RELATIVE SEA-LEVEL MOVEMENTS, PALAEO-HORIZONTALS AND THE DEPOSITIONAL RELATIONSHIPS OF UPPER ORDOVICIAN SEDIMENTS BETWEEN CORRIS AND BALA, MID WALES.

by

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Summary

Consideration of palaeo-horizontals and sediment thicknesses allows construction of palaeostratigraphic sections within which relative depositional water depths may be estimated after correction for compaction and tectonic strain. Angular relationships between successive palaeo-horizontals document relative tectonic tilting and sedimentary facies document the influence of base level changes. The analysis clarifies the depth range and depositional environment of the Allt-ddu Mudstones and the Nod Glas and proposes the correlation of the intra-Hirnantian glacioeustatic sea-level fall with the boundary between the Lower and Upper Garnedd-wen Beds of W.J. Pugh.

Introduction

Following the lead of Curtis (1970) and Vail *et al.* (1977), stratigraphers have increasingly thought of sedimentation in terms of relative sea-level movement. Positive or negative aggradation and progradation is now recognized not only in the transgressive/regressive sequences of shallow marine strata but also in their time-equivalents in deep water either by distinctive geometries (e.g. Bosellini, 1984) or by distinctive facies sequences (e.g. May *et al.*, 1984). Over the last decade it has also become increasingly appreciated that fluctuations of absolute sea-level related to global tectonic or climatic processes can be of great chronostratigraphic value - particularly in certain types of tectonic province (e.g. passive continental margins) where absolute and relative sea-level movements are often closely correlated. Moreover, fluctuations related to short period glacio-eustatic processes are often associated with distinctive sedimentary facies (or facies sequences) and are increasingly recognized as of chronostratigraphic significance (e.g. Brenchley and Newall, 1980; Williams and Wright, 1981).

After removal of the effects of compaction and (if necessary) tectonic strain, major thickness variations in time-equivalent strata relate either to filling of variable topographic relief or to variable rates of contemporaneous tectonic movement. Sedimentology, particularly in the identification of depositional surfaces approximating to the palaeo-horizontal (i.e. parallel to the plane of contemporary sea-level) and of facies sequences indicative of changing depositional base level, should allow distinction between these possibilities. An informative example of this type of approach in a tectonically active basin is given by Nagtegaal et al. (1983). It is commonly the case that the results of both end-member processes (i.e. static infill or variable subsidence beneath constant base level) are present in a thick sedimentary succession and in such cases it is particularly instructive to draw a sequence of palaeo-stratigraphic sections hung from palaeo-horizontals. If bulk strain effects can be removed, the geometry of such sections allows the relative water depths at deposition to be calculated and the effects of tectonic tilt between sections to be isolated.

This paper looks at some classic deep to moderately shallow water marine sequences of Upper Ordovician (Caradoc-Ashgill) age in north central Wales with the above considerations in mind. It will be found that several new insights result and that several problems are highlighted.

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The palaeo-stratigraphic sections

Basic data

The location of the sections is shown in fig. 1. The area discussed lies on the southeast flank of the Harlech Dome and the continuous Ashgill-Caradoc outcrops between Corris and Bala lie north of the Ashgill inliers of central Wales at and around Plynlimon (James, 1983a). Data to construct the sections given in fig. 2 have been drawn from: Bassett (1972), Bassett, Whittington & Williams (1966), James (1972), Lockley (1980), Pugh (1923, 1928, 1929) and Schiener (1970). The country southwest of Corris towards Towyn, studied by Jehu (1926) and James (1973), is not treated in fig. 2 since the problems of interpretation of the Ashgill-Caradoc are essentially the same as at Corris.

Palaeo-horizontals

Each of the sections in fig. 2 comprises a sedimentary package bounded at (or near) its top by a palaeo-horizontal. This, of necessity, is only approximate, the theoretical ideal being probably only approached by suspension deposits in ponded basins. Nevertheless, the palaeo-horizontals chosen are certainly of very low initial gradient, at least in the plane of section, and within the limits of precision of the thickness data used in fig. 2 may be treated as parallel to sea-level. The palaeo-horizontal criteria used include erosional unconformities in shallow marine sequences; thin, areally extensive, tuff horizons preserved in shallow water or partly subaerial sequences and top surfaces of turbidite bodies deposited from fully turbulent suspensions.

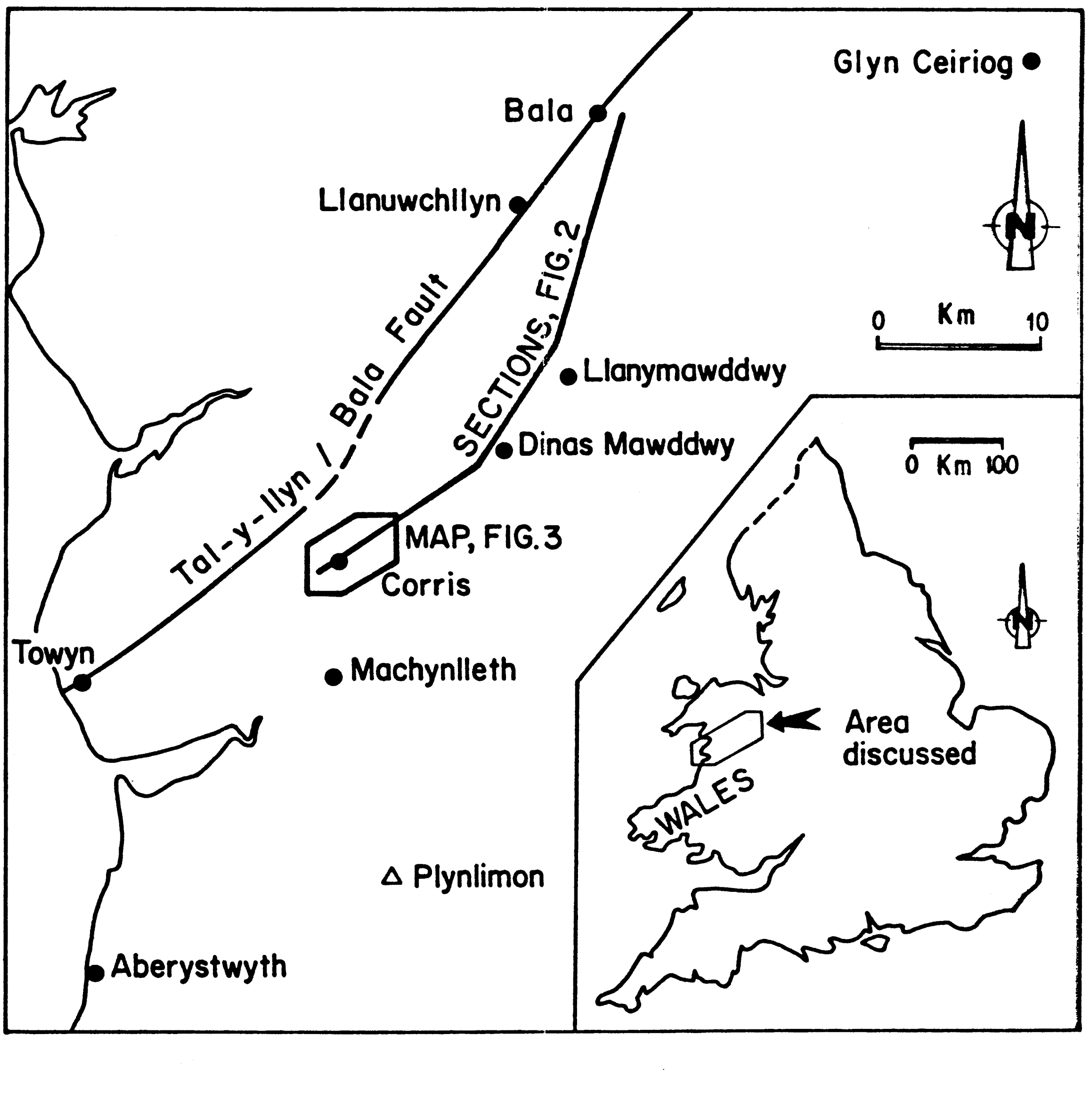

Fig. 1 Location maps for the Corris - Bala country.

Angular relationships

The data of fig. 2 is of course two-dimensional and all angular relationships shown therein are to variable extent minima. Nevertheless, within the plane of section relative tectonically induced tilts and relative water depths can in principle be calculated. To do this, corrections for overburden induced compaction (which may be differential) are required as also, since the strata are variably cleaved, are corrections for extension in tectonic *a*. Rigorous corrections of this nature are not possible since compaction is somewhat variable in different sedimentary provinces and also since no details of tectonic strain are available for the Upper Ordovician sequences studied. However, some approximations are possible and set useful limits on the likely magnitude of the corrections.

Cleavage attitude is taken to be approximately vertical, based on published information. We assume that pre-cleavage sedimentary dip is approximately horizontal and thickening thus maximal (see Rast 1969, p. 322-3 for discussion) and that the sedimentary packages can be treated essentially as mudstone. Regional strain data (Rast, 1969; Coward & Siddans, 1981) suggest that extensions of less than 30% and more than 60% are improbable for the strata under consideration. Regional data on burial history (Smith & George, 1961) and metamorphic grade (Bevins & Rowbotham, 1983) suggest, assuming palaeo-geothermal gradients of 35° C/km at shallow crustal depths, a maximum burial of about 9 km including tectonic extension. Since burial below 6 km does not significantly decrease the already extremely low porosity at that depth, the decompaction calculation is not particularly sensitive to the tectonic extension within the range quoted above. The curve of Baldwin (1971) has been used for decompaction. Results show that initial relief of the Ashgill-Caradoc sequences under consideration in the plane of fig. 2 is likely to have been in the range of 30–50% *greater* than the apparent relative relief as currently measured without extension/decompaction corrections. Such relief/water depth will be termed 'non-corrected' below.

With the above in mind we can turn to a discussion of the stratigraphic subdivisions of each of the three packages depicted in fig. 2.

Caradoc

Figure 2 shows that two sediment packages can be recognized separated by a mild tilt of 0.5 degrees. Assuming no flexuring of the thick volcanic sequences under the 1.2 km thick mudstones of the Ceiswyn Formation, about half of this tilt is probably due to differential compaction. Noteworthy in the lower package is the regressive/transgressive character of the Glyn Gower Siltstones and the slope environment of the recently defined Llaethnant Formation (Lockley, 1980). The upper package indicates renewed regression overall with muddy slope foresets and silty topsets in the Allt-ddu Mudstones. A minor transgression separates the extreme regressions of the Pont-y-Ceunant Ash and the sequence immediately underlying the Cwmerig Limestone. The erosion surface at the top of the package parallels the strata within the topsets to a degree that suggests negligible tectonic warping as a contribution to the relative sea-level fall that created it.

In both Caradoc packages the components of foreset slopes in the plane of section are consistent with the Soudleyan palaeogeography shown by Brenchley & Pickerill (1980, fig. 8). The *Sericoidea* fauna of the Allt-ddu Mudstones (Lockley, 1980, p. 38) appears to have lived (if in-situ) in non-corrected water depths of about 200 metres or somewhat more.

Nod Glas

The age of this formation is not clear. Bassett (*in* Williams *et al.*, 1972) points out that it may range from Marshbrookian to at least Onnian but that it has also been thought to be solely Onnian (Cave, 1965). Price (1984, p. 103) assigns it solely to the Caradoc and the overlying Ashgill to no older than the Rawtheyan. Since the underlying Ceiswyn or Allt-ddu Formations are Longvillian, various contrasting view points can include both continuity of sedimentation and boundaries which are non-sequences, either above or below, see also Lockley (1980, p. 37 and fig. 7).

Figure 2 indicates that erosional boundaries are improbable, the characteristic black shale facies, the Corris Shale of Lockley (1980), accumulating in non-corrected water depths in excess of 250 metres. Thus the possibilities of non-sequence must be via sediment starvation rather than erosion since thinning due to slumping does not appear to be documented. Some degree of non-sequence is probable in view of the frequently phosphatic character of the Nod Glas, and the spatially allied Cowarch Phosphate Bed (Lockley, 1980, p. 33) by analogy with similar deposits (Baird, 1978). Moreover, the water depth estimate is also consistent with the depths

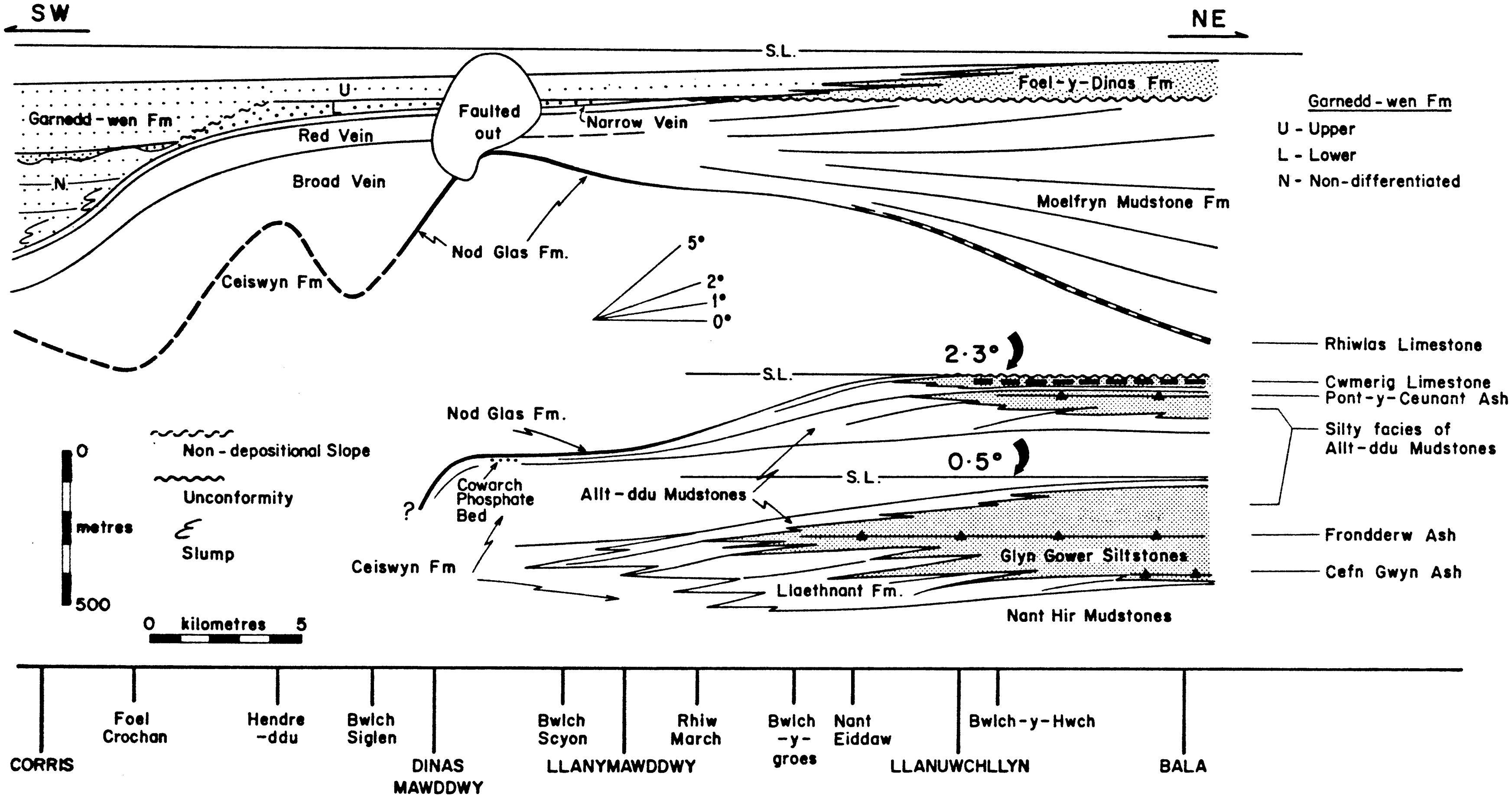

Fig. 2 Correlation and Sedimentological Restorations (Palaeostratigraphic sections) of Caradoc and Ashgill strata between Corris and Bala. Based on sources referenced in text. All thicknesses are present-day without differential tectonic thickening corrections and only the topmost portion of the Ceiswyn Formation is indicated. The lower two restorations, separated by only mild tilt, are Caradoc; the upper, overlying the major tilt, is Ashgill. The Nod Glas Formation is plotted in both Ashgill and Upper Caradoc restorations since it could well be of both ages in this area (Bassett, 1972, p. 27). Inset scale indicates angular relationships and strong arrows indicate sense and amount of rotation. S.L. Denotes sea-level.

of accumulation of modern examples (Bremner, 1980; Burnett, 1980; Marshall & Cook, 1980). In particular the upslope termination of the Nod Glas suggested by fig. 2 may be related to a depth limit below which nutrients were trapped by a thermocline (Leggett, 1980, p. 151). It is noteworthy that the area of transition between the distinctive facies of the Corris Shale and Dyfi Mudstone (Lockley, 1980, p. 36-39) corresponds with a rapid change of slope shown in fig. 2.

Ashgill

The major Nod Glas facies change in the vicinity of Dinas Mawddwy is mirrored thereabouts by changes within the lower part of the Ashgill; at higher levels the evident transgression post-dating the sub Foel-y-Dinas Formation unconformity at Bala (Bassett, Whittington & Williams, 1966) moves the area of facies transition to the NE.

The uniform nature and extremely variable thickness of the Moelfryn Mudstones, well illustrated by Lockley (1980), argues for differential tectonic subsidence SW of Bala; the identification of the sub Foel-y-Dinas unconformity as a palaeo-horizontal adds force to this suggestion. Whether or not the former slope area SW of Nant-Eiddaw at the termination of the Rhiwlas Limestone was ever onlapped by the Moelfryn Formation (a possibility not shown in fig. 2) awaits proof or otherwise of the continuity of Nod Glas sedimentation. It is interesting that the major angular discordance of 2.3° between the Ashgill and Caradoc packages was developed after an episode of faulting at Bala (Bassett, Whittington & Williams, 1966) which induced very local variation in the degree of pre-Rhiwlas Limestone erosion.

The Broad Vein (Abercwmeiddaw 'Group' of Pugh (1923)) poses problems for the restoration in fig. 2. The thicknesses are derived from Pugh's maps (1923, 1928) and appear very variable, in contrast with those for the Red and Narrow Veins which appear to be rather constant according to Pugh but which are not thick enough to redetermine with accuracy on the basis of his maps alone. Pugh did not mention variation of thickness and quoted only one figure, namely 457 metres (Pugh, 1923, p. 538). The uniform nature of the underlying Nod Glas might argue against infill of rugose topography; moreover the Broad Vein does not appear to be internally slumped. Where the writer has checked Pugh's maps, notably west of Corris where the Broad Vein appears to be only about 220 metres thick, the bounding formations appear accurately mapped and as yet unrecognized structural complications within the area of outcrop appear required for apparent major thickness variation. Further southwest of Corris similar problems appear in the ground mapped by R.M. Jehu (1926). The Broad Vein thickness is given by Jehu as 274-289 metres (*op. cit.*, p. 473) which is appreciably thinner than Pugh's estimate at Corris. However, Jehu's fig. 4 (*op. cit.*, p. 476) shows only 197-212 metres and further local apparent thinning was postulated as possibly due to internal strike faulting.

The Moelfryn Formation presumably passes laterally into the Broad Vein/Red Vein/Narrow Vein sequence with no major changes of depositional gradient between them. If the latter sequence were to onlap the Moelfryn Formation substantial depositional relief would be required around Rhiw March and the uniformity of facies mitigates against this. Faunal evidence is inconclusive but tends to support absence of appreciable onlap since the basal Ashgill appears always to be Rawtheyan in this area (Price, 1984, p. 103).

The *Foliomena* fauna of the basal Broad Vein (Harper, 1979, p. 440) appears consistent with the depositional depths exceeding 300 metres to be inferred from fig. 2 (*op. cit.*, p. 443).

Above the Narrow Vein, in the type area between Corris and Aberllefenni lie the Garnedd-wen 'Beds' and it is the internal geometry of these that is critical in postulating a chronostratigraphic correlation with the Foel-y-Dinas Formation. The key element in this geometry is the continuity of a prominent horizon of turbidites (a palaeo-horizontal) between Corris and Aberllefenni which both proves onlap against a slope and necessitates an extension of a component of this slope to the northeast since the turbidites are base-of-slope deposits displaying north-westerly transport (James, 1972). Map evidence for the continuity of this horizon has not previously been published and is given here as fig. 3b. It may be noted in passing that the new map removes the necessity for a violent twist in the axial trace of the Corris anticline (fig. 3a) about which Pugh was clearly uneasy (1923, p. 533).

This paper correlates the major arenite horizon, underlain by extensive slumped beds and overlain by rather uniform silty mudstones, with the boundary between the Upper and Lower Garnedd-wen 'Beds' (Pugh, 1928) which is seen as a regressive maximum. The succeeding transgression may conveniently be correlated with the first deposits above the intra-Ashgill unconformity at Bala (Bassett, Whittington & Williams, 1966); the overall regressive/transgressive couplet representing a response to late Hirnantian glacio-eustatic events. This correlation does not appear to have been made before and is not mentioned by Brenchley & Newall (1980, p. 27-28) in their discussion of the Hirnantian glacial event in Wales. If correct, it would refine correlation with other Ashgill sequences although the details of the sea-level fluctuations within the Hirnantian are not fully agreed (*cf* Brenchley & Newall, 1980, fig. 22 and Leggett *et al.*, 1981, fig. 1). It implies that the Narrow Vein is unlikely

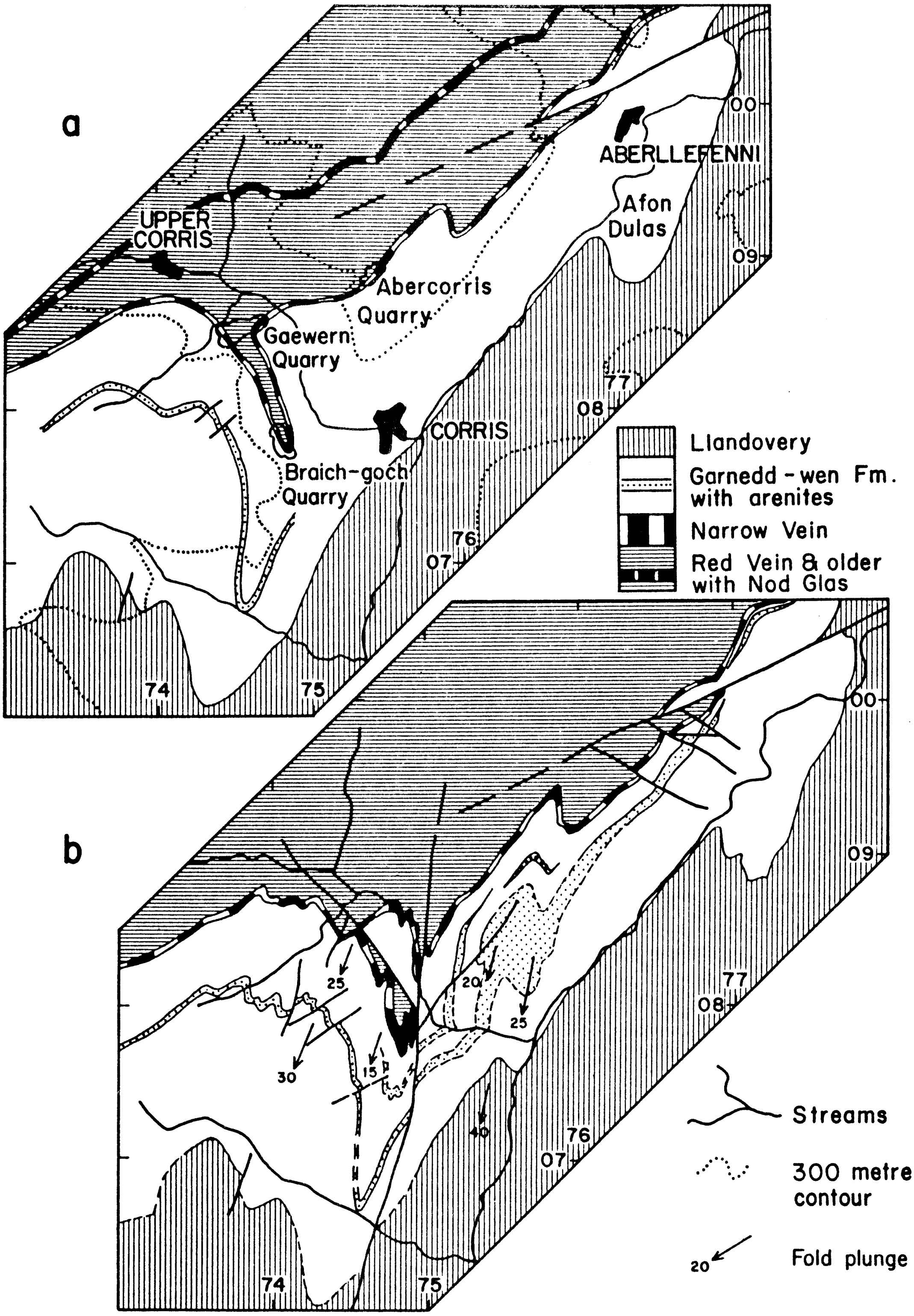

Fig. 3 Geological maps of the area between Corris and Aberllefenni; (a) after Pugh (1923) with topography and major quarries indicated, (b) based on present work demonstrating lateral continuity of the principal arenite unit in the Garnedd-wen Formation and a revised structural interpretation of the Corris anticline. (b) does not show the Nod Glas since it has not been remapped by the writer.

to be younger than early Hirnantian and this, together with increasing depth of erosion below the intra-Ashgill unconformity to the NE, is supported by a probable Rawtheyan age for the topmost Moelfryn Mudstones (Hiller, 1981). Since the Narrow Vein/Red Vein/Broad Vein sequence is of constant lithological type and great lateral extent and is clearly not foresetted in the plane of fig. 2; the Garnedd-wen onlap must be against a slope which was tectonically created (*cf* James & James, 1969). The lack of obvious thickness variation in the Narrow Vein also suggests that its upper surface is not incised by channels and that its present area of exposure was bypassed during Garnedd-wen sedimentation. Unless the Narrow Vein and the Red Vein are mud blankets occupying large depth ranges at deposition, the creation of the slope controlling Garnedd-wen deposition SW of Aberllefenni would have originated after their deposition. The slope appears to have had an inclination of about 58° and this would be consistent with the occurrence of slump and mass-flow deposits in the basal Garnedd-wen. A speculative contributory factor to the slumping, which is widespread at this time in the Welsh basinal Ashgill (James, 1983b), is melting of gas hydrates on the slope during glacio-eustatic sea-level fall (McIver, 1982). Cold basinal water at such a time might permit hydrate stability below about 400 metres water depth, and such a depth was likely on the Garnedd-wen slope near Corris prior to sea-level fall since the non-corrected depth estimate derived from fig. 2 approaches this figure. The organic rich sediments of the Nod Glas are a likely biogenic gas source.

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