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# A revised sedimentary and biostratigraphical architecture for the Type Llandovery and Garth areas, Central Wales: a field guide

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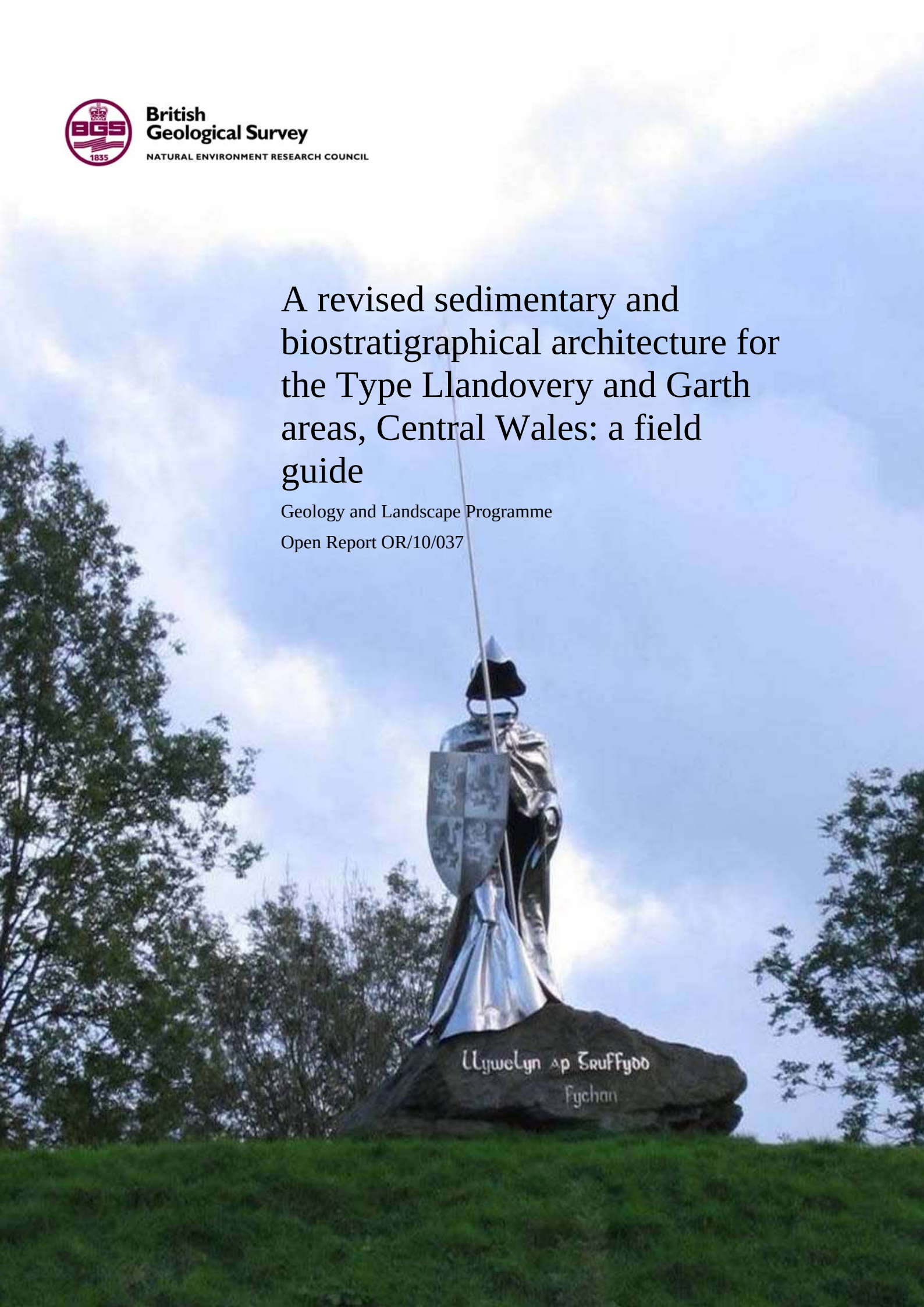

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*Front cover*

Statue of Llywelyn ap Gruffydd Fychan, Llandovery Castle. The castle is built on the late Hirnantian, glacio-regressive Cwmcringlyn Formation [SN 7678 3425].

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BRITISH GEOLOGICAL SURVEY

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# A revised sedimentary and biostratigraphical architecture for the Type Llandovery and Garth areas, Central Wales: a field guide

Jeremy R Davies[1], Richard A Waters[2], Jan A Zalasiewicz[3], Stewart G Molyneux[4], Thijs R A Vandenbroucke[5] and Mark Williams[3]

*[1]British Geological Survey, Cardiff;*
*[2]National Museum Wales, Cardiff;*
*[3]University of Leicester;*
*[4]British Geological Survey, Keyworth;*
*[5]University of Lille 1 (formerly of Ghent University)*



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**BGS Central Enquiries Desk**

Tel 0115 936 3143 Fax 0115 936 3276

email enquiries@bgs.ac.uk

**Kingsley Dunham Centre, Keyworth, Nottingham NG12 5GG**

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Recently published maps and sheet explanations covering the Llandovery and Garth areas, and adjacent regions of mid Wales, are available for purchase from BGS sales outlets.

**Permission to visit the sites described in this guide should be sought from Forestry Commission Wales or the appropriate landowner.**

# Contents

# 1 Introduction

The guide presents some of the results of collaborative research undertaken by the British Geological Survey, National Museum of Wales, and Leicester and Ghent universities in the Type Llandovery and Garth areas of Central Wales (Figure 1a and b), focusing on the late Ashgill, Llandovery and early to mid Wenlock strata. It is based on an earlier version produced for the Ludlow Research Group (LRG) Annual Field Meeting to the Llandovery and Garth areas in September 2009, but contains new data and interpretations based on significant subsequent discoveries in the Type Llandovery area. It highlights the following:

- The significance of the intra-Ashgill Shelvian Event.
- A reinterpretation of the Hirnantian glacio-eustatic event.
- A revised and unified lithostratigraphy for the Llandovery and Garth areas, which addresses the problems of correlating between the northern and southern Llandovery areas.
- New graptolite, acritarch and chitinozoan dating, especially in the Aeronian, Telychian and Wenlock.
- The importance of re-sedimentation processes including slumping and synsedimentary sliding within the succession.
- The relationship between the Llandovery and the overlying Wenlock successions.

## 1.1 BACKGROUND

The seminal work of O T Jones (1925, 1949) (Figure 2a) and his student Alwyn Williams (1951, 1953) established the early Silurian succession of the Llandovery area in south-central Wales as one of the best studied and well documented in the UK. Jones' A, B and C divisions and their subdivisions (e.g. $C_1$ to $C_6$) were initially lithostratigraphical conceptions. However, the co-occurrence of graptolite and benthic assemblages allowed these units also to be defined in biostratigraphical terms and, following Williams' (1951) work on brachiopod assemblages and lineages, they became widely adopted as biostratigraphical subzones.

The need for international correlation invited further detailed study and led ultimately to the landmark publication of Cocks et al. (1984), which established the Llandovery succession as the international type area for early Silurian strata – the Llandovery Series (Figure 2b). The constituent Rhuddanian, Aeronian and Telychian stages all take their names from sections in the Llandovery area. Although the adoption of Dob's Linn in Scotland for the basal Silurian stratotype made it the *de facto* base of the Rhuddanian Stage, both the other stages have their international stratotype localities in the area and are described in this field guide.

Robin Cocks and his co-workers re-assessed Jones' mapping and structural interpretation for the Llandovery region. They rigorously re-examined the graptolite and brachiopod faunas and, for the first time, undertook a detailed study of acritarch assemblages (Hill and Dorning, appendix in Cocks et al., 1984). This work underpinned a new lithostratigraphical and architectural model that emphasised the intact nature of the succession and allowed the key biozonal events to be identified (Figure 2b).

Over the last 25 years, the British Geological Survey (BGS) has undertaken the systematic geological mapping of the deep water facies of the Lower Palaeozoic Welsh Basin which crop out in central Wales (Figure 1). This has allowed a detailed understanding of Silurian facies architecture (Figure 3) and depositional events and processes to be elucidated (e.g. Davies et al., 1997, 1999; Schofield et al., 2009a). During the last 9 years, this work has been extended into

the shelfal successions of the Garth and Llandovery areas (Figure 1b) with the help of co-workers from Leicester, Ghent and Durham universities, and from the National Museum of Wales. One of the main aims has been to establish an event stratigraphy common to both the basinal and shelfal successions.

The new map of the Type Llandovery area (derived from British Geological Survey, 2005a and b; 2008) is shown in Figure 4 and the revised stratigraphical architecture in Figure 5. Historically, the southern and northern sectors of the type area have been mapped separately and differing stratigraphical nomenclatures erected in the two regions. A key aim of the new mapping, therefore, was to rationalise these different schemes and to establish a standard nomenclature for the Type Llandovery succession. Though this has led to the introduction of some new lithostratigraphical nomenclature, as many as possible of the widely cited Cocks et al. (1984) terms have been retained. The new and pre-existing lithostratigraphical nomenclature is shown in Figure 6. Key changes include the recognition and mapping of a sandstone facies of the Rhydings Formation as the now separately named Cefngarreg Sandstone Formation. An upper unit of the Cefngarreg Sandstone mapped on the Brecon Sheet (BGS, 2005b) is now confirmed as the equivalent of the Wormwood Formation of the south Llandovery area. The base of the Wormwood Formation has also been revised downwards to include the newly erected, mudstone-rich Ydw Member; significant as the unit in which *sedgwickii* Biozone graptolites first make their appearance in the Llandovery area.

The BGS mapping has revealed the presence of a series of progradational sequences (progrades), the bases of which overlie flooding surfaces (Figure 7). Each prograde comprises a coarsening upwards sequence from mudstone to sandstone, through sandy mudstones and muddy sandstones. Bioturbation is ubiquitous, but increases in intensity upwards within each prodrade sequence. The deepest facies are turbiditic and hemipelagic whereas the shallowest are shoreface in origin. Major flooding surfaces allow a sequence stratigraphy for the Type Llandovery to be erected (Figure 8), which though significantly different in detail, echoes the subdivisions first recognised by Jones (1925). The new mapping has also demonstrated that unconformities and compound non-sequences are a feature of proximal regions of deposition, in the north and south, and has shown that major slump units and slide planes are important, particularly in the distal facies of the central Llandovery area and in the upper parts of the succession (Figures 5, 7 and 9).

Key to the improved understanding of the basin architecture was the systematic collection of graptolite assemblages for correlation. The effort in the Llandovery area has sought to replicate this success in shelfal facies. Accordingly, the mudstone-prone, deeper and more off-shore facies that typically succeed the flooding surfaces were targeted for graptolite collection (Figures 6). The success of this strategy has permitted the distribution of the main Llandovery graptolite biozones to be charted (Figure 10) with significant differences compared to previously published accounts. In addition, systematic sampling for acritarchs and chitinozoans has allowed Hill and Dorning's acritarch biozonation to be tested and, for the first time, a chitinozoan biostratigraphy to be erected for the Type Llandovery succession (Figures 11 and 12). The fossil assemblages reported by Jones (1925, 1949), Williams (1951, 1953), Cocks et al. (1984) and also by Temple (1987) continue to provide essential data for correlation, and no systematic re-assessment of their brachiopod work has been attempted by BGS. Figure 13 synthesises the current biostratigraphical data for the Type Llandovery area including first appearance data (FAD) and last appearance data (LAD) for some of the key brachiopod taxa plotted against the new lithostratigraphy.

The success of the collecting strategy has underpinned significant and ongoing revisions to the geological map, stratigraphical and facies architecture and biostratigraphical framework for the Type Llandovery area. Much of this enhanced understanding is encapsulated in recent BGS publications for the region (British Geological Survey, 2005a and b; 2008; Barclay et al., 2005; Schofield et al., 2004; 2009b). The purpose of this guide is to document some of the key field

localities investigated as part of this study and to assess their significance for Llandovery stratigraphy, including the implications of some of the most recent discoveries within the type succession. A complementary field guide for basinal Llandovery facies in mid Wales is also available from BGS (Davies et al., 1999).

# 2 Itinerary

## 2.1 SECTIONS IN CRYCHAN FOREST (NORTHERN LLANDOVERY AREA)

The geographical positions of localities are shown on Figure 14 and their position in the stratigraphy on Figure 15.

### 2.1.1 Locality 1. Scrach track section [SN 8415 3942 – 8465 3959] GCR site (Figures 16 & 17)

This section was described by Cocks et al. (1984, Transect i1 and i2) as showing a conformable succession from the late Ashgill (Rawtheyan) Tridwr Formation through the latest Ashgill (Hirnantian) Scrach Formation to the early Llandovery (Rhuddanian) Bronydd and Crychan formations.

Davies et al. (2009) have reinterpreted the lower part of the succession (Figure 16) in the context of events associated with the Late Ordovician glaciation. A previously unrecognised angular unconformity between the Tridwr and Scrach formations is interpreted as the product of the intra-Ashgill Shelvian tectonic event (Toghill, 1992) as well as erosion during the glacioeustatic lowstand. Overlying the unconformity, the Cwm Clyd Sandstone Formation comprises a basal conglomerate, together with the succeeding 3 m of shallow water sandstones. The latter pass up conformably into dark grey mudstones and thin sandstones of the Garth House Formation. The Scrach Formation was interpreted as regressive and deposited during the end Ordovician (Hirnantian) glacioeustatic lowstand (Cocks et al., 1984), but the Cwm Clyd Sandstone and Garth House Formation are clearly transgressive and record the first post-glacial sea level rise. The term Scrach Formation has now been abandoned (see Davies et al., 2009, for fuller discussion).

Two localities within the section have been examined in detail. Firstly a small quarry at the base of the section (Locality 1a) and secondly the base of the Bronydd Formation (Locality 1b).

*Locality 1a. Small quarry at the base of the section*

This quarry (Figures 16 and 17) exposes steeply dipping, thinly interbedded sandstones and mudstones of the Rawtheyan Tridwr Formation. This is unconformably overlain by the transgressive Cwm Clyd Sandstone Formation, with its basal boulder conglomerate, and by the succeeding Garth House Formation.

The Tridwr Formation is dated by *anceps* Biozone graptolites elsewhere in the Type Llandovery area (Cocks et al. 1984). The Cwm Clyd Sandstone Formation contains an unidentified fragmentary shelly fauna, including brachiopods, preserved in decalcified sandstone that immediately overlies the basal conglomerate. The Garth House Formation has yielded no macrofauna, but casts of trace fossils are abundant on the bases of lenticular, commonly ripple-marked sandstone beds (see Locality 10). Both the Cwm Clyd Sandstone and Garth House formations are assumed to be late Hirnantian in age.

*Locality 1b. Base of the Bronydd Formation*

The contact between the barren dark grey, smooth mudstones and thin sandstones of the Garth House Formation and the grey bioturbated, shelly sandy mudstones of the Bronydd Formation is sharp. The basal bed of the Bronydd Formation is very sandy with dispersed granules. The coarser grain sizes, compared to the Garth House Formation, suggest a shallowing, but its sharp nature, together with regional correlations, point to the basal Bronydd contact being transgressive. The coarser basal bed may contain reworked material introduced during a preceding, but cryptic shallowing event.

The Garth House Formation is unfossiliferous apart from trace fossils. The *Hirnantia* fauna reported from the former Scrach Formation comes from elsewhere in the area, from synglacial regressive facies now termed the Cwmcringlyn Formation. A horizon low in the Bronydd Formation has yielded *Climacograptus normalis*, the morphology of which suggests a level no higher than the *acuminatus* Biozone and probably as low as the *persculptus* Biozone (Cocks et al. 1984). Brachiopods are relatively common.

### 2.1.2 Locality 2. Aeronian Stage basal stratotype [SN 8380 3953] - Trefawr track section GCR site (Figures 18 & 19)

The base of the Aeronian Stage was defined by Cocks et al. (1984) at the entry of the *triangulatus* Biozone graptolites within the sandy mudstones of the Rhuddanian to Aeronian Trefawr Formation. The base of the *triangulatus* Biozone is taken at the incoming of *Monograptus austerus sequens* at Locality 72 of Cocks et al. (1984) (Figures 18, 19). However, the LAD of the precursor *cyphus* Biozone subspecies, *M. austerus vulgaris*, is over 18m below the boundary stratotype. Accordingly, Temple (1988) has argued that there is insufficient precision in the faunal distributions to justify erection of the stage stratotype at this locality.

Facies at the stratotype locality are noticeably coarser grained than adjacent parts of the Trefawr Formation and comprise bioturbated muddy sandstones with scattered angular coarse sand grains and granules. These strata are viewed as an early prograde of Cefngarreg Sandstone facies following the contraction and abandonment of the sand-prone Crychan/Goleugoed system during the upper part of the *cyphus* Biozone (see Figures 5 & 6).

### 2.1.3 Locality 3. Coed Cochion viewpoint [SN 8347 3920] – the missing stratigraphy (Figure 20)

View looking north-westwards across the Ashgill shelf and slope succession present beneath the Type Llandovery and towards the Tywi Anticline in the far distance (see Figure 14).

The Ashgill rocks preserved beneath the unconformity at Locality 1 belong to the pre-glacial maximum (Rawtheyan) Tridwr Formation. Traced westwards across the Crychan Fault Belt, the Ashgill succession expands beneath the Cwm Clyd Sandstone/Garth House Formation to include some 1.2 km of strata not seen at Locality 1. This includes the glacio-regressive Hirnantian Cwmcringlyn and Ciliau formations and the early to mid Ashgill, Cribarth and Nantmel formations (see Schofield et al. 2009b). The valley in the foreground follows the line of one of the Crychan Fault strands which appears to have been active during the Shelvian tectonic event and, subsequently, to have influenced the pattern of erosion and overstep associated with the glacio-eustatic lowstand (Davies et al., 2009). The Tywi Anticline is cored by basinal Ashgill sediments.

### 2.1.4 Locality 4. Cwm-coed-oeron track section [SN 8338 3889 – 8375 3903] GCR site (Figure 21a)

This section (also known as Cwm-coed-Aeron in other accounts) was described by Cocks et al (1984, Transect i3) as showing sandy mudstones of the Trefawr Formation passing up into sandy mudstones and muddy sandstones of the Rhydings Formation. The two facies of the Rhydings Formation have been mapped separately by BGS, the sandy mudstones retaining the name Rhydings Formation and the muddy sandstones and sandstones being assigned to a new division, the Cefngarreg Sandstone Formation. In the northern Llandovery area, as at this locality, the Cefngarreg Sandstone is dominant.

A few metres of Trefawr Formation are seen at the base of the section, the junction with the overlying Cefngarreg Sandstone being gradational. The basal levels of the latter comprise pebbly and gritty muddy sandstones which pass up into sandstones with sparse pebbles at the top (Figure 21a). The Cefngarreg succession becomes cleaner and less gritty upwards, but displays high levels of burrow-mottling throughout. It represents the lowest of the three sandy progradations present in the formation in the northern Llandovery area (Figure 6). Apart from widely spaced master bedding planes and pervasive burrow-mottling, there are few internal sedimentary structures. The fabric of the sandstones has been attributed to bioturbation that has homogenised a primary facies of interbedded pebbly sandstones and subordinate mudstones. There are several problems with this interpretation and the suggestion that the sandstones represent mass flow deposits is under consideration.

The Cefngarreg Sandstone is poorly fossiliferous, but brachiopods are locally present. Graptolites reported by Cocks et al. (1984) from the locality include *Rastrites linnaei, Orthograptus bellulus, Monograptus* sp. and *Glyptograptus* sp., but this fauna has been lost. Cocks et al. (1984) placed the base of the *sedgwickii* Biozone at the base of their Rhydings Formation (here broadly equivalent to the Cefngarreg Sandstone), but evidence from elsewhere suggests that *sedgwickii* Biozone faunas enter at a much higher level, at the base of the Wormwood Formation. All three Cefngarreg Sandstone progradations therefore probably lie within the *convolutus* Biozone (Figure 10).

### 2.1.5 Locality 5. Coed Glyn-moch track section [SN 8158 3760 – 8195 3765] GCR site (Figures 21b to 24)

This track cutting was described by Cocks et al. (1984, Transect f3) as Rhydings Formation overlain successively by the Wormwood and Cerig formations. As the Rhydings Formation here comprises muddy sandstones, it has been reclassified as Cefngarreg Sandstone Formation by BGS.

At the base of the eastward-younging section are steeply dipping, burrow-mottled sandstones at the top of the Cefngarreg Sandstone. These are overlain by 21 m of heterolithic facies comprising thin bedded, fossiliferous and variably bioturbated, dark grey mudstones, siltstones and muddy sandstones, punctuated by a unit of thick bedded, gritty and pebbly sandstone, that comprise the basal Ydw Member of the Wormwood Formation (Figure 21b). A *sedgwickii* Biozone graptolite fauna has been obtained from near the base of the member (Figure 22). The remaining part of the Wormwood Formation comprises well bedded to thick bedded, bioturbated, muddy fine grained sandstones, with relict, only partially burrowed sandstone beds. Dips increase and bedding becomes overturned towards the east.

The upper part of the Wormwood Formation is truncated by a synsedimentary slide, overlain by a chaotic sedimentary mélange. Note, however, that because of the inverted nature of the strata, the truncated Wormwood Formation occupies the upper part of the track cutting (Figure 21b, 23 & 24). At the base of this disturbed unit are contorted rafts of interbedded sandstone and mudstone, together with pillows and blocks of sandstone set in a dark grey mudstone matrix (Figure 24). The upper part of the mélange comprises disturbed dark grey mudstone with widely scattered ‘clasts’ of sandstone. The basal slide plane can be seen to cut down into the structurally inverted Wormwood

Formation by at least 60 m (Figure 23), suggesting that it represents the margin of a major synsedimentary submarine landslide. The slide complex extends for 3 km to the south-west and locally affects the whole of the Wormwood Formation. Overlying the disturbed unit are undisturbed, green-grey, burrow-mottled mudstones of the Telychian Cerig Formation. Cocks et al. (1984) recovered a specimen of the long-ranging graptolite ?*Pseudoclimacograptus* sp. from this level. The slide was probably initiated sometime during the deposition of the latest Wormwood Formation or earliest Cerig Formation.

### 2.1.6 Locality 6. Fire Tower Hill track section [SN 8534 3848 – 8540 3843] (Figures 25 & 26)

This is the lower part of Transect 'n' of Cocks et al. (1984). The late Aeronian Derwyddon Formation occupies the core of a south-westerly plunging anticline within the Pen-y-waun Fault Belt. The formation unconformably overlies the mid to late Ashgill Tridwr Formation (not seen at his locality) and is overlain by the Telychian Cerig Formation for which this is the new type section (see Locality 7).

The Derwyddon Formation comprises a fining-upwards succession of transgressive, shallow water sandstones. Locally gritty and pebbly in the lower part, the sandstones become finer and thinner bedded upwards. Burrowing and mud content increase upwards. The brachiopod fauna is represented by a shallower assemblage than the contemporaneous assemblages to the west (Cocks et al. 1984), with the distinctive 'arrow-head' moulds of *Pentamerus oblongus* particularly common in lenticular coquinas (Figure 26).

The underlying unconformity is probably compound, reflecting several periods of footwall uplift on the Pen-y-waun Fault Belt, ranging from intra Ashgill (Shelvian) to Aeronian. Cocks et al. (1984) regarded the Derwyddon Formation here as coeval with the Wormwood Formation to the west of the fault belt and there is no reason to dispute this. A *sedgwickii* Biozone age would accord with the formation's transgressive motif.

The green-grey, burrow-mottled mudstones of the Cerig Formation sharply overlie the Derwyddon Formation. Cocks et al. (1984) obtained *Monograptus runcinatus* from near the base of the Cerig Formation at this locality, suggesting the early *turriculatus* Biozone s.l. During the present work, *Spirograptus guerichi* (Figure 25) was found within 3m of the base of the formation, confirming a *guerichi* Biozone age (= early *turriculatus* Biozone s.l.). The Cerig Formation has been widely used on published maps and in accounts throughout mid Wales, but discoveries made at Cefn Cerig (Locality 7) demand that this now be abandoned as the formation's type section. The Fire Tower Hill track section offers a preferred, well-dated and exposed alternative in the Llandovery region. The introduction of the Cerig Formation offshore shelf muds appears to record a further deepening event.

## 2.2 SECTIONS IN THE MYDDFAI-LLANGADOG AREA (SOUTHERN LLANDOVERY AREA)

The geographical position of localities is shown on Figure 14 and their position in the stratigraphy on Figure 15.

### 2.2.1 Locality 7. Upper part of Cefn–Cerig (or Fron) road section [SN 774 334 – 775 323] GCR site (Figures 27 to 32)

This locality was described by Cocks et al. (1984, Transect 'd3') as a series of quarries and road sections traversing the upper part of the Wormwood Formation and the lowermost part of the overlying Cerig Formation, for which this was the type section (see below). The BGS mapping (British Geological Survey, 2008) depicts a similar relationship. A quarry in the uppermost part of the Wormwood Formation contains the Telychian basal stratotype (Figures 28 & 29).

*Locality 7a. Basal Telychian stratotype quarry [SN 7743 3232].*

The quarry exposes steeply dipping, well-bedded, bioturbated, muddy sandstones and sandy mudstones of the Wormwood Formation. The base of the Telychian is taken within a 29 cm thick bed of bioturbated siltstone, below which a fossiliferous rottenstone horizon has yielded the highest records of the Aeronian brachiopod taxa *Eocoelia intermedia* and *Stricklandia lens progressa* (Figures 28 & 29); this is locality 162 of Cocks et al. (1984).

*Locality 7b. Road section and old farm entrance track [SN 7742 3231]*

In the adjacent road section, from a level 45 m stratigraphically above the stratotype boundary (their locality 163), Cocks et al. (1984) obtained brachiopods said to be diagnostic of the Telychian Stage, specifically *E. curtisi* and *S. laevis* (Figure 30); and it was from this level that Hill and Dorning (Cocks et al., 1984, Appendix 1) obtained a *monospinosa* Biozone acritiarch assemblage. However, a detailed re-examination of the section requires the significance of these faunas to be challenged.

The discontinuous road section begins 22.5 m above the basal Telychian stratotype (Figure 30). The Wormwood Formation is terminated by a sharp cross-cutting contact (Figure 27) above which is a c. 40 m-thick sequence that includes three separate levels of Builth Mudstones Formation, interleaved within a slide-disturbed succession. The section is clearly inappropriate as a type locality for the Cerig Formation, and a new well-dated and undisturbed type section (see Locality 6 above) has now been selected. The lowest unit of Builth Mudstones yields *riccartonensis* Biozone graptolites (Figure 31) and *margaritana* Biozone chitinozoans; the upper unit contains a possible *dubius* Biozone fauna (Figure 32). The sharp basal contact is interpreted as a major slide plane above which is a stack of slump sheets incorporating both pre- and post-Cerig Formation strata. The evidence here and elsewhere suggest that this slide event occurred during the mid Wenlock *dubius* Biozone.

The highly fossiliferous muddy sandstones and sandy mudstones on the west side of the road, which comprise locality 163 of Cocks et al. (1984) (identified during the LRG field meeting), are now known to be part of this complex, slump/slide disturbed succession (Figure 30). The sandy mudstones with abundant yellow-weathering shell debris and discontinuous shell beds (coquinas) are in fact very similar to parts of the underlying Wormwood Formation, but also present are units of slump-disturbed and recrystallised laminated mudstone (?Builth Mudstones), thinly interbedded laminated and burrow-mottled mudstone (?Dolfawr Formation), and unfossiliferous pale green mudstone with phosphate nodules (?Cerig Formation). Bedding orientations vary widely and the contacts between the various lithologies are commonly cross-cutting. The reported *E. curtisi* and *S. laevis* clearly came from the shelly facies, but their stratigraphical relevance must now be questioned, as must the position and composition of the *monospinosa* acritarch Biozone within the Type Llandovery succession. Chitinozoans newly recovered from this part of the section, including *Eisenackitina ithoniensis*, are more consistent with a Wenlock age (Figure 30), but it is unclear whether these record the age of the ‘matrix’ or of a ‘clast’ within a mélange that includes rafts of different age and lithostratigraphical provenance.

### 2.2.2 Locality 8. Penlantelych Farm – viewpoint [SN 7846 3338] and Wormwood/Cerig Formation contact [SN 7864 3345] (Figure 14)

The viewpoint, situated on the Wormwood Formation, looks northwest over the ridges formed by late Hirnantian regressive facies and the Llandovery progradations of the Cefngarreg Sandstone. Beyond to the west lies the Ashgill shelf/slope succession and the town of Llandovery; to the east is the local, much disturbed, Wenlock and Ludlow succession.

The Wormwood/Cerig formation contact is exposed in a small enclosure behind the farm. The contact is a slide plane with slumped and disturbed Cerig Formation overlying bedded Wormwood Formation.

### 2.2.3 Locality 9. Mandinam [SN 7365 2813] (Figures 33 &34)

In this area, the latest Ashgill and Type Llandovery succession thins westwards as a result of internal attenuation and unconformities. It is finally terminated to the west by several faults.

*Locality 9a. New excavation [SN 7372 2801] across Cerig/Builth Mudstones Formation contact.*

The base of the Builth Mudstones Formation (formerly Gwernfelen Formation) was assumed by Cocks et al. (1984) to be conformable in the Llandovery area.

The excavation in beds that dip steeply to the north, but are inverted, exposes green, grey, burrow-mottled Cerig Formation mudstones apparently conformably overlain by brown-weathered anoxic laminites of the Builth Mudstones Formation. The laminates, however, yield mid Wenlock (*dubius* Biozone) graptolites (Figure 33), suggesting that the lower Wenlock is missing due to slumping and that the contact is a sedimentary slide, draped by mid Wenlock facies. Shelly oxic mudstones overlie the laminates and though undated, are similar to those developed in the Wenlock succession over the adjacent Llandeilo 'high'.

*Locality 9b. Track side quarry by Afon Bran (River Sefin of earlier accounts) [SN 7421 2815]*

The quarry exposes highly fossiliferous, dark grey, bioturbated, muddy sandstones of the Wormwood Formation which dip steeply to the north-west, but are structurally inverted. Graptolites of *sedgwickii* Biozone age (Figure 34) are common in the pyritic sandstones, together with a rich shelly fauna that includes abundant *P. oblongus* and *E. hemisphaerica*. The stratigraphically underlying grey-green mudstones with bioturbated beds of shelly sandstone exposed in the adjacent track floor and tributary stream are the 'Sefin Shales' of Williams (1951). In addition to a rich brachiopod fauna which includes *Stricklandia lens progressa, E. hemisphaerica* and abundant *Leptostrophia tenuis*, these strata also contain *sedgwickii* Biozone graptolites and, though previously included in Jones' (1925) $C_1$ division, are now viewed as the local representative of the transgressive Ydw Member at the base of the Wormwood Formation (Figure 6).

## 2.3 ASHGILL TO LLANDOVERY SUCCESSIONS OF THE GARTH INLIER AND BUILTH ORDOVICIAN VOLCANIC INLIER.

The geographical positions of localities are shown on Figure 35 and their position in the stratigraphy on Figure 36. A summary of the Llandovery succession in both inliers is included in Davies et al. (1997) and Schofield et al. (2004). For the geological map of the area see British Geological Survey (2005a).

### 2.3.1 Locality 10. Garth House quarry [SN 9248 4995] (Figures 37 & 38)

The quarry provides a section through the Rawtheyan Cribarth Formation overlain unconformably by the late Hirnantian Cwm Clyd Sandstone and Garth House formations. The Cribarth Formation comprises thoroughly bioturbated, shelfal, sandy mudstones with a shelly fauna that includes brachiopods and trilobites. The Cwm Clyd Sandstone comprises a post-glacial transgressive unit which fines upwards from conglomerate into sandstones. The distinctive, smooth, dark grey mudstones and thin, lenticular, ripple marked sandstones (Figure 37) of the Garth House Formation are unfossiliferous, apart from abundant trace fossils on the sandstone bedding planes (Figure 38). In common with Locality 1a, the early Hirnantian glacial lowstand sequence is absent here due to associated erosion of the emergent shelf, combined with

the effects of an intra-Ashgill (Shelvian) episode of fault-related deformation and uplift (see Locality 1a).

### 2.3.2 Locality 11. Crags and view point [SN 9545 5310] at Penrhiwmoch (Figure 35)

The crags expose the early Hirnantian synglacial succession (Ciliau Formation) between the Cribarth Formation and the Cwm Clyd Sandstone Formation. Trenching by BGS and Liverpool University in 1999 exposed the entire succession apart from the slack beneath the Cwm Clyd Sandstone. The succession coarsens upward from sand laminated sandy mudstones into shelly and bioturbated thin bedded sandstones and mudstones. Rawtheyan brachiopods were obtained from the uppermost part of the Cribarth Formation in the trench. The Ciliau Formation crags on the spine of the hill yielded an *Hirnantia* fauna to Williams and Wright (1981). The contact between the Ciliau Formation and the Cwm Clyd Sandstone is unconformable.

From the viewpoint, the craggy ground of the Cribarth Formation and the Cwm Clyd Sandstone can be seen. Traced north towards the basin, the crops of these two formations diverge, letting in an increasing amount of synglacial distal shelf and slope stratigraphy (Figure 35). This expanding succession becomes increasingly disturbed as it is traced basinwards. Two progradations, separated by a mud-prone interval, are identified (Figure 36). The proximal part of the lower one is exposed in the crags at Penrhiwmoch; the upper one is capped by the shallow water Cwmcringlyn Formation.

### 2.3.3 Locality 12. Comin Coch [SN 9562 5200] (Figures 35 & 36)

*Locality 12a. Roadside crag*

The late Rhuddanian sandy mudstones of the Trefawr Formation are bioturbated and contain scattered pebbles. A rich brachiopod fauna is present. Graptolites include abundant *Rhaphidograptus toernquisti*, and also cf. *Pribylograptus sandersoni* and *Climacograptus* ex. gr. *innotatus*, suggesting an *acinaces* or *cyphus* Biozone age.

*Locality 12b. Hillside crags*

The transgressive, late Aeronian Tyncoed Sandstone Member (also known as the Pentamerus Grit) lies unconformably on the Trefawr Formation. Erosion associated with the unconformity was responsible for the absence of the early and mid Aeronian part of the Trefawr Formation. About a kilometre to the south-west, the Trefawr Formation is cut out completely and the Tyncoed Sandstone rests on the Crychan Formation. The Tyncoed Sandstone can be regarded as an attenuated correlative of the Derwyddon Formation of the Llandovery area (see Locality 6). It contains disarticulated valves of *Pentamerus oblongus*.

*Locality 12c. Roadside pits*

This strike section exposes the bioturbated, shelly, green-grey, gritty and pebbly mudstones of the Comin Coch Formation that overlies the Tyncoed Sandstone. A single specimen of *M.* cf. *sedgwickii* supports a late Aeronian *sedgwickii* Biozone age. This unit is the likely correlative of the Ydw Member (Wormwood Formation) of the Llandovery area (see Locality 5).

*Locality 12d. Quarry [SN9268 5204]*

The Comin Coch Formation seen in Locality 3c coarsens up into the Tymawr Sandstone Formation seen in the quarry. Thick bedded, fine to coarse grained, poorly sorted sandstone with dark burrow mottles passes up into thin to medium bedded muddy sandstones with stringers and thin beds of granule conglomerate. The Tymawr Sandstone is viewed as a correlative of the Wormwood Formation of the Llandovery area.

The low ground to the east of the quarry is overlain by the green mudstones of the Telychian Cerig Formation that represents renewed transgression. Although no graptolites have been obtained from the basal part of the formation in the Garth area, there is no evidence to suggest that the contact, as at Locality 6, is other than conformable.

### 2.3.4 Locality 13. Afon Chwefri, east of Brynieuau [SN 9726 5676 - 9734 5661] (Figure 39)

The Chwefri valley exposes some of the most distal late Ashgill (Hirnantian) and early Llandovery facies in the Garth Inlier (Figure 39). The steeply dipping, eastwards-younging succession exposed in the stream begins in the post-glacial part of the Yr Allt Formation that comprises dark grey silty mudstones with thin sandstones. It is abruptly overlain by the Mottled Mudstone Member, a unit of pale grey burrow-mottled mudstones that form a widespread marker in the basin. The '*persculptus* band', a thin unit of anoxic hemipelagites that is typically present in the lower part of the member, is not developed here. The member, which records a widespread basin ventilation event, correlates with the burrow-mottled Ystradwalter Member and basal Bronydd Formation (see Locality 1b) of the Type Llandovery shelf succession (Davies et al., 2009).

Overlying the Mottled Mudstone Member is the late Hirnantian to Rhuddanian Tycwtta Mudstones Formation, a thick slope deposit of interbedded oxic and anoxic hemipelagites and turbidite mudstones. Slumping is widespread, and bedding is commonly absent. Graptolites from the basal 100m of the Tycwtta Mudstones suggest the *persculptus* or *acuminatus* Biozone.

In about the middle of the Tycwtta Mudstones is an impersistent mass flow unit, the Allt-y-clych Conglomerate Member, which can be followed across country for some 6 km (Figures 35 & 39). The geometry of this turbidite conglomerate suggests that for much of its outcrop it occupies a NW/SE orientated channel within the confining slope succession. However, the Chwefri section exposes the feather edge of the unit and here tabular bed geometries and finer grain sizes suggest deposition in an unconfined, overbank setting. Graptolites from the Tycwtta Mudstones suggest that the Allt-y-clych Conglomerate is either *acinaces* or *cyphus* Biozone in age.

### 2.3.5 Locality 14. Trecoed [SO 0530 5530], Builth Wells (Figure 36)

This locality is situated on the western side of the Builth Ordovician Volcanic Inlier. It exposes the thinnest (14 m) late Llandovery Cerig Formation succession in mid Wales. At the base, 4.5 m of transgressive, dark grey, pyritic, shelly bioturbated sandstones (Trecoed Sandstone Member) unconformably overlie Llanvirn black mudstones of the Builth Inlier. The overlying 9 m of unfossiliferous green-grey and grey mudstones with local burrow mottles are capped by the late Telychian/early Wenlock '*Acidaspis* Limestone' (0.8 m), a distinctive, green, fossiliferous mudstone (Davies et al., 1997). The succeeding finely laminated and graptolitic Builth Mudstones Formation records hemipelagic deposition during the *centrifugus* Biozone.

The basal transgression is dated as late Aeronian on the brachiopod fauna which includes *Stricklandia laevis,* but also an earlier subspecies, either *S. lens progressa* or *intermedia*, suggesting that the remainder of the condensed Cerig Formation spans the Telychian. The condensed nature of the mudstone succession at Trecoed, including the capping *Acidaspis* Limestone, is thought to relate to its position on a Builth bathymetric 'high' that was sustained by footwall uplift on the NE/SW-trending faults that flank the western side of the inlier. To the west, the Cerig Formation thickens rapidly to about 250 m.

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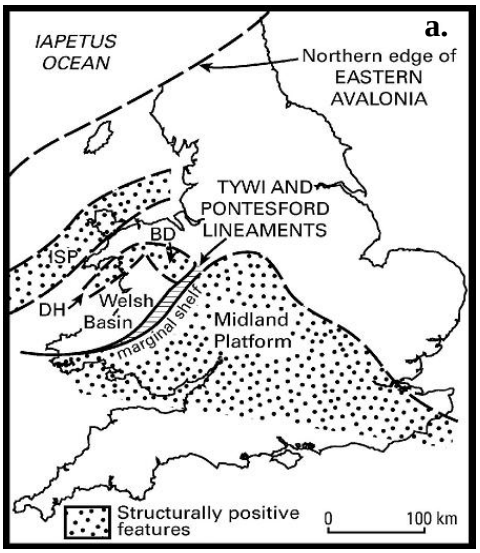
# FIGURES



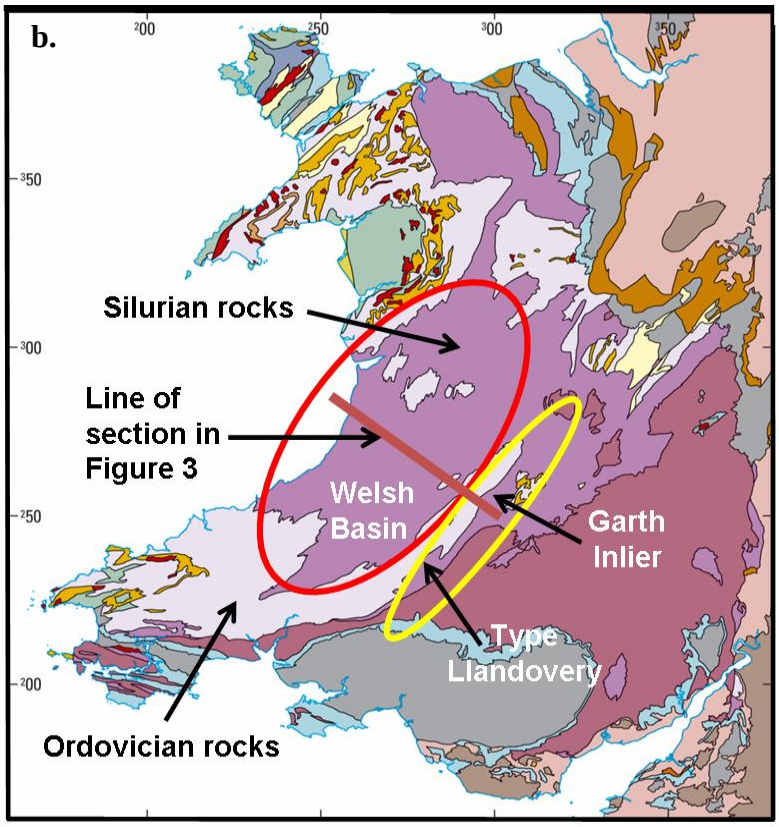




Figure 1. Location and context of the Llandovery Series in central Wales: a) Setting of the Welsh Basin in the early Silurian (after Davies et al., 2009) (BD, Berwyn Dome; DH, Derwen Horst; ISP, Irish Sea Platform); b) Geological map of Wales showing position of the Type Llandovery area and the Garth Inlier.

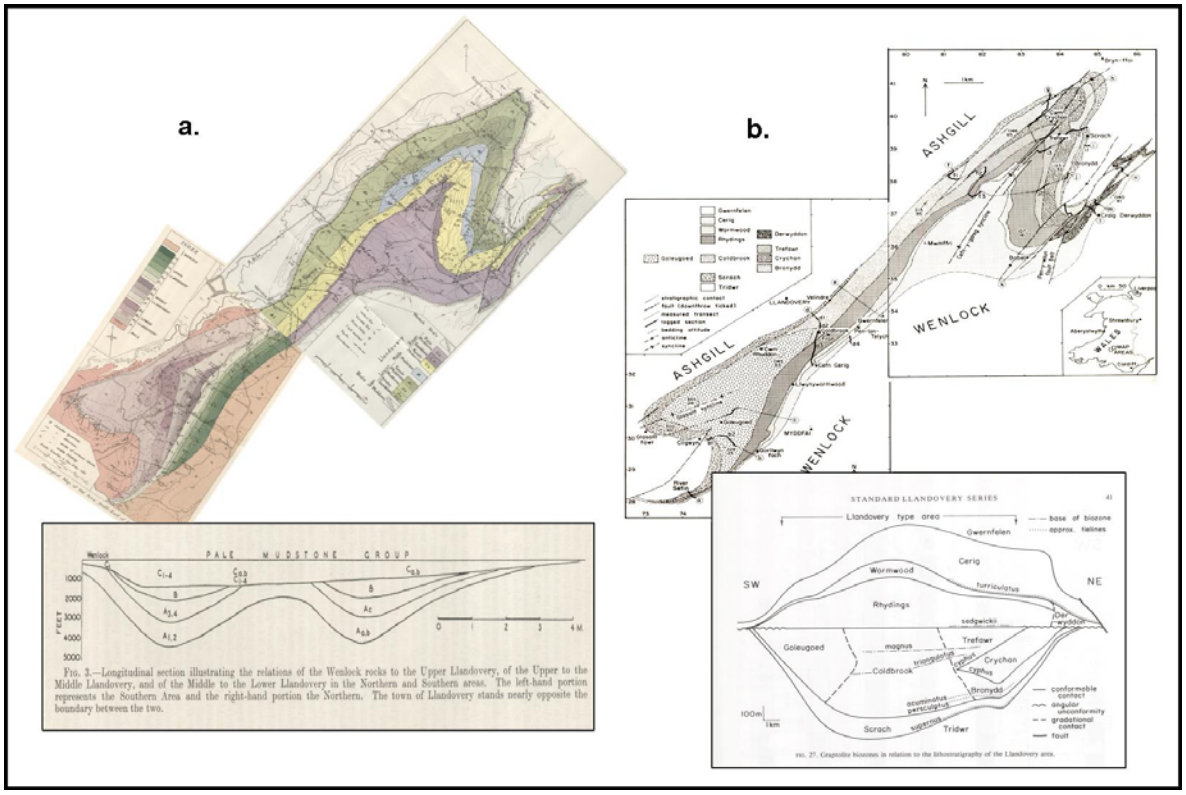



Figure 2. Previous geological maps and stratigraphical architectures for the type Llandovery area: a) Jones (1925; 1949); b) Cocks et al. (1984); see original sources for keys to symbols, ornaments and colours. The maps and section in Figure 2a are reproduced by permission of the Geological Society of London; those in Figure 2b are reproduced by permission of the Natural History Museum, London.

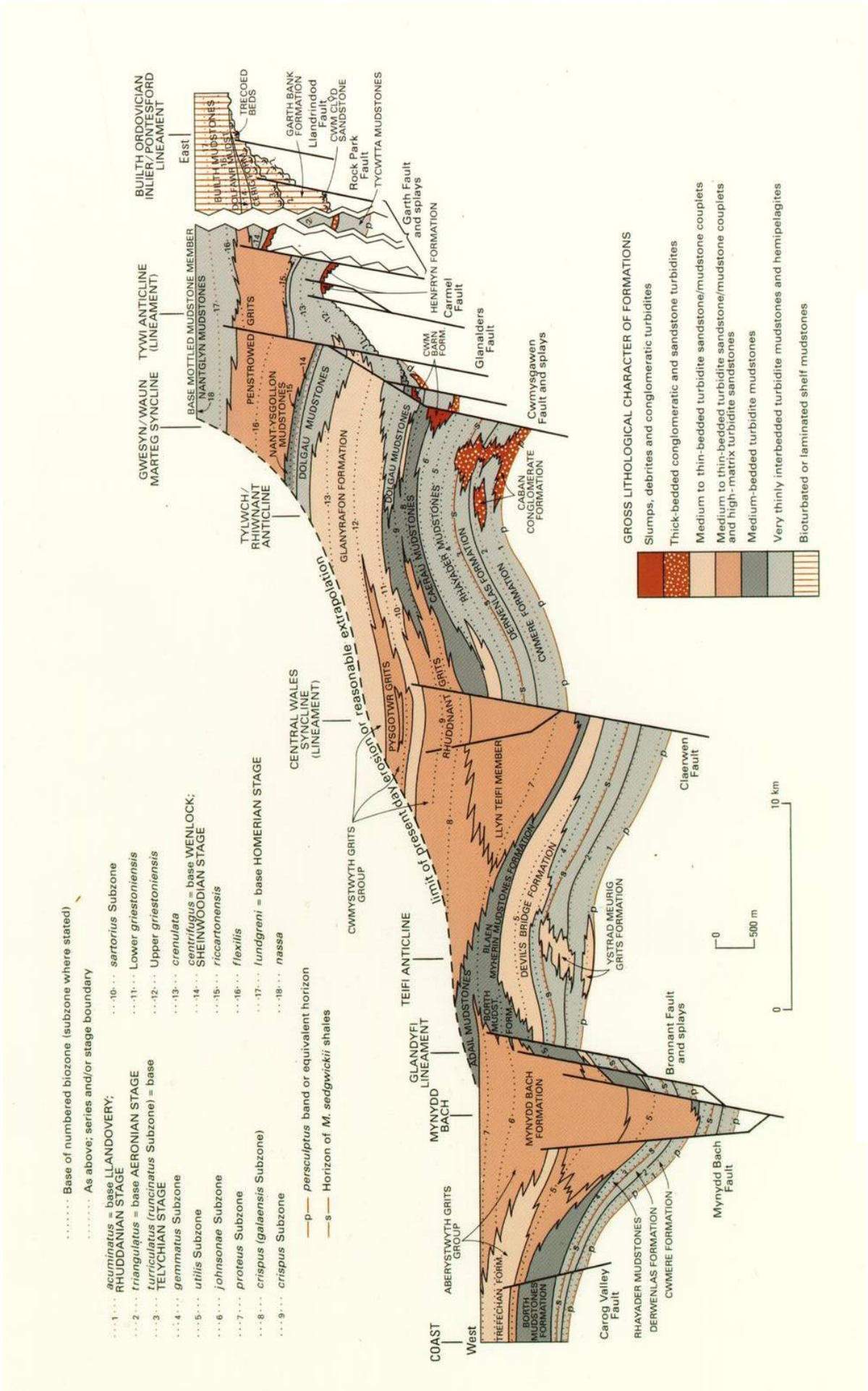



Figure 3. Schematic pre-Acadian cross section across the central part of the Welsh Basin showing stratigraphic and facies architecture (after Davies et al., 1997). For line of section, see Figure 1.

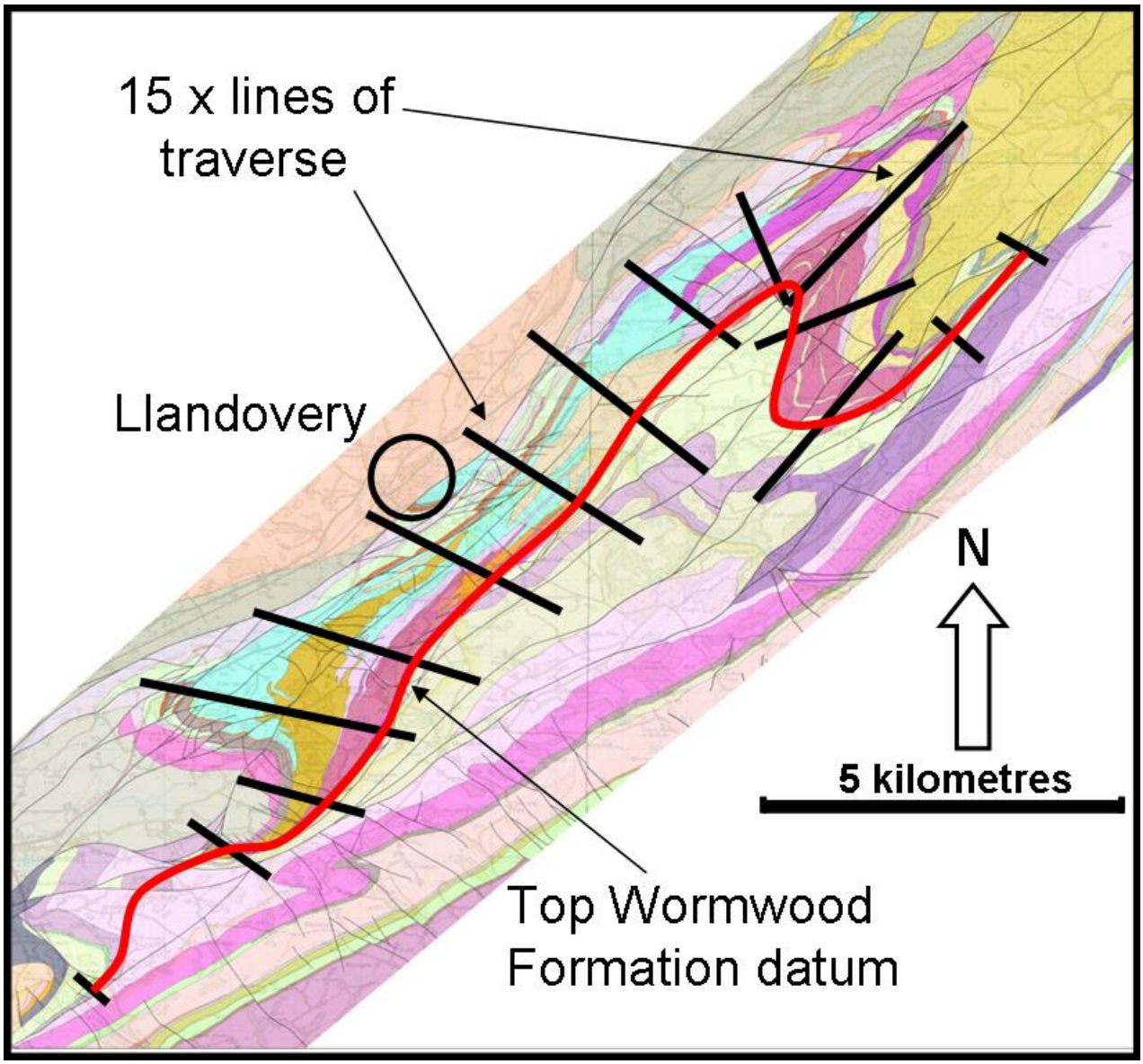



Figure 4. New geological map of the Llandovery type area (based on BGS, 2005a & b; 2008), showing the lines of traverse used in Figure 5 (numbered 1-15, south to north). See published maps and Figures 5 and 6 for keys to colours.

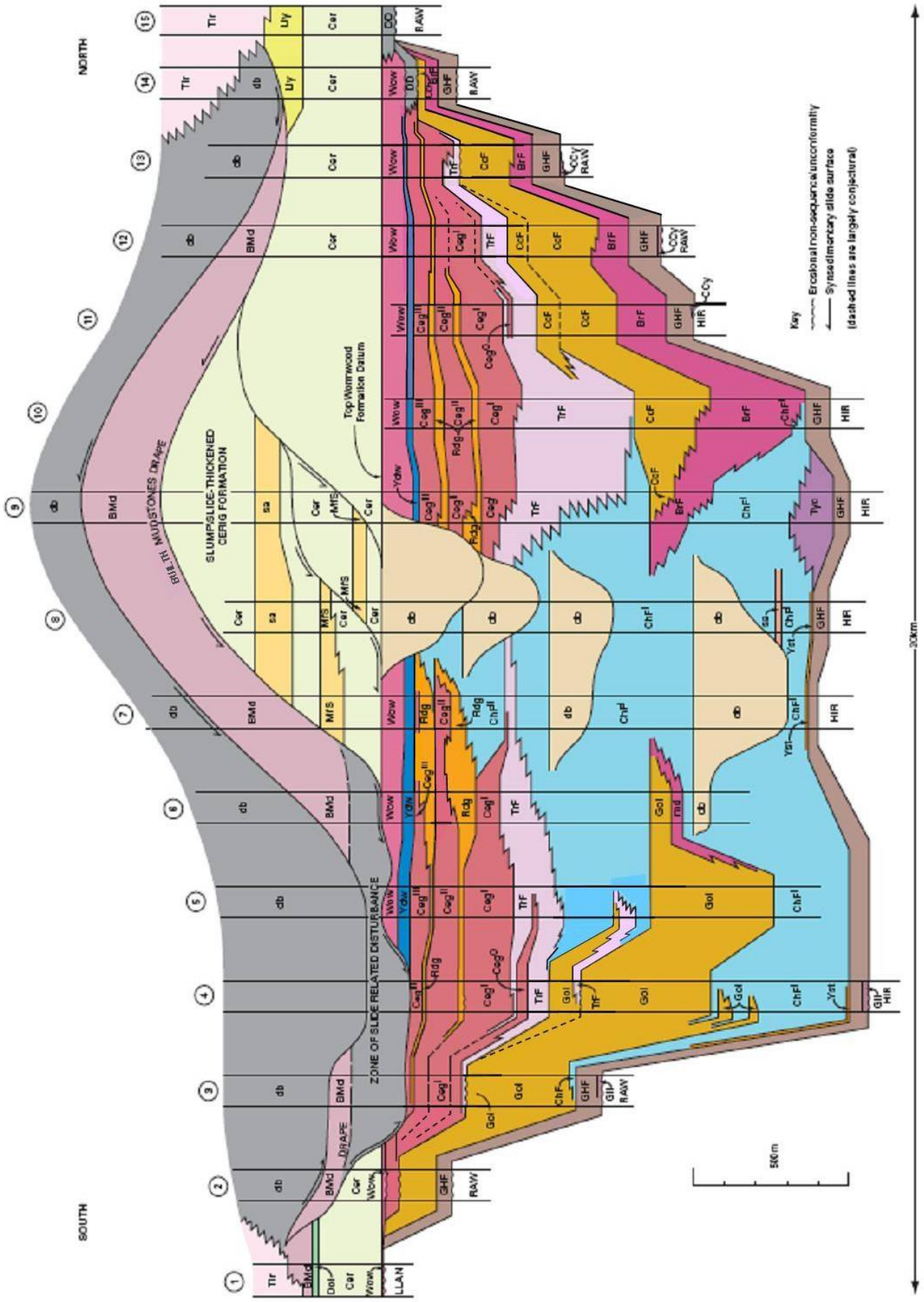



Figure 5. New architectural model for the Type Llandovery succession; see Figure 6 for key to names and colours and Figure 4 for location of lines of traverse (DD, Derwyddon Formation; Tir, Tirabad Formation; Tyc, Tycwtta Mudstones Formation; HIR, synglacial Hirnantian facies; LLAN, Llandeilo rocks; RAW, Rawtheyan rocks; lower sa unit in Cerig Formation is Mwmffri Sandstone Member (MfS) of Figure 6)

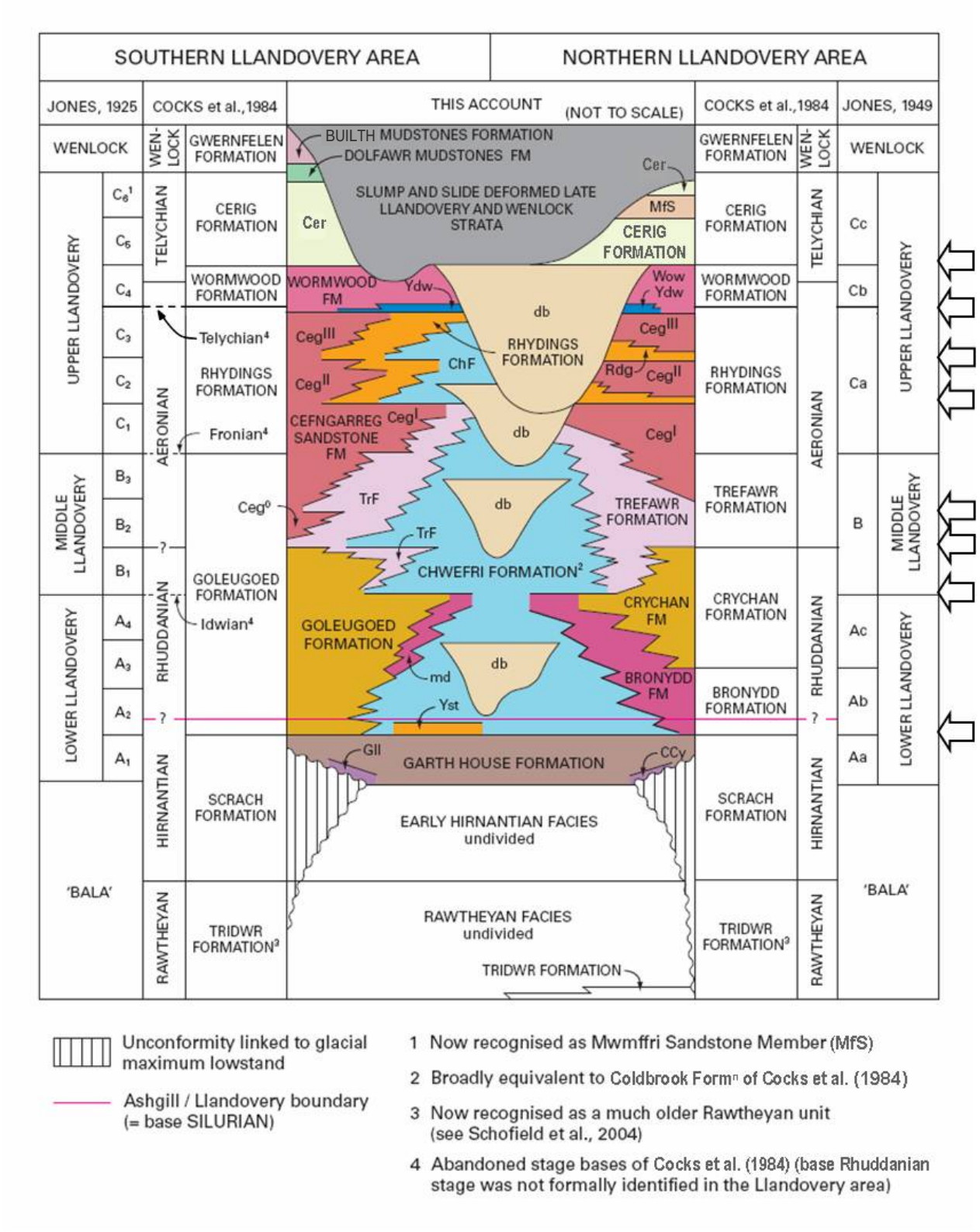



Figure 6. New and previous lithostratigraphical classifications of the Llandovery type area (significantly modified after Schofield et al. (2009b) (CCy, Cwm Clyd Sandstone Formation; db; 'disturbed beds'; Gll, Glasallt-fawr Sandstone Formation; md, sandy mudstones in the Goleugoed Formation; Ydw, Ydw Member of Wormwood Formation; Yst, Ystradwalter Member of Chwefri Formation) (Derwyddon and Tycwtta Mudstones formations omitted, see Figure 5). Arrows on right indicate some of the major flooding surfaces targeted for biostratigraphical sampling.

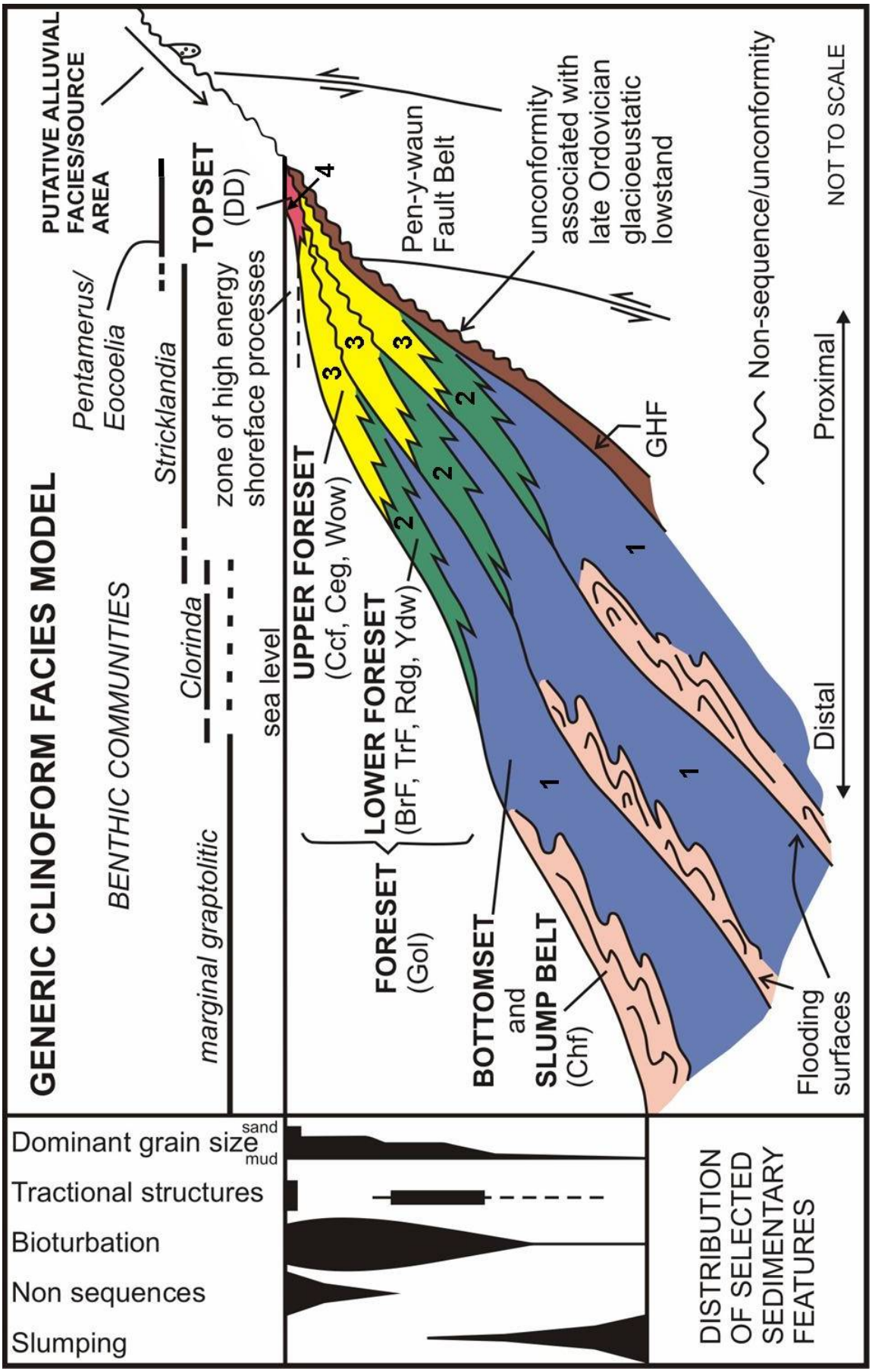



Figure 7. Generic clinoform model for the type Llandovery area showing relationships of facies, formations and faunal communities (for key to symbols see Figures 5 and 6). 1- silty mudstones, 2- sandy mudstones, 3- muddy sandstones, 4- shelly sandstones.

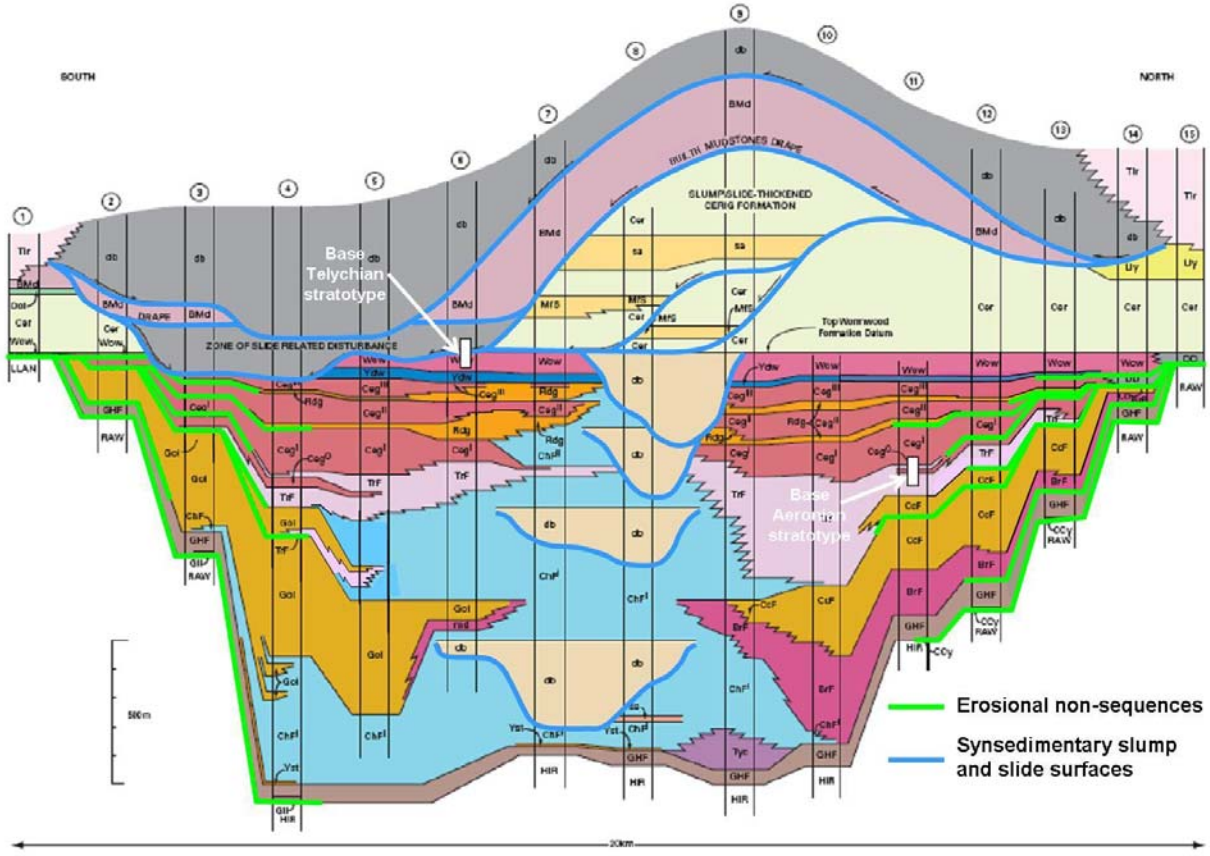



Figure 8. Stratal loss in the Llandovery type area showing the position of synsedimentary slumps and slide surfaces, and main erosional non-sequences (see Figures 5 and 6 for key to symbols and colours).

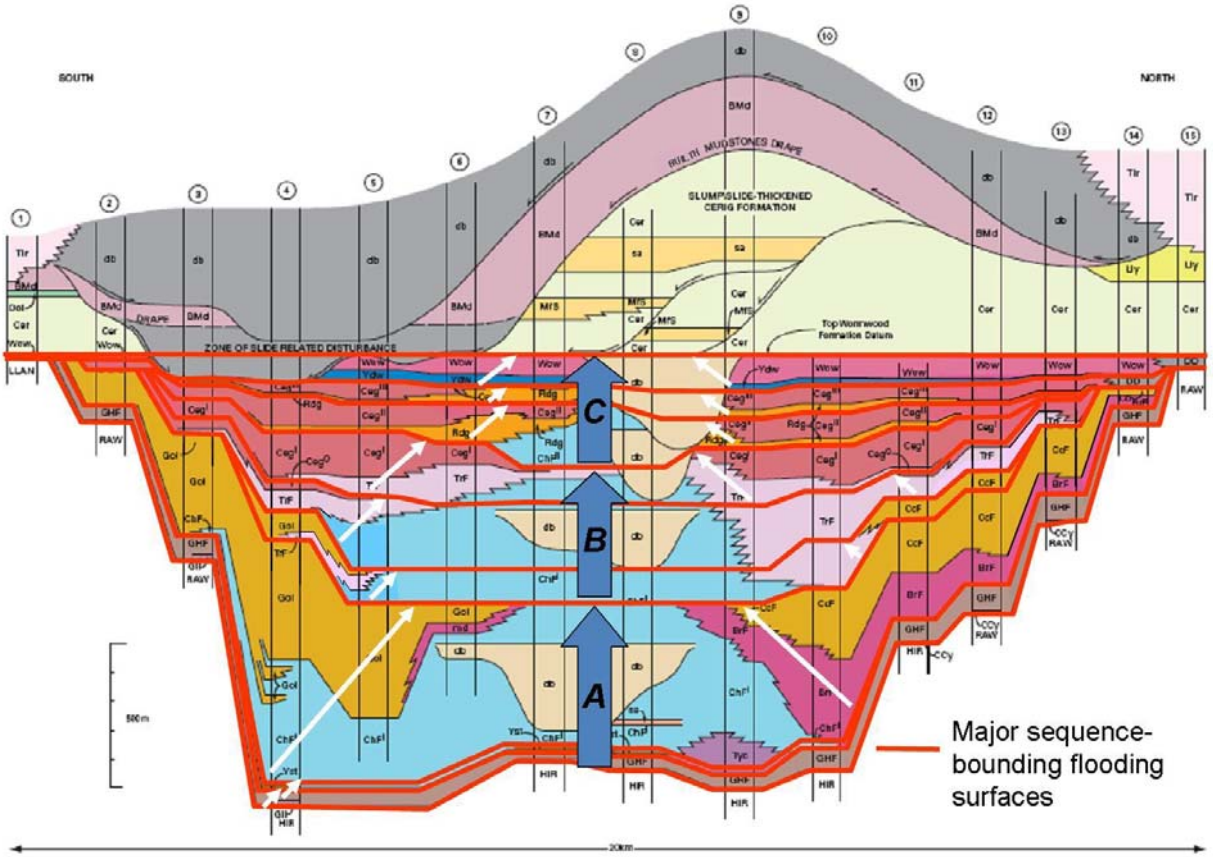



Figure 9. Late Hirnantian to Aeronian sequence stratigraphy for the type Llandovery area. Progradational sequences (white arrows) can be grouped into three compound sequences *A* to *C* (blue arrows) (cf. Jones, 1925; lowermost sequences are discussed by Davies et al., 2009).

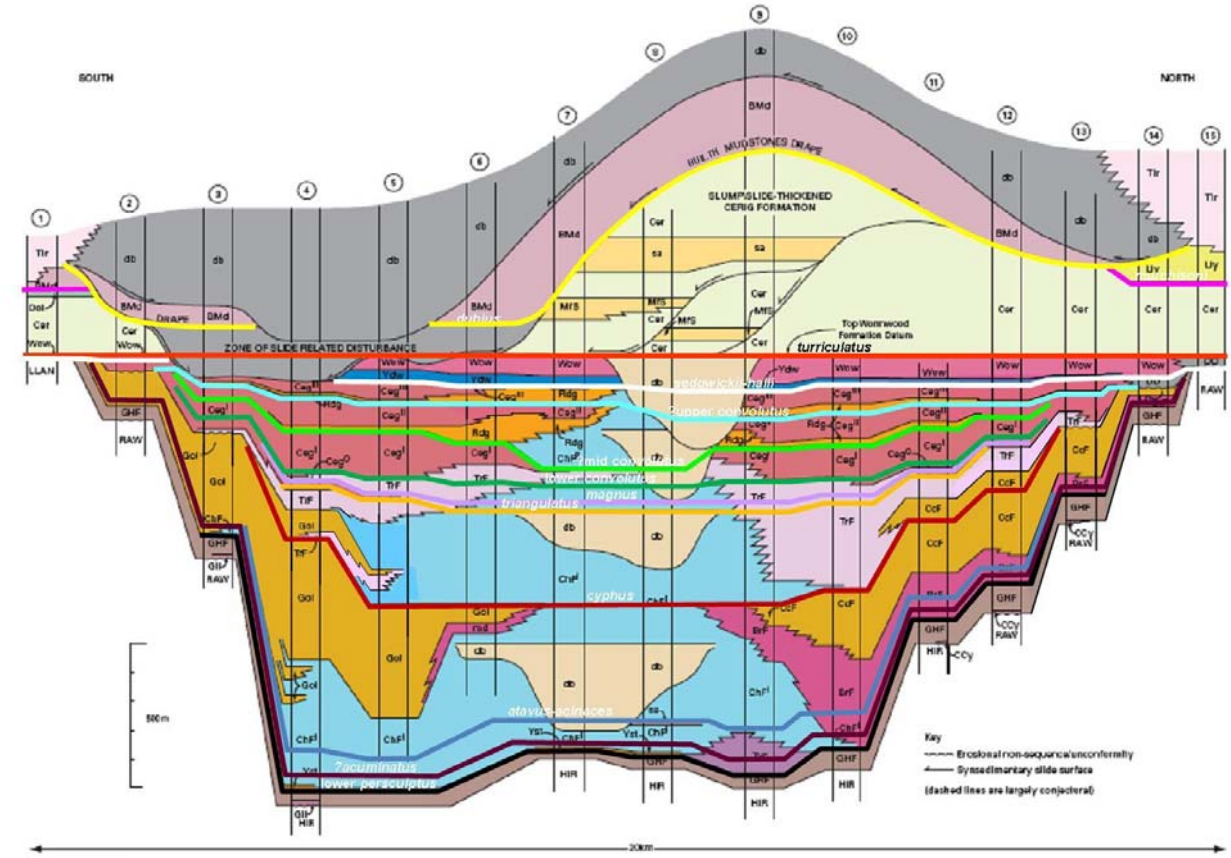



Figure 10. Revised position of graptolite biozones in the Type Llandovery area (see Figures 5 and 6 for key to symbols and colours).

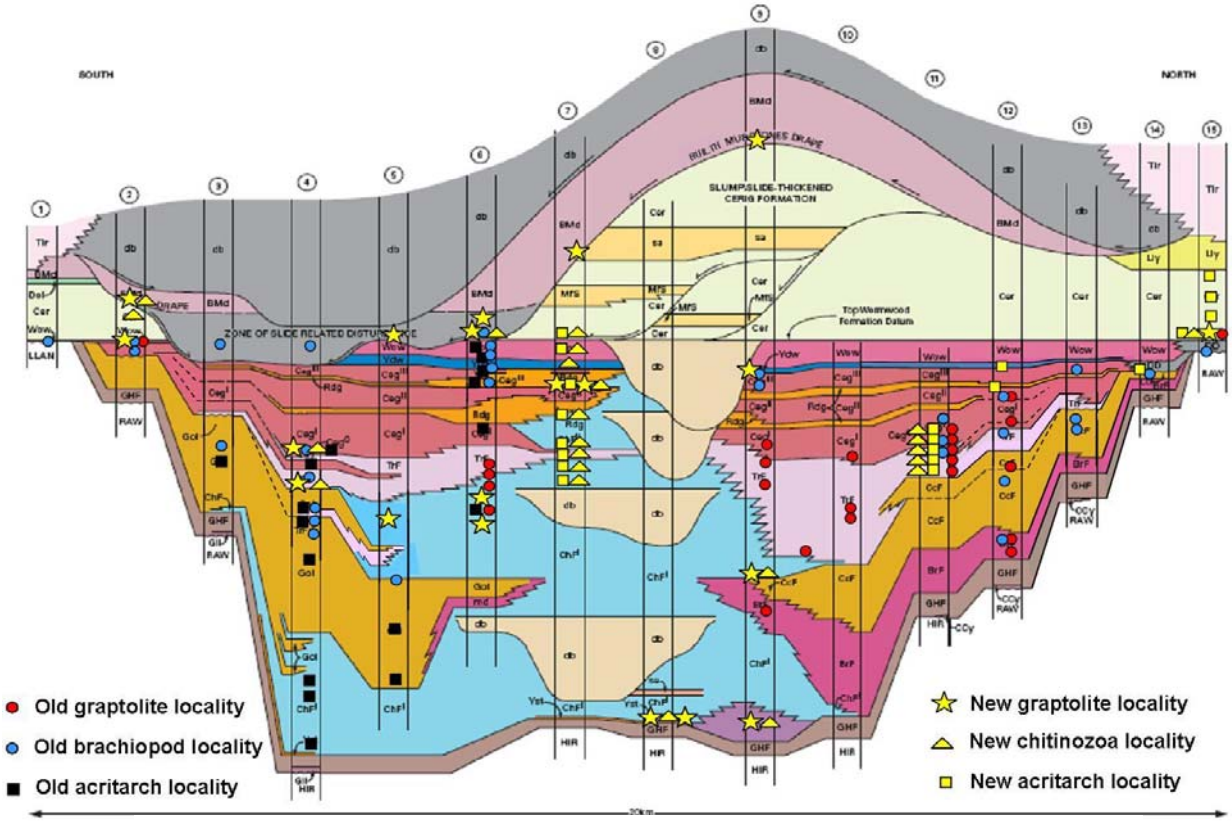



Figure 11. Position of some of the key new and old biostratigraphical sampling points in the Type Llandovery area plotted relative to the new stratigraphical architecture

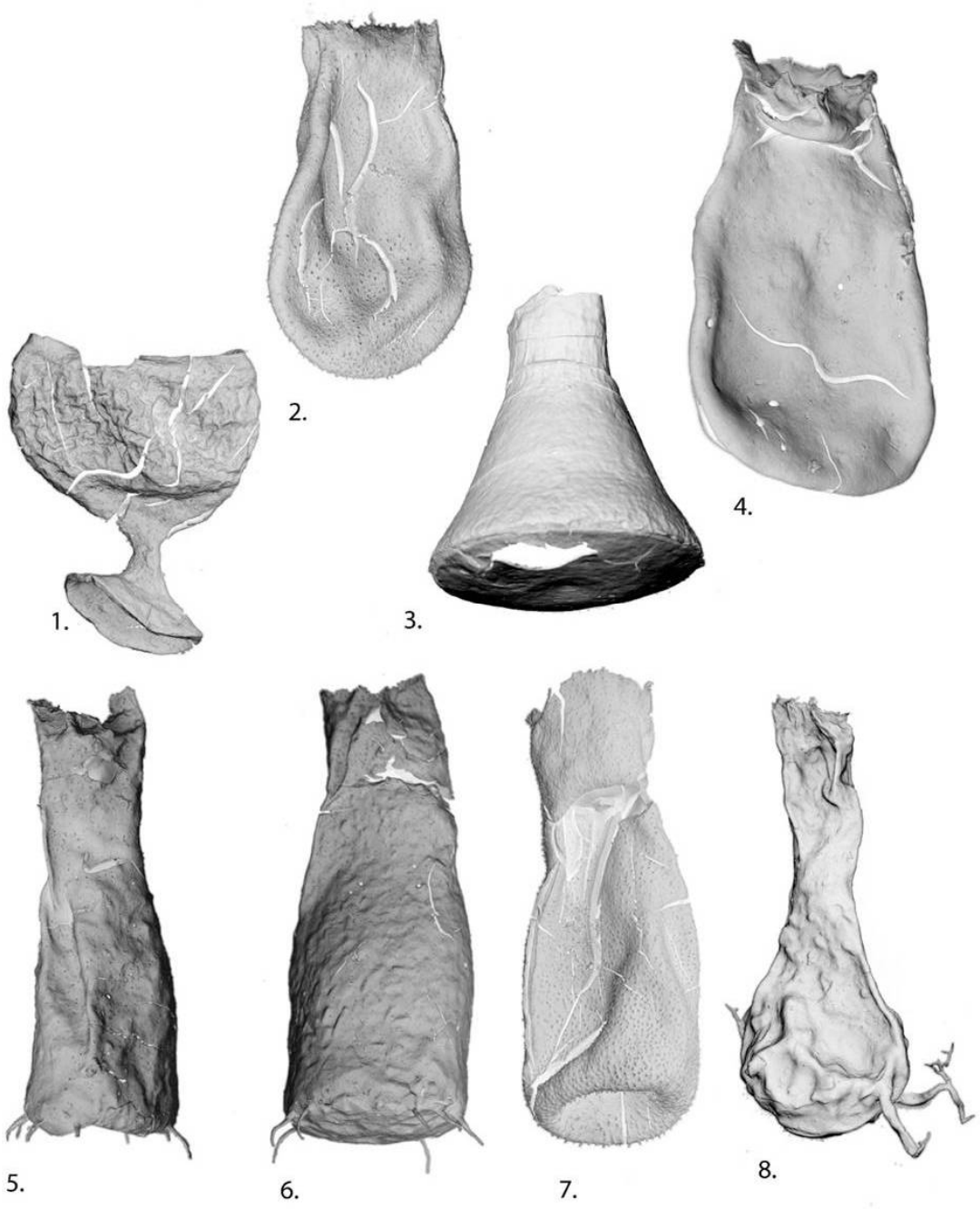



Figure 12. Examples of chitinozoans from the Type Llandovery area. 1.*Margachitina margaritana*, length = 0.100 mm 2. *Belonechitina ?aspera*, length =0.145 mm 3. *Cyathochitina camanulaeformis* group, length = 0.230 mm. 4. *Eisenackitina dolioliformis*, length = *0.140.* 5. *Spinachitina maennili*, length = 0.165 mm. *6. Spinachitina maennili*, length = 0.175 mm. 7. *Belonechitina postrobusta*, length = 0.210 mm. 8. *Ancyrochitina* sp., length = 0.130 mm. Images by Thijs Vandenbroucke.

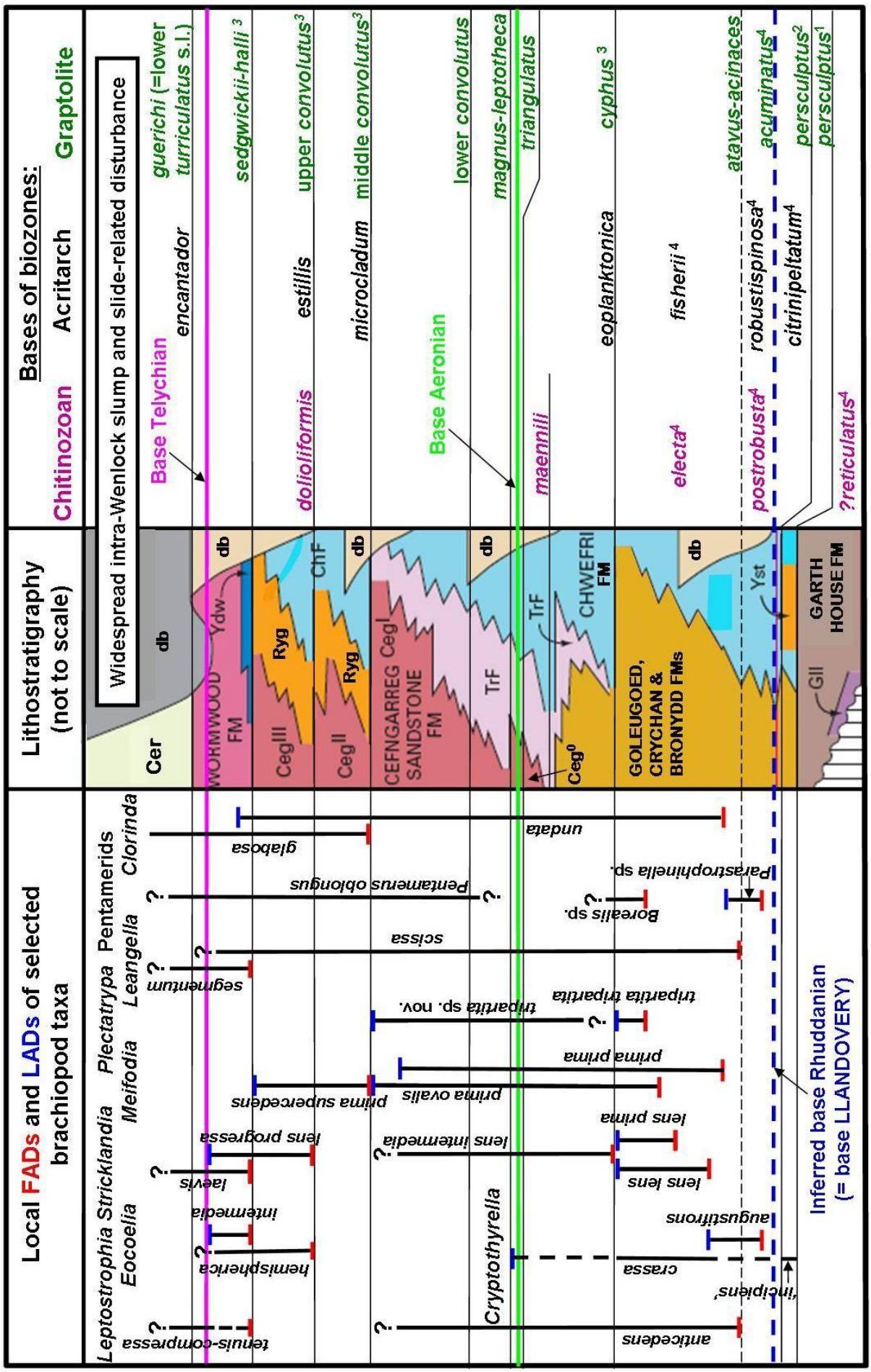



Figure 13. Summary of biozonal data and FADs and LADs of key brachiopod taxa in the Type Llandovery area (Lithostratigraphy column is adapted from Figure 6) ([1] and [2] refer to separate morphotypes described by Davies et al., 2009; [3] biozonal boundaries in significantly revised positions relative to Cocks et al., 1984; [4] positions of biozonal boundaries uncertain).

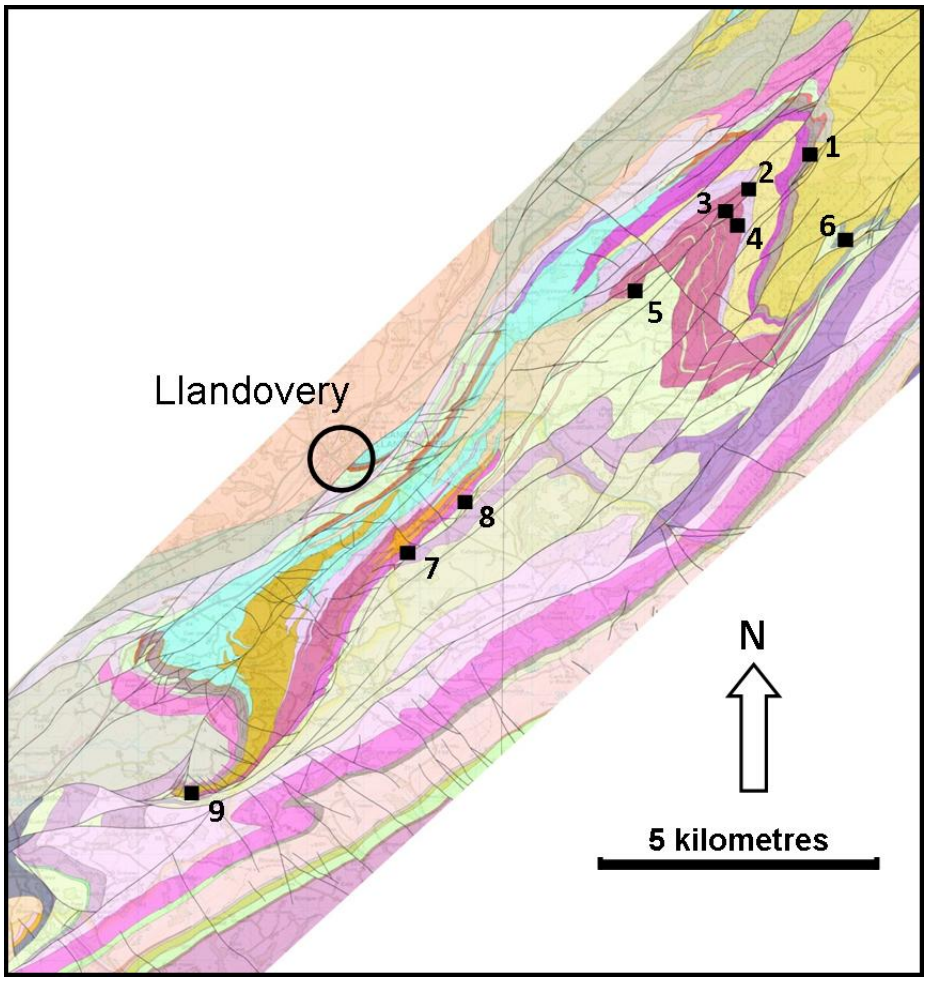



Figure 14. New BGS map of the Type Llandovery area showing position of localities described in this guide. See published maps and Figures 5 and 6 for keys to colours.

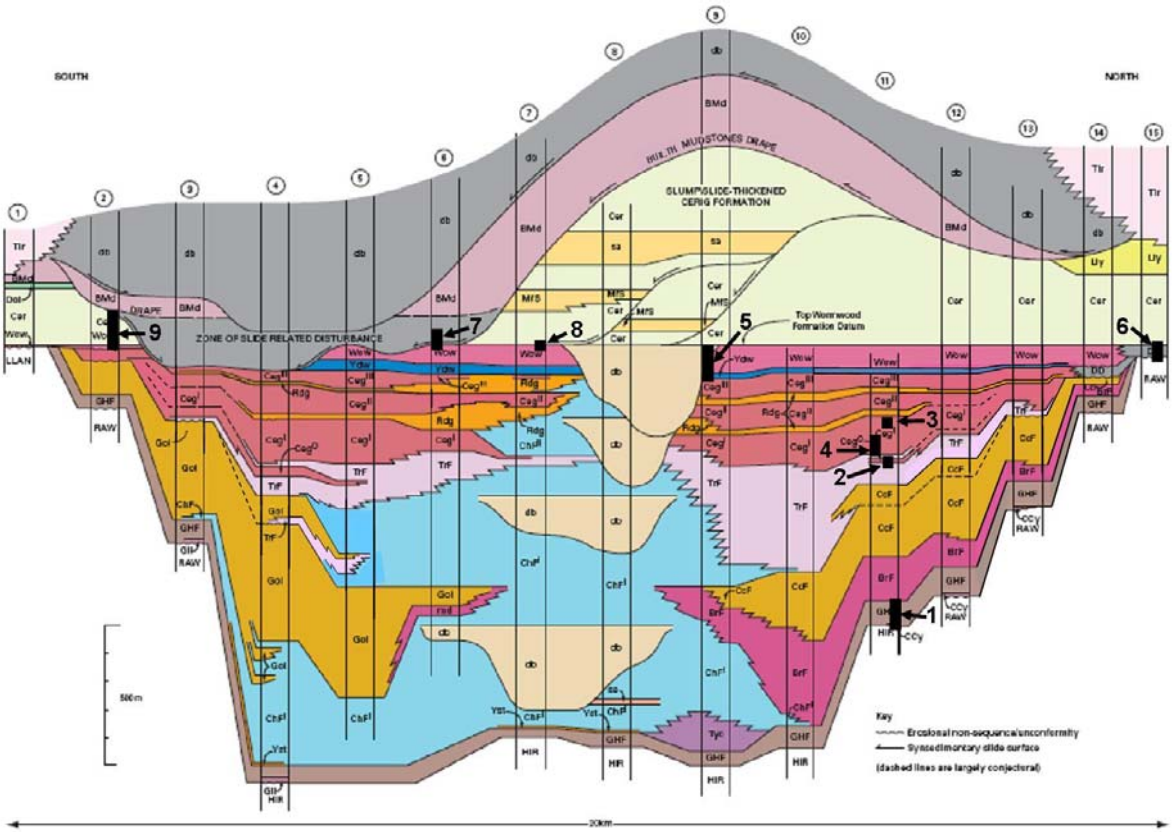



Figure 15. Position of the Type Llandovery localities described in the guide within the revised stratigraphy.

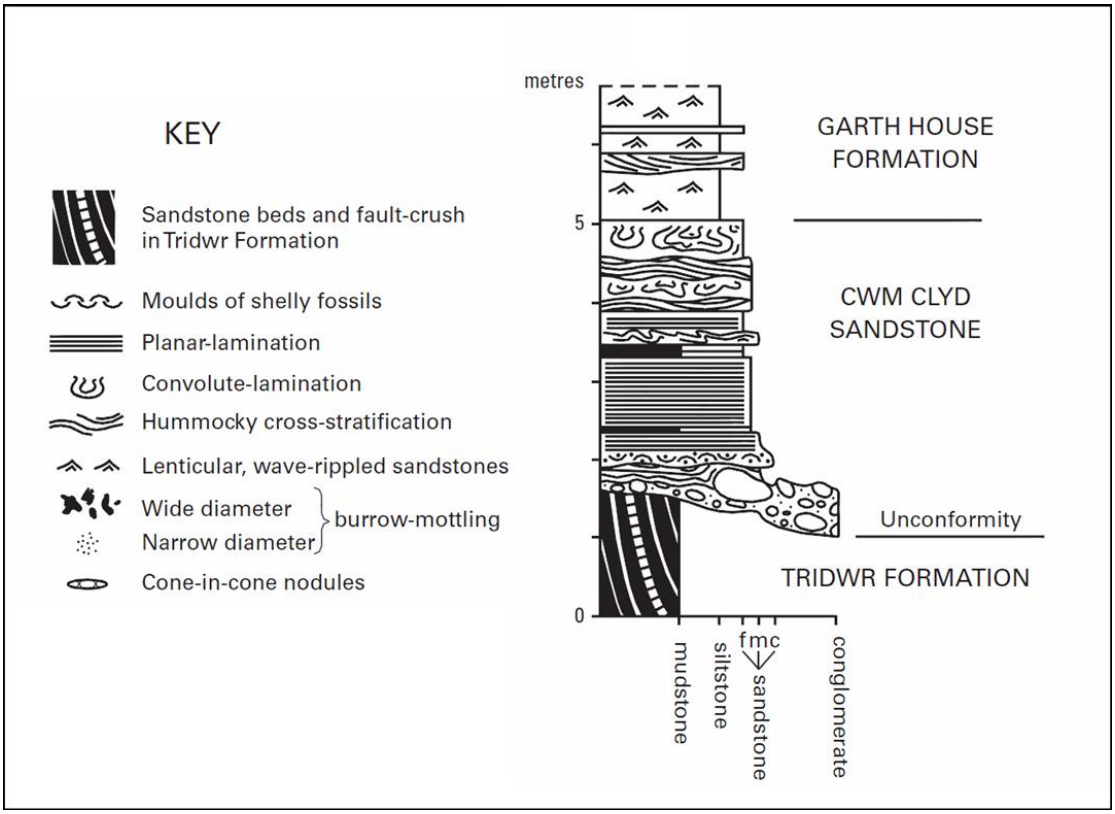



Figure 16. Locality 1a, small quarry at base of Scrach Track section (also known as Crychan Forestry Quarry) (after Davies et al., 2009).

Figure 17. Unconformity (at hand level) between steeply dipping Tridwr Formation and boulder conglomerate at base of the Cwm Clyd Sandstone, as Figure 16 (Locality 1a).

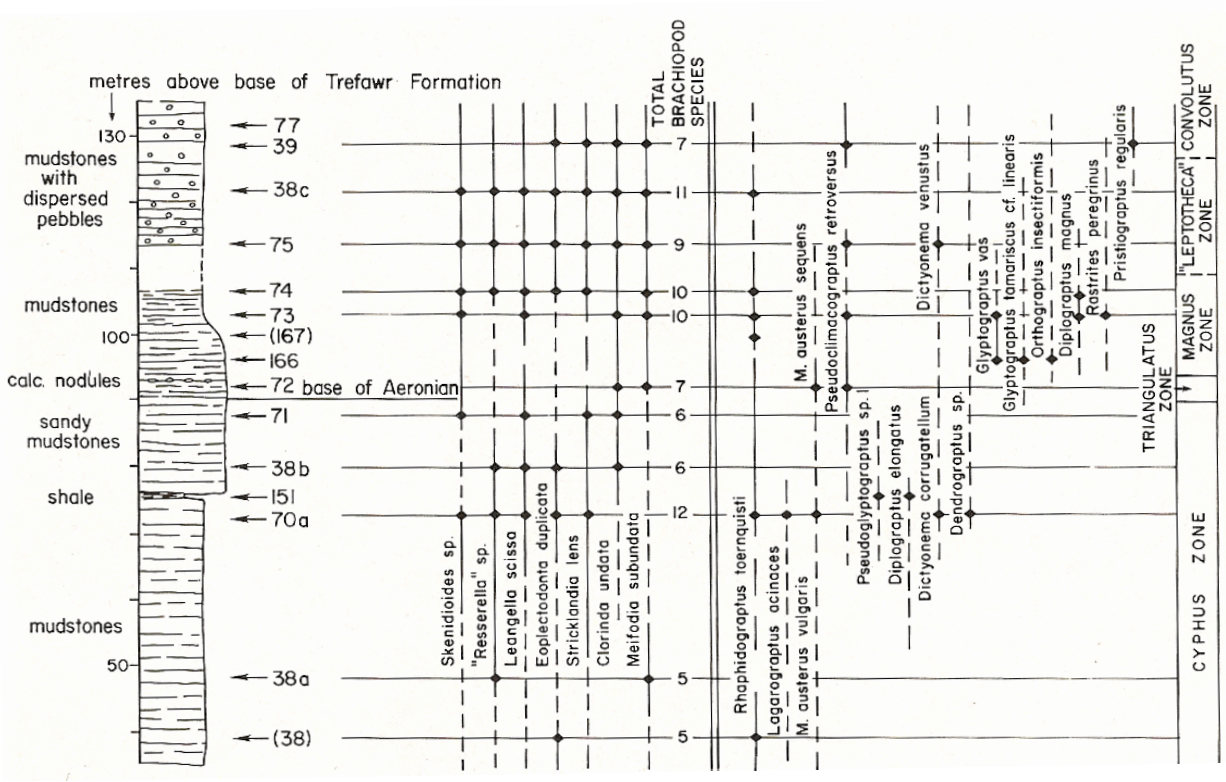



Figure 18. Brachiopod and graptolite ranges across the Rhuddanian-Aeronian boundary at the Aeronian stratotype, Trefawr track section (Locality 2) (after Cocks et al., 1984; but note that in this account strata between locality numbers 151 and 167, and above 75 are included in the Cefngarreg Sandstone Formation (see Figure 15). Reproduced by permission of the Natural History Museum, London.

Figure 19. Aeronian stratotype newly cleared for the 2009 Ludlow Research Group field meeting; stage boundary arrowed, see Figure 18 (Locality 2).


Figure 20. View looking north-westwards from Locality 3. The succession, over a kilometre thick, of late Ashgill rocks underlying the green fields in middle distance are those removed by erosion associated with the unconformity exposed at Locality 1a. Hills in the far distance are formed by basinal Ashgill facies of the Tywi Anticline.

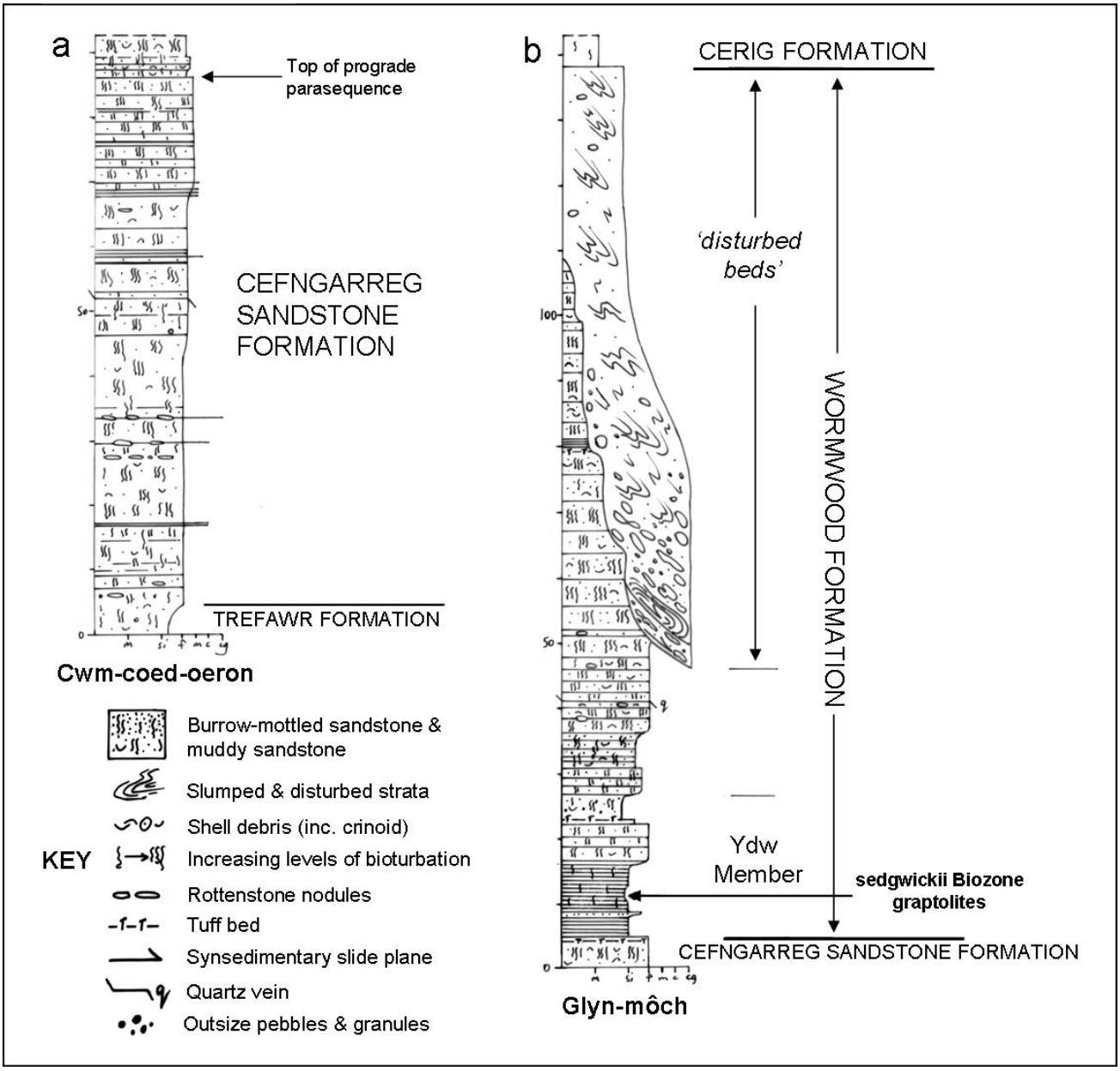



Figure 21. Modified sedimentary field logs: a) Cwm-coed-oeron track section (Locality 4); b) Coed Glyn-moch track section (Locality 5). For key to grain sizes at base of logs see Figure 16.

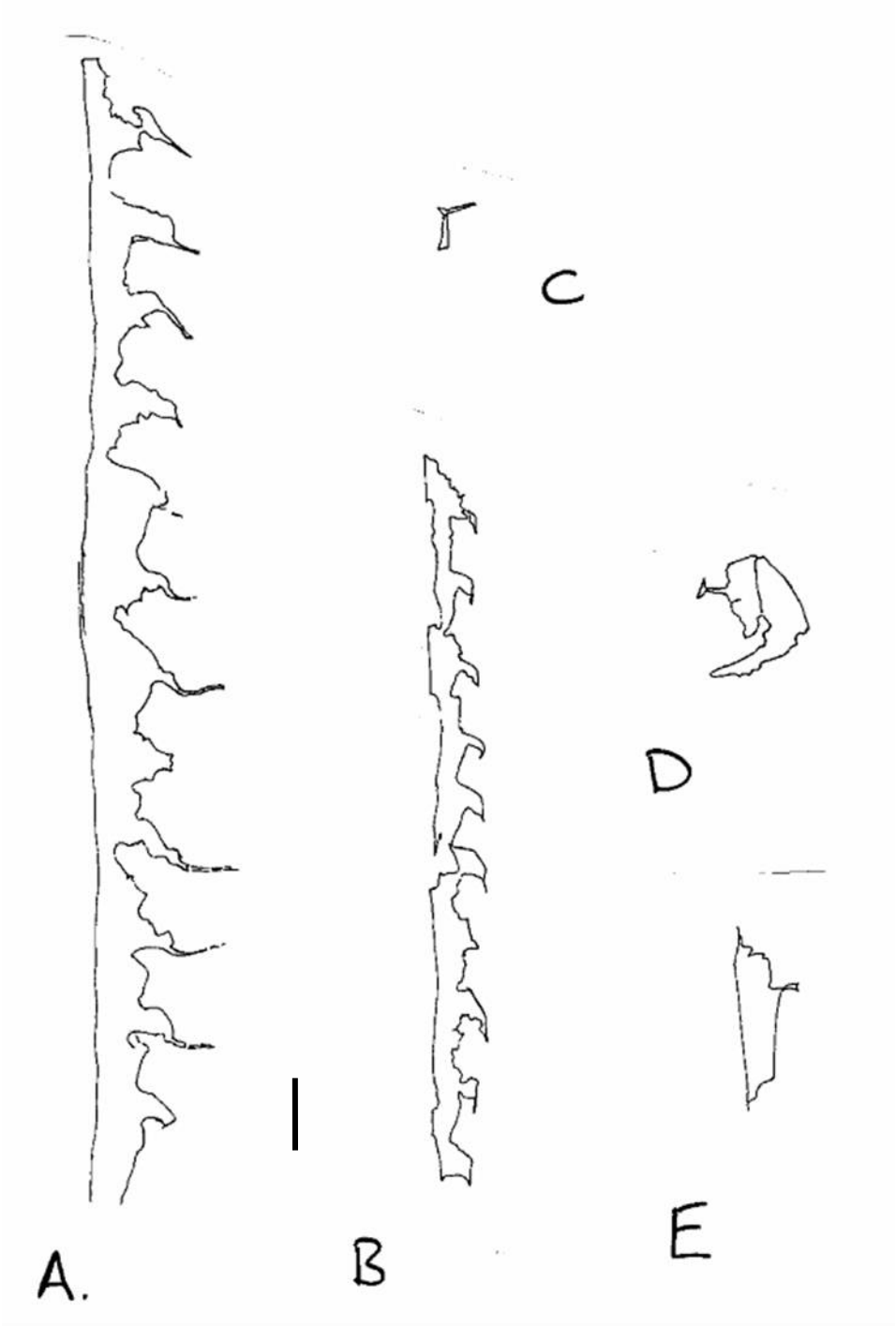



Figure 22. Examples of *sedgwickii* Biozone graptolites from the Ydw Member (Wormwood Formation) of the Coed Glyn-moch track section (Locality 5). A, *Stimulograptus sedgwickii*; B, as A (near proximal fragment); C, *Rastrites* sp (*gracilis*?); D and E, *Neolagarograptus* cf. *tenuis* (D is predated). Scale bar is 1 mm. Line drawings by Jan Zalasiewicz.

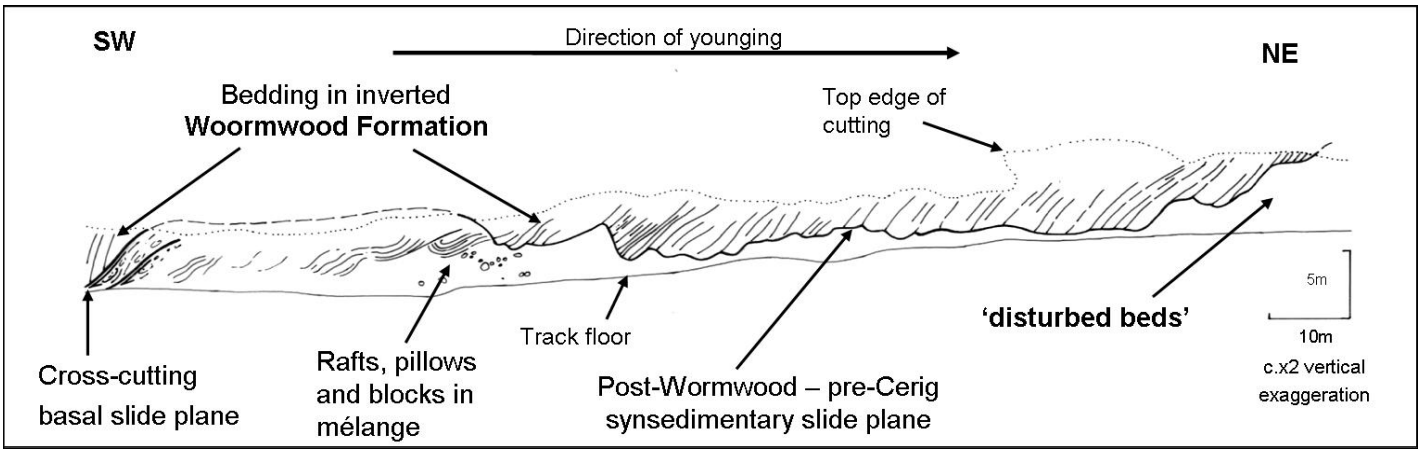



Figure 23. Synsedimentary slide and mélange exposed in the upper part of the Coed Glyn-moch track section (Locality 5) (see figures 21b & 24).

Figure 24. Basal slide plane (dashed line) truncating inverted bedding in Wormwood Formation sandstones (left) and stratigraphically overlain by mélange (right), Coed Glyn-moch track section (see figures 21 and 23) (Locality 5).

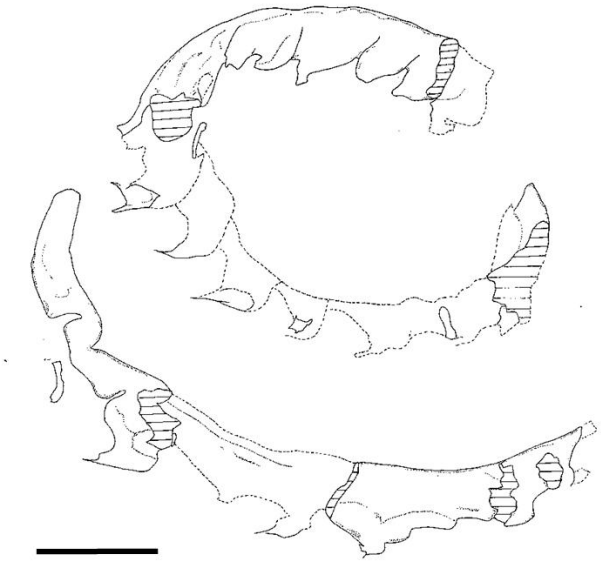


Figure 25. *Spirograptus guerichi* from the base of the Cerig Formation at the Fire Tower Hill track section (Locality 6). Scale bar is 1mm. Line drawing by Mark Williams.

Figure 26. Coquina of *Pentamerus oblongus* valves in Derwyddon Formation sandstone (Locality 6).


Figure 27. Vertical slide plane (arrowed above shaft of right hand hammer) truncating inclined bedding in Wormwood Formation (left) with Wenlock Builth Mudstones to right, Cefn Cerig road section (Locality 7b).

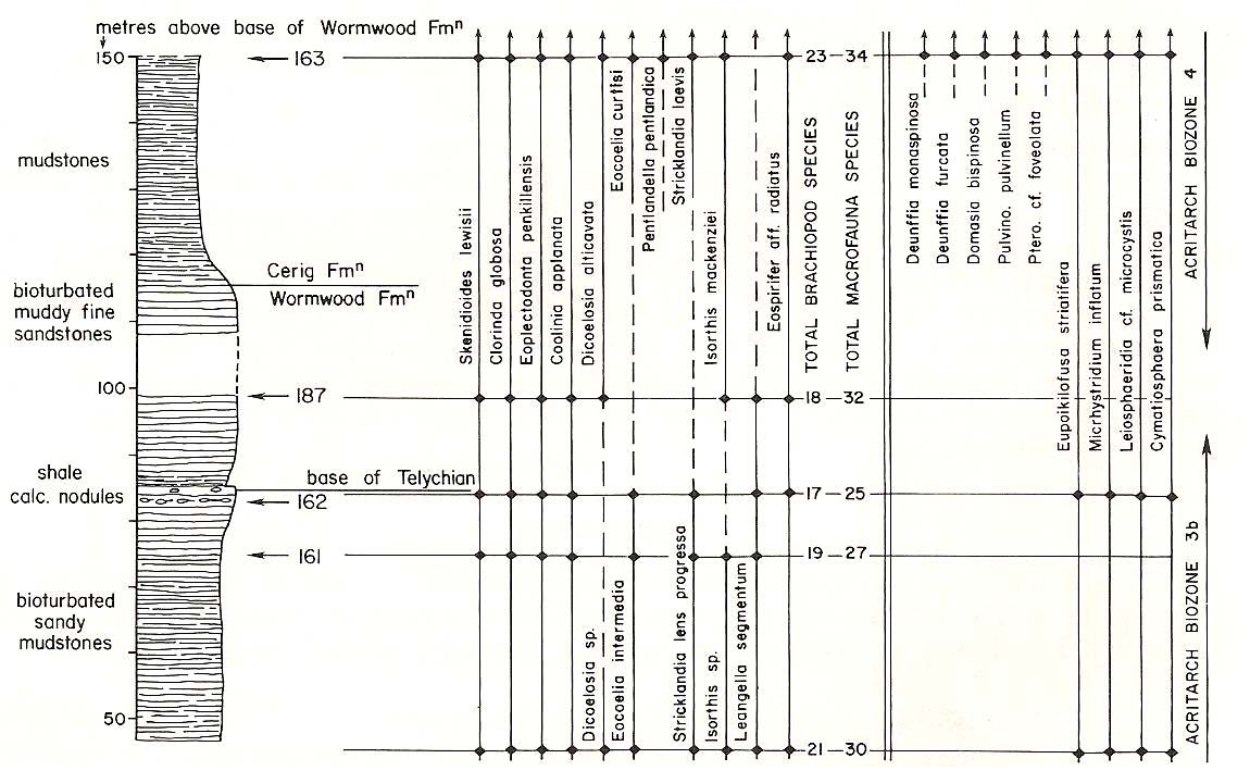



Figure 28. Distribution of selected brachiopod and acrtitarch species across the Aeronian-Telychian boundary in the Cefn Cerig Road section (after Cocks et al., 1984; compare upper part of log with Figure 30) (Locality 7). Reproduced by permission of the Natural History Museum, London.

Figure 29. Telychian stratotype quarry in the Wormwood Formation as visited during the 2009 Ludlow Research Group field meeting; base Telychian Stage boundary arrowed (Locality 7a).

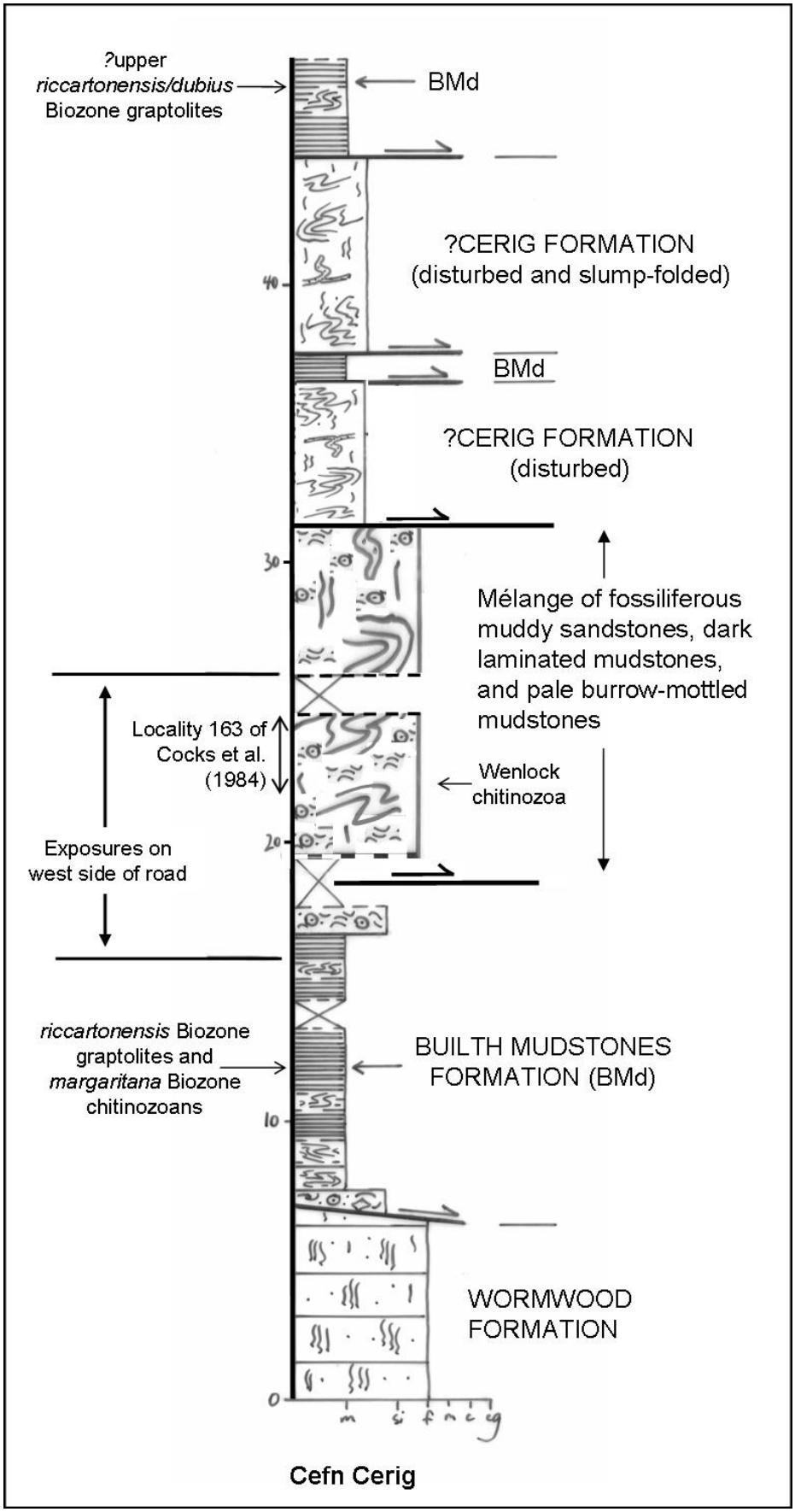



Figure 30. Modified sedimentary field log of the upper part of the Cefn Cerig (Fron) road section (Locality 7b). For key, see figure 16 and 21. Base of section is 22.5 m above the base Telychian boundary stratotype (see figures 28 & 29).

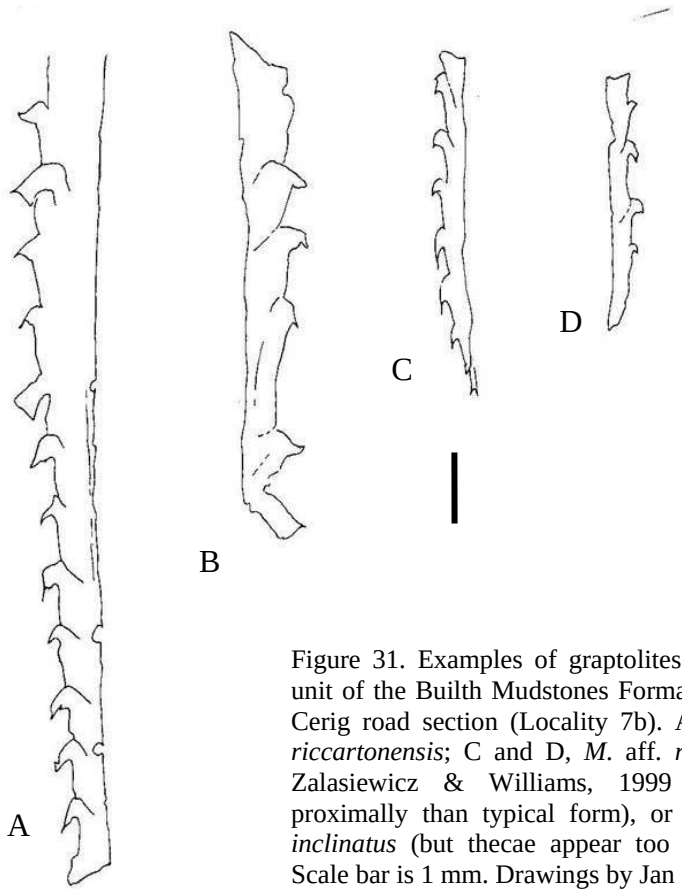



Figure 31. Examples of graptolites from the lower unit of the Builth Mudstones Formation in the Cefn Cerig road section (Locality 7b). A and B, *M*. cf. *riccartonensis*; C and D, *M*. aff. *riccartonensis* of Zalasiewicz & Williams, 1999 (more slender proximally than typical form), or *M*. *radotinensis inclinatus* (but thecae appear too closely spaced). Scale bar is 1 mm. Drawings by Jan Zalasiewicz.

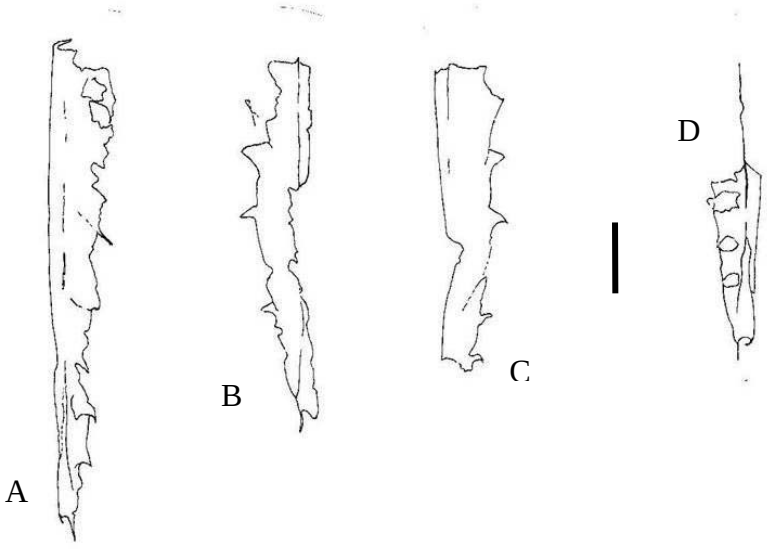



Figure 32. Examples of graptolites from the upper unit of the Builth Mudstones Formation in the Cefn Cerig road section (Locality 7b). A, B and C, *M*. cf. *riccartonensis*; D cf. *Pristiograptus dubius* sl. Scale bar is 1 mm. Drawings by Jan Zalasiewicz.

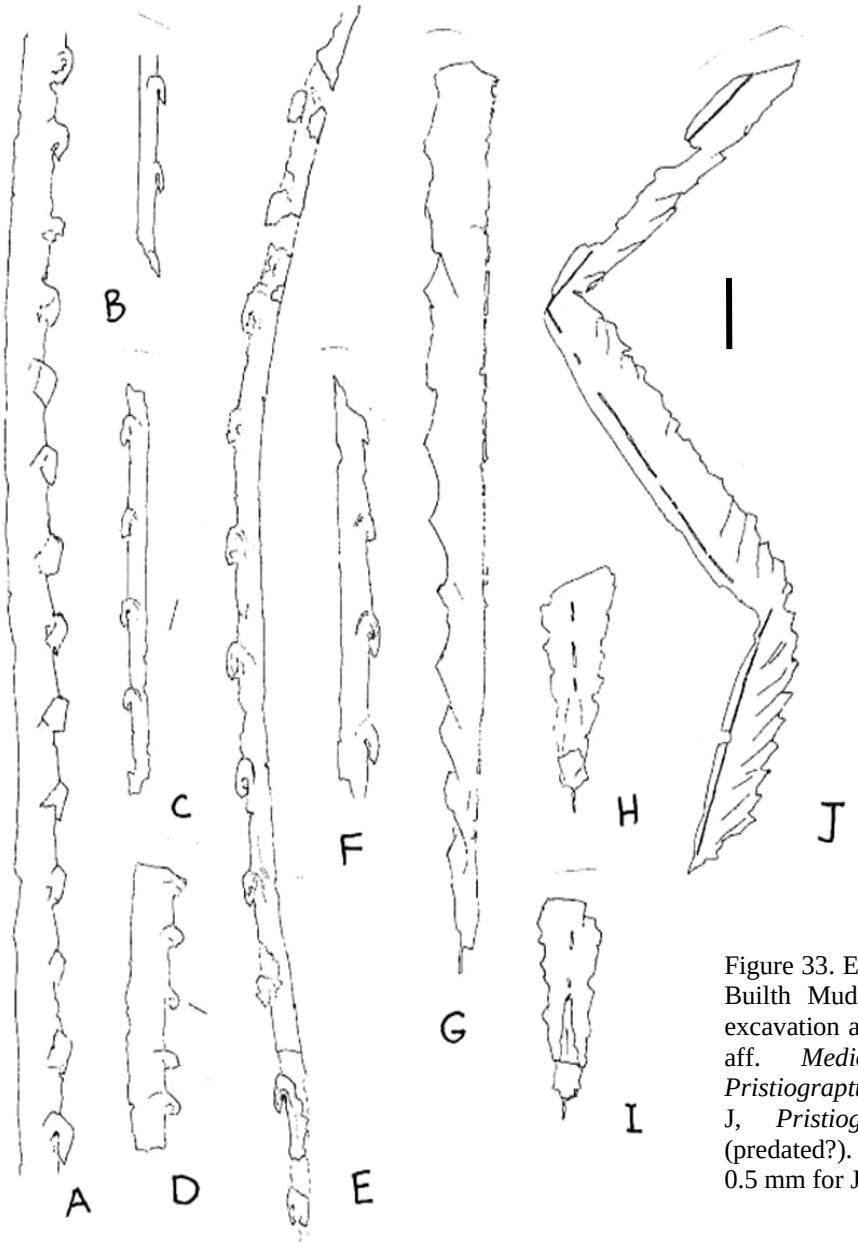



Figure 33. Examples of graptolites from the Builth Mudstones Formation in the new excavation at Mandinam (Locality 9a). A-F aff. *Mediograptus retroflexus*; G-I, *Pristiograptus dubius* (H, I dorsal aspect); J, *Pristiograptus dubius pseudolatus* (predated?). Scale bar is 1 mm for A-I and 0.5 mm for J. Drawings by Jan Zalasiewicz.

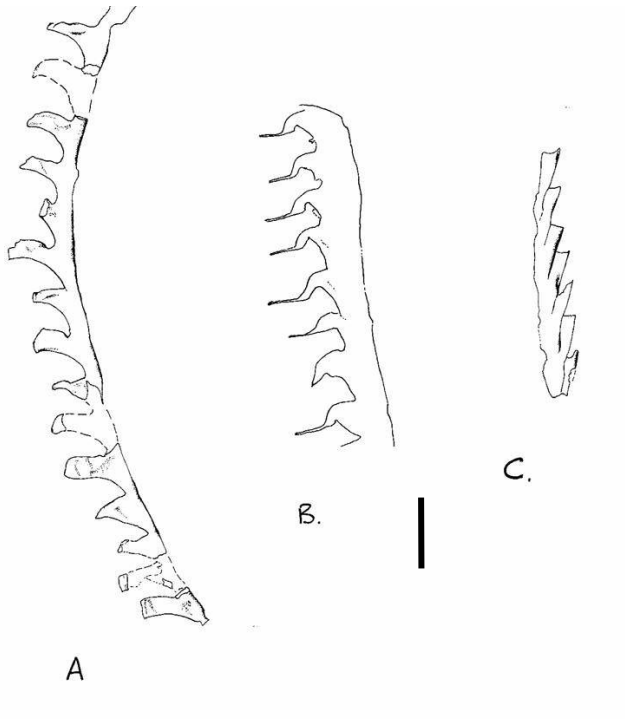



Figure 34. Examples of *sedgwickii* Biozone graptolites from the Wormwood Formation exposed in the quarry (Locality 9b) by the Afon Bran at Mandinam. A, *Torquigraptus* cf. *magnificus*; B, *Stimulograptus sedgwickii*; C, *Pristiograptus* cf. *regularis*. Scale bar is 1 mm. Drawings by Jan Zalasiewicz.

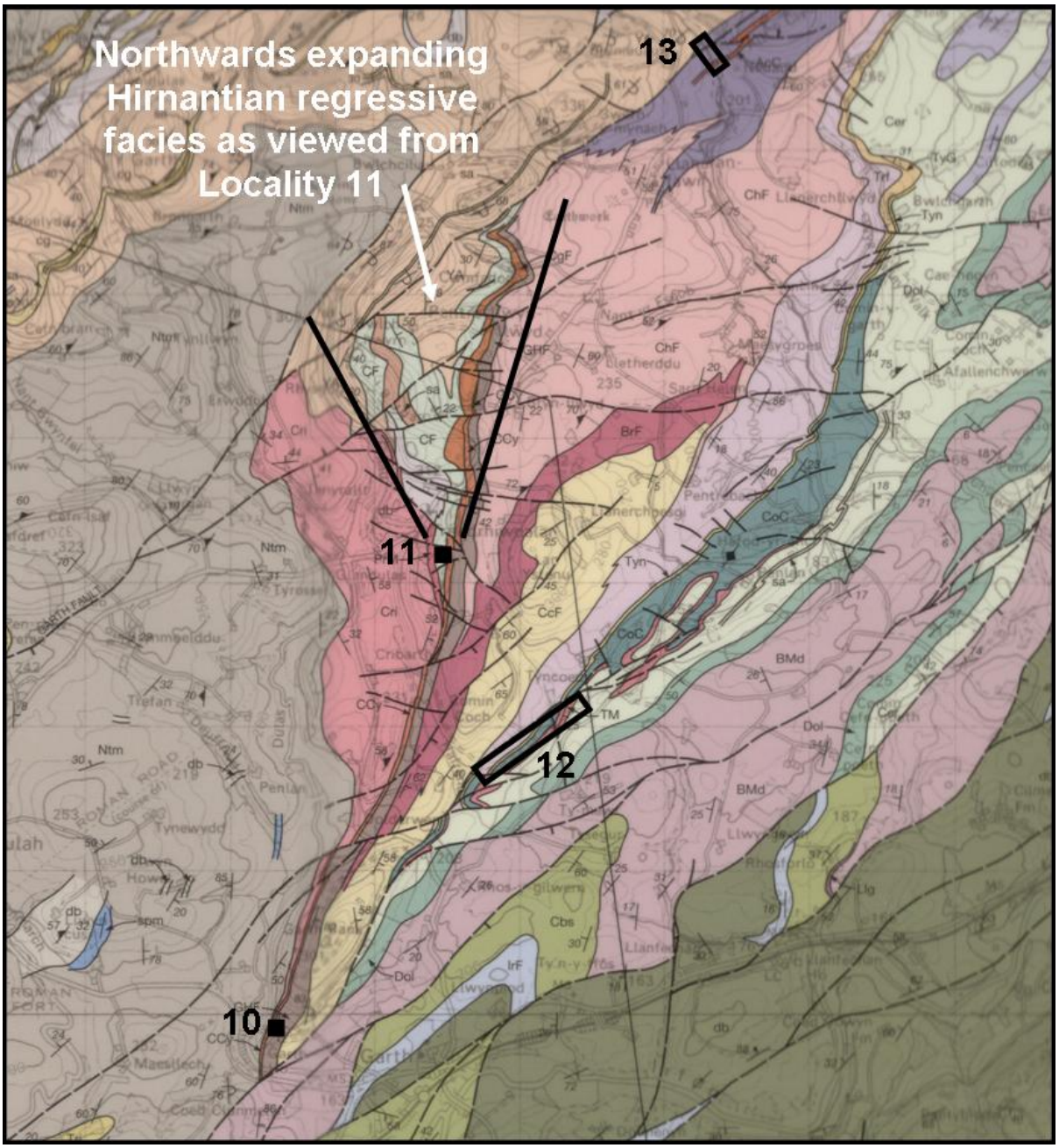



Figure 35. Geological map of the Garth area showing position of localities described in this guide (from BGS 2005a); see published map and Figure 36 for keys to symbols and colours.

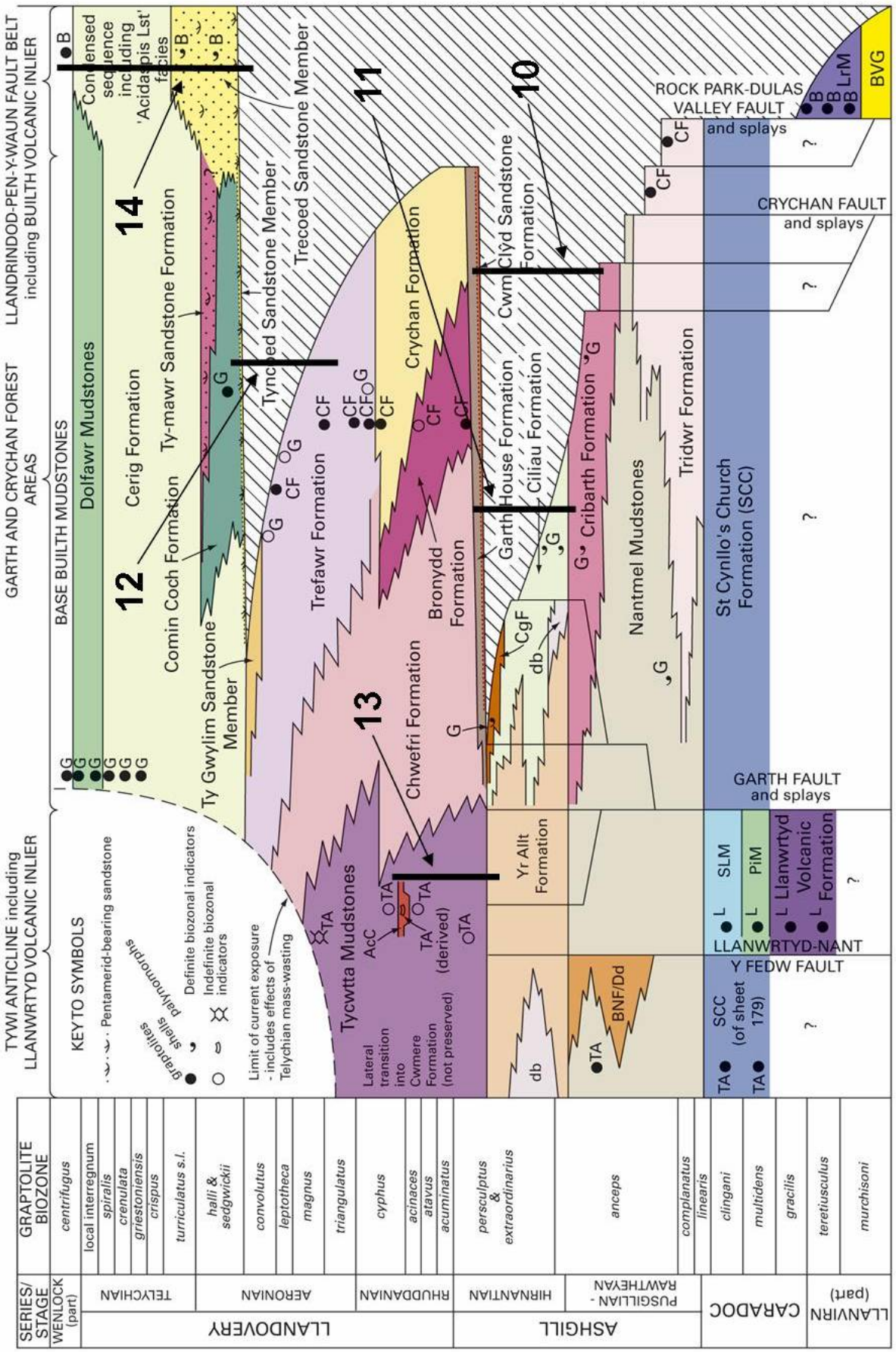



Figure 36. Chronostratigraphical architecture for the Ordovician and Llandovery succession of the Garth and Builth Wells areas, central Wales (from Schofield et al., 2004), showing position of localities 10 -14 described in this guide (CgF, Cwmcringlyn Formation; AcC, Allt-y-clych Congomerate Member; see source for key to other symbols).

Figure 37. Casts of ripple marks on the bases of sandstone beds, Garth House Formation, Garth House Quarry (Locality 10).

Figure 38. Casts of trace fossils on the base of sandstone bed, Garth House Formation, Garth House Quarry (Locality 10).


Figure 39. Chwefri valley with crags of vertically dipping Allt-y-clych Conglomerate within the Tycwtta Mudstones Formation (younging direction is from left to right) (Locality 13).