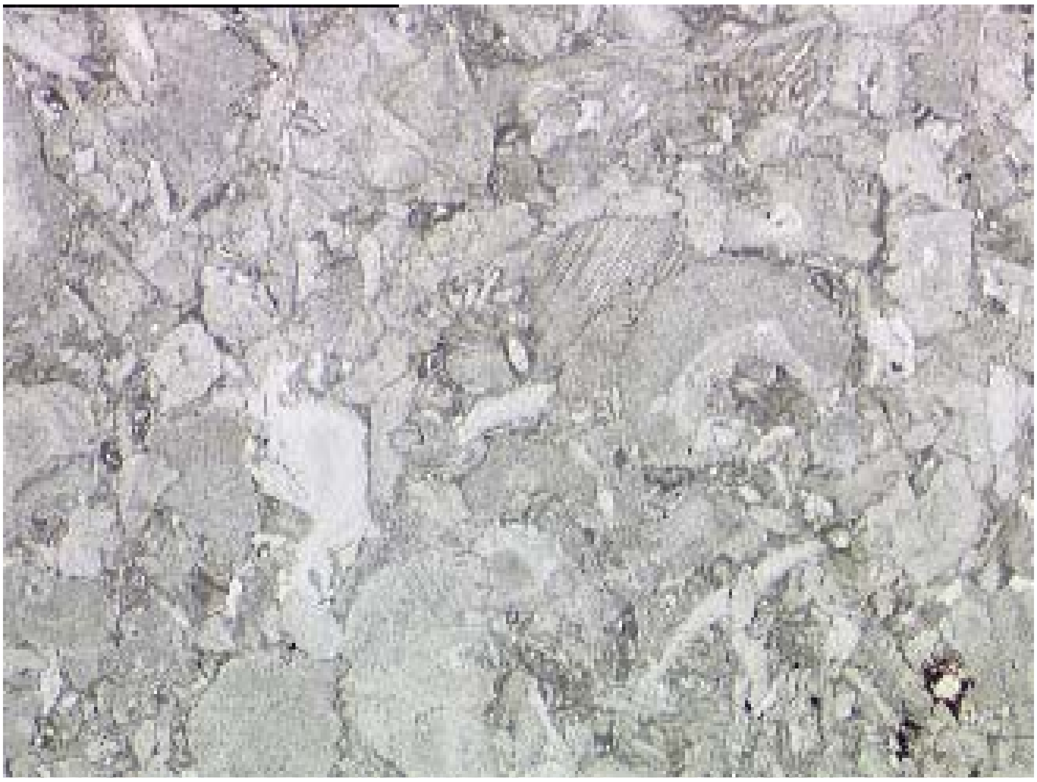

Plate 12. Crinoidal packstone with sutured grain contacts, subordinate allochems of brachiopd and foraminifera, Minera Formation, northern Hafod-y-calch quarry (VK 23). Maximum field of view 8mm.