# A systems-based lithostratigraphy for the Lower Palaeozoic Welsh Basin and adjoining region

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*Front cover*

Cliffs north of Llangranog in the newly named, mid-Hirnantian St. Crannog Formation (Yr Allt Group), overlooked by a statue of the eponymous saint.

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Keyworth, Nottingham British Geological Survey 2025

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# Foreword

## SCOPE AND STRUCTURE OF THIS REPORT

This preliminary framework document presents an overview of the **Ordovician** and **Silurian** successions of the **Lower Palaeozoic Welsh Basin (LPWB)**, adjoining parts of the **Midland Platform** and contiguous regions in south-west Wales. It seeks to rationalise disparate formational nomenclatures and advance a hierarchical lithostratigraphy for these strata and, in doing so, substantially revises and updates an unreleased draft by D. Wilson and J. R. Davies placed on file in 2012. It should be read in conjunction with the Stratigraphical Framework Report on the Ordovician volcanic successions of Snowdonia and the Llyn Peninsula by Rushton and Howells (1998) and the report on Old Red Sandstone of the Anglo-Welsh Basin by Barclay *et al*. (2015). Although this current report provides guidance on formational and member nomenclature, and cites their source documentation, it does not give full lithostratigraphical definitions; these may form the remit of future reports. It is important to understand that this report is a baseline statement that is capable of refinement and improvement with time. The report is in five parts: Part 1 explains the methodology used to develop a group and subgroup scale lithostratigraphical framework for the whole of the post-Tremadoc Ordovician to (?)Early Pridoli Silurian succession of the study area; Part 2 shows how this approach has been used to develop a new group and sub-group scale lithostratigraphy; Part 3 in addition to group and sub-group definitions, provides a comprehensive account of their component formations and members; Part 4 summarises and presents the principal recommendations arising from the study; and Part 5 includes the reference list and appendices. The report, though intended as a standalone document, is best read in conjunction with the relevant BGS 1:50 000 scale geological maps, memoirs and sheet explanations listed in Appendix 1. Text boxes are used to provide important background context for some of the key decisions relating to systems tract definitions and nomenclature.

## AUTHOR’S NOTES

This report was compiled in the author’s capacity as an Honorary Research Associate of BGS, and it is released as a BGS Open Report. The models and interpretations described in this report are those of the author. Some are already incorporated into published BGS maps and some are recommendations for future updates to BGS maps.

At an advanced stage in the compilation of this report, the author exchanged draft manuscripts with the authors (Molyneux *et al*., 2023) of a now published book chapter on the Ordovician of Britain and Ireland. Unsurprisingly, the latter overlaps significantly with the current account for strata included in Tract Assemblage A (Preseli Supergroup) and parts of Tract Assemblage B (Hafren Supergroup). However, the *raison d’etre* of the two texts differs. Molyneux *et al*.’s account of these rocks offers an authoritative assessment of the scientific status quo. The current report, by seeking principally to assess and rationalise lithostratigraphical nomenclature, attempts a radical reappraisal of these rocks. Nevertheless, the published chapter by Molyneux *et al*. (2023) provides an important and complementary synopsis of biostratigraphical and other dating data currently available for the Ordovician succession of the study area.

Also during the writing of this report, a team led by A Tingly and co-workers published an independent provisional geological map of the Knighton sheet and surrounding area. This map reworks older lithostratigraphical nomenclature but also introduces several new terms. The absence of supporting documentation, makes it difficult to assess the terminology and geological decisions made in drawing up the map. However, it is understood that the team intends to produce a supporting report which will likely facilitate this in the future.

# Acknowledgements

Many people have been involved in the study of the Lower Palaeozoic Welsh Basin over the last forty years and more from a wide range of earth science disciplines. They include BGS staff and academic researchers too numerous to mention, who have participated in the long-running programme of geological surveying that has been an essential prerequisite to our understanding of the stratigraphy of the Ordovician and Silurian rocks of Wales. Many have freely given their advice, collected data, or provided local knowledge essential to the compilation of this report. It is important to acknowledge the contributions made over many years by former colleagues in BGS, in particular, by members of the Wales mapping team and by BGS palaeontologists. The collaborative work undertaken by staff and students from numerous academic institutions, notably from Aberystwyth, Cambridge, Cardiff, Durham and Leicester universities, the National Museum of Wales and Natural History Museum, London is also acknowledged. Particular thanks are extended to Mark Williams, Jan Zalasiewicz and Stewart Molyneux for their biostratigraphical contributions made over many years. The final report has benefited from the informed reviews undertaken by Dick Waters (formerly of BGS and National Museum of Wales) and David Schofield (BGS). Rhian Kendall, the current BGS Chief Geologist for Wales, is warmly thanked for her ongoing encouragement and support.

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# Part 1 – A methodology for group and subgroup subdivision

## 1 Scope and objectives

### 1.1 INTRODUCTION

Herein, the aim is to develop a standardised supergroup, group and sub-group scale lithostratigraphical nomenclature for the Ordovician and Silurian rocks that comprises the fill of the **Lower Palaeozoic Welsh Basin (LPWB)** and the coeval strata that blanket the adjacent **Midland Platform** (Fig. 1). The opportunity to rationalise formation and member level terminology is also taken (see Part 3). The hope is that the proposed scheme could inform future generations of BGS maps and map-based environmental and resource-focused products. Figure 1 presents the geological maps of the study region. Figure 1A, BGS's traditional, small scale, largely chronostratigraphical geological map, shows the distribution of Ordovician and Silurian strata and adjacent stratigraphy. Figure 1B utilises linework from the BGS 1:625 000 scale map of the region to show outcrops of the overarching lithostratigraphical divisions, both newly conceived, that are the principal focus of this report: the Arenig to Caradoc **Preseli Supergroup** and the Ashgill to (?)Early Pridoli **Hafren Supergroup**. Both comprise predominantly marine sedimentary strata and volcanic rocks that in some parts of the LPWB provide a record of almost continuous accumulation initiated by the Moridunian (Arenig) global transgression and terminated by the diachronous late Silurian onset of terrestrial red-bed sedimentation. The latter marks the base of the succeeding Old Red Sandstone Supergroup (see Barclay *et al*., 2015) (Plate 16). Herein, the British regional chronostratigraphical scheme for the Lower Palaeozoic (Cocks *et al*., 2010) is utilised. Historically, work on the LPWB and its adjoining successions informed the erection and naming of many of these Lower Palaeozoic divisions and, as such, the British terminology is strongly linked to the region's rock record. For that reason, it continues to offer the most concise terminology to label the ages of its lithological units and the geological events that shaped them (e.g. Brenchley *et al*., 2006b). Tables 1A and 1B show the relationship of the British Ordovician and Silurian chronostratigraphical terminology to the UK graptolite biostratigraphical scheme of Zalasiewicz *et al*. (2009), to modern conodont and chitinozan biozones and to internationally recognised divisions (see Gradstein *et al*., 2020).

The LPWB has traditionally been viewed as a region of enhanced subsidence that accommodated a thick succession of Cambrian, Ordovician and Silurian volcanic and sedimentary facies. Much of this succession comprises facies of deeper water aspect, but it also includes deposits formed under shallower water conditions and it was the deposition of such facies that prevailed for long periods across the basin's evolving margins and across the adjoining platform. This report seeks to standardise the lithostratigraphy for only the post-Tremadoc Ordovician to (?)Early Pridoli Silurian portions of these successions. Cambrian to Tremadoc rocks in Wales and in the Welsh Borderland that display the impacts of events with links to the North American Penobscotian orogenic episode, are here considered to predate the development of the LPWB (see Schofield *et al*., 2020). The Lower Palaeozoic successions on Anglesey and western extremities of the Llŷn Peninsula lie outside the LPWB as defined in this account (see below). Silurian graptolites from Anglesey, in appearing to display affinities to Scottish Iapetean forms rather than those endemic to parts of the LPWB, support ongoing doubts concerning the palinspastic relationships of the two successions (Chopey-Jones *et al*., 2003). Schofield *et al*. (2020) offer a detailed tectono-sedimentary reassessment of the strata on Anglesey and these rocks are not dealt with further in this report. Accounts of the Lower Palaeozoic succession in the Maesteg Deep Borehole (e.g. Penn, 1987) have influenced palaeogeographical reconstructions (e.g. Rushton *et al*., 2000), but the age and lithostratigraphical assignment of these rocks remain problematical and they are also not considered further in this report.

The long history of geological research undertaken on the Lower Palaeozoic rocks of Wales, including their role in the early development of stratigraphy, presents both opportunities and challenges. Building on the seminal work of Murchison, Sedgwick, Lapworth and their 19th century contemporaries, subsequent investigators erected local stratigraphies that, as was standard for the time, conflated biostratigraphical, chronostratigraphical and lithostratigraphical concepts of subdivision (see review by D. Bassett, 1969). Subsequent advances in stratigraphical thinking paved the way for the separate and hierarchical lithostratigraphical, biostratigraphical and chronostratigraphical schemes that are in use today (Tables 1A and 1B). More recent analyses commonly employ sequence stratigraphical techniques as an additional means to unpick the key events that shaped the basin's volcano-sedimentary fill and the successions that bordered it (e.g. Woodcock, 1990; and *et al*., 1996; Davies *et al*., 2011, 2013, 2016; Ray *et al*., 2010). Geological surveying of the region area (see Fig. 2; Appendix 1) was initiated in the mid-nineteenth century and subsequent generations of maps show how BGS (and its precursor bodies) progressively altered the way it defined and depicted stratigraphical divisions.

The global significance of the LPWB and adjoining successions was underlined when these were selected as hosts for many of the Silurian Global Stratigraphic Sections and Points (GSSPs) (see Holland and Bassett., 1989).

Thus, this report covers the type successions for the Llandovery, Wenlock and Ludlow series and, with the exception of the Rhuddanian, the stratotypes for the majority of their constituent stages. During the compilation of this report, significant amendments to the criteria used to define some Ordovician and Silurian series and stage boundaries and their GSSPs have occurred, and some remain under review. Of relevance are problems recognised with many of the Silurian stage and series stratotypes (see Davies *et al*., 2011, 2013; Melchin *et al*., 2020, 2023). It is important for readers to be aware that strata assigned to certain series and stages in this report may, subsequently, come to be included in new or redefined regional and international chronostratigraphical divisions. The Geologic Time Scale (Gradstein *et al*., 2020) documents these ongoing reviews and provides the most up to date regional and international chronostratigraphical schemes.

Of necessity, it is the lithostratigraphical nomenclature employed by BGS, as shown on its maps and used in accompanying memoirs and sheet descriptions, that serve as a starting point for this study. In addition, the reviews of Nigel Woodcock and his co-workers (e.g. Woodcock, 1990; Woodcock & Soper, 2006; Woodcock & Strachan, 2012), and by Bevins *et al*. (1992), Brenchley *et al*. (2006b) and Cherns *et al*. (2006) have been relied upon heavily. The Geological Society correlation charts for the Ordovician (Fortey *et al*., 2000) and Silurian (Cocks *et al*., 1992) rocks of the British Isles were also essential sources, as were the complimentary Geological Conservation Reviews undertaken by Stephenson *et al*. (1999), Rushton *et al*. (2000) and Aldridge *et al*. (2000). The findings of Hillier *et al*. (2024) have been utilised for Ludlow and Pridoli strata. Collectively, these publications offer access to the extensive earlier literature that charts the progression in our understanding of the complex geological history of the study region and of the processes that shaped it.

Detailed discussion of the evolving plate tectonic setting of the LPWB is beyond the scope of this report but is summarised in figures 3 and 4.

In addition to the literature cited above, the accounts by Waldren *et al*. (2014), Pharaoh (2018), Schofield *et al*. (2020) and Cocks and Torsvik (2021) supply further background and offer recent insight. In summary, the LPWB and Midland Platform were structural components of small tectonic plate that, together with adjacent terranes, it remains convenient to label Avalonia and which formed part of a faunal province that is recognised as the Anglo-Acadian Belt by Cocks and Fortey (1990). The shaping of post-Tremadoc (post-Penobscotian) successions was in response to events associated with the late stages of the Caledonian orogenic episode. These include the early Ordovician separation of Eastern Avalonia from the southern supercontinent of Gondwana, both the southwards and northwards subduction of the Iapetus Oceanic Plate, a Late Ordovician fusing with Baltica, followed by Silurian convergence and collision with the Laurentian plate (see Figs 3, 4). Verniers *et al*. (2002) in reviewing the complex internal composition and tectonic history of 'Far Eastern Avalonia', a component of their 'Avalonian Terrane Assemblage', highlight the additional impact on the LPWB of tectonism linked to the southerly closure of the Rheic Ocean and the early evolution of the Variscan Orogen. The origins of the major intra-Devonian cleavage forming deformation that affected Lower Palaeozoic rocks throughout the region, and that has been linked to the North American Acadian Orogeny, are reviewed by Woodcock and Soper (2006; see also Woodcock *et al*., 2007; Woodcock and Strachan, 2012). Parts of the Midland Platform located principally to the south of the Bristol Channel, but that were subsequently displaced during the Variscan Orogeny, acted as a persistent source of sediment for the LPWB. Cope and Bassett (1987) label this cryptic region **Pretannia**.

Global events, principally movements in sea level, also played their part and during some periods were likely the dominant influence on facies distribution and geometry, and in determining patterns of erosion. Notable deepening episodes are associated with the bases of the Arenig and Llanvirn series. Glacioeustasy had a huge impact during the Hirnantian, and post-glacial deepening was a factor during the early Silurian. The effects of subsequent Silurian transgressions are also recognised. Many of these sea levels events had links to global-scale episodes of environmental change and associated faunal flux, often associated with named carbon isotope excursions, as for example HICE, Ireviken and Mulde (e.g. Aldridge *et al*., 1993; Jeppsson, 1998, Goldman *et al*., 2020; Melchin *et al*., 2020; Cramer and Jarvis, 2020). Figure 5, by summarising the tectonic history, evolving subsidence regimes and the timing of global-scale sea level and climatic episodes, highlights the key events that operated, typically in concert, to shape the fill of the LPWB and the successions of its adjoining regions. It is the impacts of many of these events that inform in the revised group-scale lithostratigraphical scheme advance herein.

### 1.1.1 Notes

*The Ordovician-Silurian boundary* - In areas of Wales where the stratigraphy is intact, the position of the Ordovician-Silurian boundary shown on small scale chronostratigraphical geological maps is inaccurate. Its position has never been updated following changes to the criteria used to define the base of the Silurian (see Holland and Bassett, 1989). The level shown on these maps continues to be the historical level, located in strata now recognised as Hirnantian in age (e.g. Cave and Hains, 1986; Davies *et al*., 1997). In such areas, the modern base of the Silurian - as defined by the entry of *ascensus-acuminatus* Biozone graptolites (see Table 1B) - lies some distance above this historical horizon. In the Wye valley, for example, Davies *et al*. (1997) found that the diagnostic fossils first occur close to 100 m above the older level. The modern system boundary is no longer associated with a lithostratigraphical contact and its location, in many areas, is unknown. Currently, it is practically impossible to generate accurate replacement boundary linework for use on regional maps covering large areas of the LPWB.

*Use of the term (?)Early Pridoli* - The youngest strata considered in this report are widely cited as being of Early Pridoli age. Facies and faunal changes linked to the level of the Ludlow Bone Bed and its correlatives have, since its erection, been taken to mark the base of the Pridoli Series in Wales and the Welsh Borderland (e.g. White and Lawson, 1989). The level coincides with the entry of microfloral taxa not reported from underlying parts of the Silurian succession and these new forms are recognised accordingly, but not without an element of circular reasoning, as Pridoli markers. However, Loydell and Fryda (2011) interpret the significant isotope excursion they discovered spanning the Ludlow Bone Bed and extending into the overlying stratigraphy (see Part 3), as the global Lau Event. If confirmed, this would demonstrate a late Ludfordian age for these strata and, *defacto*, their microfloral assemblages. Turner *et al*. (2017) have sought robustly to defend the *status quo*, and it is not the place of this report to arbitrate. Nevertheless, were Loydell and Fryda's contention found to be correct, the stratigraphy dealt within herein would likely entirely predate the Pridoli Series. It is to convey this uncertainty that the expression **(?)Early Pridoli** is used throughout this account (see also Hillier *et al*., 2024).

*Digital BGS maps*- Use herein of the term 'BGS digital maps', or similar, refers principally to the publicly available British Geological Survey (onshore) 1:50 000 scale geology map database accessible via the BGS Geology Viewer weblink.

## 1.2 DEFINING THE BASIN AND STANDARDISING ITS TERMINOLOGY

### 1.2.1 Principal structural features

The principal structural and palaeogeographical features of Lower Palaeozoic Wales are shown in Figure 6 (see also Figs 12-14). Current outcrop patterns principally reflect the impact of an early-mid Devonian compressive deformation (see below) which saw the fill of the LPWB folded and much of it cleaved. Dominant features are the major NE-SW-trending fault and fold belts that traverse Wales. Principal amongst these are the **Menai Strait** and **Bala lineaments**, the **Central Wales Lineament**, and components of the complex **Welsh Borderland Fault System** (**WBFS**) including the **Pontesford Lineament** and the **Church Stretton Fault Zone**. The influential **Severn Valley Fault Belt** has long been held to be contiguous with the more southerly **Tywi Anticline** with both viewed as components of a Tywi Lineament. An argument is presented here (see Text Box 1) to reject this assertion and terminology. The belt of faulting and associated vergence divides traversing west Wales, recognised as the **Llangranog Lineament** (Craig, 1987; Kokelaar, 1988), appears essentially synonymous with the 'Glandyfi Lineament' of other authors (e.g. Cave and Hains, 1986; Fitches and Campbell, 1987) and is here extended also to include the **Bronnant Fault Zone** (see Davies *et al*., 1997, 2006b). However, it appears to form only the eastern flank of a broader tectonic lineament that was active in south-west Wales during the early development of the LPWB. This includes the **Cardigan-Fishguard Fault Belt**, which incorporates the influential **Aber Richard** and **Newport Sands faults** and was host to the **Fishguard Caldera**. The **Robell Fracture Zone** (RFZ) acted as a coeval feature in North Wales and invites speculation that there once existed a contiguous **Fishguard-Robell Fracture Belt** (cf. Kokelaar, 1988). The belt of faults that occupies the western side of the Harlech Dome and which includes the **Mochras Fault** is recognised by Kokelaar (1988) as the Barmouth Fracture Zone. The suggestion that this extended into central and northern Snowdonia, where it acted as a focus for Caradoc vulcanicity, appears to have been rejected by Smith *et al*. (1995).

In Pembrokeshire, the E-W trending **Benton-Johnson Fault Zone** record the potentially substantial late Variscan displacement of precursor structures that were once influential in defining the southern margin of the LPWB and that served to separate it from the **Skomer Sub-basin** to the south (e.g. Dimberline *et al.*, 1990). These fundamental features, and their predecessor and linking structures, have long histories of movement. They served collectively to define the principal palaeogeographical features of the LPWB and its adjoining regions including the limits of the basin, the location of internal graben and longer-lived sub-basins, as well as intervening axes of uplift and more extensive sub-platforms (see Figs 6, 12-14, 22, 23).

**Text Box 1. Welsh Borderland Fault System:** The form and definition of the WBFS has largely gone unchallenged since it was first proposed as a concept by Woodcock and Gibbons (1988). However, subsequent BGS mapping has shown its three principal fold and fracture belts to be individually more complex. In particular, the Tywi and Pontesford lineaments are now known to encompass a series of secondary fault belts that differ in their histories of movement and stratigraphical impacts (e.g. BGS, 1993a, 1994, 2005 a,b, 2008). These findings also question the degree to which these lineaments were separate entities with faults trending to the west of the Builth Inlier, including strands of the Garth Fault Belt, appearing to have affinities to both. The Tywi Lineament loses obvious definition as it is traced south-westwards into Carmarthenshire. There, structures such as the Crychan Fault Belt, Sawdde Fault and Cwm Cynnen Fault appear to be more significant as structural and sedimentological divides; all having *en echelon* links to the Garth Fault Belt and Pontesford Lineament.

It has seldom been questioned that the gross alignment of the more northerly Severn Valley Fault Belt (SVFB) with the Tywi Anticline of earlier literature (e.g. Bassett, 1969) offers compelling reason to view both as components of the Tywi Lineament (Woodcock and Gibbons, 1988). Yet their operational histories are very different. Davies *et al*. (1997) have shown that the stratigraphy and structural expression of the Tywi Anticline was largely shaped by intra-Telychian movements on its master faults, associated mass wasting and by later Acadian reactivation. Throughout much of the Caradoc to mid Llandovery, the Cwmysgawen, Carmel and Nant y Fedw faults operated principally in a deep-water setting. The fractures that effected the transition between deeper and shallower settings, most notably the Garth Fault Belt, are located along the anticline's eastern flank. Only during the acme of the Hirnantian regression, in the Abbeycwmhir area, did shallower water facies encroach further west. The Severn Valley Fault Belt has a very different history. It acted as a tectono-topographic feature that influenced the geometry of exclusively shallow water Caradoc and early Llandovery facies. It remained active during the Telychian in promoting condensed shallow water facies deposition (Ty brith Member). Its stratigraphical impacts, rather than with those of the Tywi Anticline region, compare with those seen in the vicinity of the Builth Inlier and in the Garth and Llandovery areas and, hence, are comparable to those associated with of the Pontesford Lineament. Whereas the region of the Tywi Anticline underwent foundering to accommodate southerly sourced Wenlock turbidite facies, the Severn Valley Fault Belt continued to operate within a region of relative uplift from which these sand-prone deep-water facies were excluded (e.g. Bassett *et al*., 1992; Cave and Hains, 2001; Cave 2008).

Hence, the current definition and perceived role of the Tywi Lineament is as problematical. Outcrop patterns associated with the N-S trending SVFB are made complex by its interference with a wide belt of ENE-WSW orientated folds and cross-faults parallel to the Ystwyth and Bryn Posteg fractures. However, exposures permit an alternative alignment of the SVFB's master faults - with those of the Garth Fault Belt (Fig. 6). The Tywi Lineament is then reduced to the crudely anticlinal belt of faulted Ordovician rocks that plunges out northwards beneath Silurian strata near Abbeycwmhir and abuts the Cwm Cynnen belt of faults east of Carmarthen; and on this basis should be excluded from any formal definition of the WBFS. The locally adjacent Severn-Garth-Cwm Cynnen Fault Zone (SGCFZ) emerges as a more extensive, if in places arbitrary palaeogeograhical and structural divide. Along much of its length, the latter separates the region of curvilinear fold axes and faults that typifies the deformed deep-water succession of the South Wales Sub-basin, including the Tywi Lineament, from the shallower facies regimes of the more structurally heterogeneous Marginal Belt. To the north and south-west, this facies transition diverges to track the flanks of the North Powys and North Pembrokeshire sub-platforms respectively (Figs 12-14). Here, the SGCFZ forms the contact between the MB and these sub-platformal extensions (Fig. 6).

The north-western margin of LPWB lay along the line of the Menai Strait Fault Zone (see Schofield *et al*., 2020). Its component basin-facing fractures include the **Dinorwic** and **Aber-Dinlle faults** of the Bangor district, and contiguous features recognised on the Llŷn Peninsula including the **Llŷn Shear Zone** and **Amlwch-Rhiw Fault**. Though the fault zone clearly acted as a terrane-defining feature, it is clear from the geological maps of the Llŷn and Bangor regions that several of its component faults were onlapped by rocks which form part of the LPWB's stratigraphy. In this report, it is the Dinorwic Fault, and its extensions offshore and on Llŷn, that are taken to mark the north-western limit of the basin (Figs 1A, 6). To the north-west, a narrow **Irish Sea Platform** (or Horst) is widely assumed to have formed a partial or periodic barrier between northern parts of the LPWB and the largely coeval Lake District Basin, although their palinspastic relationships of these structural units has been shown to be uncertain (see Hillier *et al*., 2024). The role of the WBFS in defining the south-eastern margin of the LPWB is discussed more fully below; to the east and south, the tectonically stable Midland Platform had links to the cryptic southern source region that Cope and Bassett (1987) recognised as 'Pretannia'.

Intra-basinal fractures were important in locating the sites of volcanic eruption and controlling the location and preservation of sedimentary facies. Notable amongst the persistently positive palaeogeographical regions within the basin were the *en echelon* **Harlech Horst** (note that this differs conceptually from the structural **Harlech Dome**; see Kokelaar, 1988), **Derwen Anticline** (sometimes listed as Horst or Ridge) and **Berwyn Dome**. These served as sites of periodic shallow water deposition and of sediment starvation and erosion, including submarine mass-wasting. At times when the crestal regions of these features operated in concert, they can be recognised as a **Derwen-Berwyn Axis** that acted to subdivide the LPBW into a **North Wales Sub-basin** (North Wales Basin of Warren *et al*., 1984; Denbigh Trough of Cummins, 1959) and a **South Wales Sub-basin** (Woodcock, 1984) (Figs 6, 12-14). The Arenig to early Caradoc **Snowdon Trough** (not to be confused with the Snowdon Graben) was an early expression of the North Wales depocentre that extended into the Llŷn Peninsula (Smith *et al*., 1995). It is doubtful that a significant thickness of post mid-Telychian sediment accumulated across Snowdonia and the Llŷn, during which time these areas supplied sediment a deeper setting then located to the east of the **Conwy Valley Fault Belt** (Warren *et al*., 1984). At times, the structural barriers between the North and South Wales sub-basins were ineffectual and facies development more uniform. Opinions differ about the relationship of the E-W **Black Rock Sands Fault** to the N-S Mochras Fault and its attendant fractures. BGS (1982) show the latter truncating the former, but other sources dispute this (e.g. Hesselbo *et al*., 2013). Though BGS maps fail to identify any eastward extension of the Black Rock Sands Fault beneath the largely drift-filled Vale of Ffestiniog, exposures permit the existence of such a structure. Patterns of intra-Ordovician erosion and deposition to the north of the valley, associated with the southern margin of the Snowdon Trough (Smith *et al*., 1995), point to the presence of an important structural hinge recognised as the **Vale of Ffestiniog Lineament**. This formed part of an influential belt of *en echelon* E-W and NE-SW trending structures that includes segments of the

**Fynnon Eidda** and **Ysbyty Ifan faults**. By extending it further east to include fractures associated with the northern flank of the Derwen Anticline and the powerful Llanelidan Fault, this putative structural line emerges as a feature that served both to define and subdivide the North Wales Sub-basin (Fig. 6).

In detail, the successions of the Berwyn Dome and the Brogan and Guilsfield anticlines, west of Welshpool, and arguably of the more northerly Cyrn-y-brain and Mynydd Cricor inliers, attest to the presence of a more extensive region that sustained shallower water conditions and promoted omission at various times during the evolution of the north-eastern sector of the basin. It is convenient, if imprecise, to recognise this as the **North Powys Sub-platform**. The newly named **North Pembrokeshire** and **Llŷn sub-platforms** had comparable impacts in other regions of the basin. Traversing faults served to compartmentalise these structurally positive features and influence their associated successions (see Appendix 4). Nor was the Midland Platform a uniform structural entity. It was traversed by fault belts and hosted fault-bounded sub-basins that were active at different times during the Lower Palaeozoic. At times, it is appropriate to view the platform as comprising an outer region, adjacent to the Church Stretton Fault Zone, and an ill-defined inner sector to the south. Traversing the latter were the periodically influential NE-SW trending **Leinthall Earls Fault** and the **Swansea Valley** and **Vale of Neath disturbances** and the NW-SE orientated **Woolhope Fault Belt**. Comparable fractures in south Pembrokeshire include the ESE-WNW trending **Musselwick** and **Ritec faults**. The north-south trending **Malvern Line** (or Lineament) is a further long-lived and fundamental structural feature that served to separate the Midland Platform into western and eastern components.

### 1.2.2 Definitions and usage

The successions of the WBFS broadly reflect their transitional position between prominently deeper water, typically turbiditic, successions of the subsidence-prone South Wales Sub-basin and the incomplete, shallow water successions that characterise the structurally positive Midland Platform. In detail, however, the boundary between these differing facies and subsidence regimes migrated over time in response to eustatic and/or tectonic events, so that it is simplistic to categorise the WBFS as marking the location of fixed 'basin margin' as is commonly implied.

It becomes clear that the terminology for different settings within and adjacent to the LPWB, and the changing succession of facies they hosted over time, needs careful definition. Typically, the terms 'basin' or 'basinal' has been used rather loosely and to serve two purposes: as a palaeogeographical label for the subsidence-prone depocentre as a whole, but also as a descriptor for the deep-water facies that were seen to characterise substantial parts of it. This usage was complimented by the use of 'shelf' or 'shelfal' as terms for regions and successions typified by facies and faunas of shallower water aspect that, by simplistic implication, lay outside the ‘basin’. Such successions were characterised as being thinner and to provide evidence for periodic, and at times protracted, subaerial erosion. They were viewed as contiguous with those of the Midland Platform (see Bassett, 1969) though it was well established that the latter, defined on its western side by the Church Stretton Fault Zone, was a separate structural entity and hosted a significantly thinner, incomplete and, for the most part, compositionally distinct succession of facies.

This conceptual conflation works well for some intervals. For example, Davies *et al*.’s (1997) adoption of the Garth Fault as the basin’s eastern defining structure during the Llandovery, adequately served this dual purpose. It fulfilled this role less well during the Wenlock and arguably not at all during the Ludlow and (?)Early Pridoli. And the rifted structural foundations of the LPWB’s Ordovician successions mitigate against such a simplistic differentiation. The periodic inactivity of intra-basinal highs and sub-platforms is a further obstacle to establishing a fixed view of the basin’s palaeogeography. It becomes clear that the interface between shallow and deep-water facies and the locations of subsidence-prone regions evolved and migrated over time and in patterns that were not always in concert with one another; building successions that record complex vertical and lateral changes in depositional setting and subsidence regime.

The broad scope of this report, dealing as it does with the whole of the LPWB’s marine evolution, requires a more circumspect approach. Thus, the term ‘basin’ as used herein pertains to the entire Ordo-Silurian depocentre that was once confined between the Menai Strait Fault Zone’s Dinorwic Fault (see above) and the easternmost stands of the Church Stretton Fault Zone (Fig. 1A). It is reasonable to refer to all the rocks that formed within this broad region, both sedimentary and igneous as ‘basinal’. The facies that developed within this region are categorised as either of ‘deep-water’, or ‘shallow water’ aspect based on their sedimentological and faunal characteristics (Fig. 7; Table 3). For practical purposes, successions that describe rapid and complex transitions between these depth-related states can be recognised as ‘mixed’. The terms ‘platform’ and ‘platformal’ are retained as labels for the exclusively shallow water successions associated with the Midland Platform and its western extension into south Pembrokeshire (Figs 1A, 6). The report takes the intra-platformal Malvern Line as its eastern limit. In the context of tectono-sedimentary terranes, Woodcock (2000) ascribes the area of interest to the **Avalon Composite Terrane**. As components of the latter, the LPWB is recognised as the **Cymru Terrane**, and the parts of the Midland Platform sited to the west of the Malvern Line as the **Wrekin Terrane**. The more northerly Irish Sea Horst region comprises the **Monian Composite Terrane** (Schofield *et al*., 2020).

The complexities of the WBFS demand that it is recognised as a distinct structural and palaeogeographical region of the LPBW. It manifestly formed a flanking region to the South Wales Sub-basin, but the common assertion that it acted as a marginal shelf is only crudely applicable in so far as it intervenes between areas with the thickest and oldest successions of deeper water aspect, to the west, and platformal successions to the east (see below). The term ‘shelf’ seems inappropriate for successions that testify only periodically to the blanket deposition of offshore muds in a low gradient setting and to the presence of a distinct shelf edge break. Other intervals record a ramp-like continuum between deeper and shallower settings. There were also periods when facies distributions and thicknesses attest to a complex internal topography with active sub-basins and axes of uplift, to localised mass-wasting, slumping, debritic and olistostromic deposition and to structural inversion (Plate 1). The role of this flanking region also changed significantly in late Ludlow times as eastern parts of the basin experienced partial uplift and the WBFS became the focus of subsidence and deposition.

The term **Marginal Belt** is used here as a descriptive term to encompass the region occupied by the WBFS and the complex stratigraphical relationships and transitions associated with it. The North Powys and North Pembrokeshire sub-platforms were both attached to the Marginal Belt and served to extend the reach of shallower facies into areas of the basin that, at other times, were sites of deep-water facies accumulation. In having links to the Irish Sea Horst, the Llŷn Sub-platform, which merged periodically with the Harlech Horst, appears to have acted in a comparable manner in the north of the basin. Subsidence affecting northern parts of the Marginal Belt during the Ludlow allowed the focus of deep-water deposition shift significantly eastwards. Recent studies prefer to recognise this younger region of subsidence as a distinct **Clun Forest Sub-basin** (see Part 3). The definition and limits of this feature, and its relation to the ‘Montgomery Trough’ or ‘Clun Forest Basin’ of earlier authors, have been revisited by Hillier *et al*. (2024; see Figs 21, 22). The Central Wales Lineament likely formed its western margin. In the east, facies associated with the sub-basin onlapped the CSFZ. The evolution of the Clun Forest Sub-basin was precursor to the more profound changes in subsidence regime that overtook the sites of LPWB and Midland Platform during the late Ludlow, Pridoli and Early Devonian. These allowed the region to accommodate orogenic Old Red Sandstone molasse being shed southwards from uplifted Caledonian source areas. The tectonic context of this **Anglo-Welsh Basin** is assessed more fully by Barclay *et al*. (2015) and Hillier et al. (2024).

Volcanic and intrusive igneous rocks are defined and described according to a separate set of parameters that largely lie outside the remit of this report. Their lithostratigraphical definitions and usages, except where stated otherwise, largely follow the recommendations of their original sources. Herein, the lithostratigraphical synthesis provided by Rushton and Howells (1998) for the Ordovician volcanic units of North Wales is largely unchallenged, but their group and subgroup-scale recommendations for the associated and enveloping sedimentary succession are not (see below). Finally, the term ‘tract’ is used in a very specific way in this report (see below) and so its use in a descriptive geographical sense has largely been avoided.

## 1.3 OUTSTANDING PROBLEMS

Although a framework of events can be established for the Ordovician and Silurian of Wales, there remain a number of obstacles to the goal of a comprehensive, basin-wide stratigraphical synthesis. Structural complexities resulting from the Acadian deformation have resulted in the irregular distribution of individual successions and, notably for outcrops of Ordovician strata, minimal surface connectivity between them. Historically, this has promoted geographically restricted studies of inliers and outliers and, as a consequence, the erection of multiple, geographically limited stratigraphical schemes for rocks of comparable age and facies. Of course, the need for regional and far-field correlations was widely acknowledged by even the earliest of workers, but in the absence of complete map coverage and with only a limited understanding of correlations, most were content to add to, rather than rationalise the ever-expanding lexicon of stratigraphical terms.

### 1.3.1 Biostratigraphy and other methods of correlation

Regional studies of individual time slices within the LPWB were first attempted in the 1950s and 1960s, but were hampered by incomplete biozonal schemes and a limited understanding of how schemes for different taxonomic groups and erected in different facies matched with one another. Subsequent biostratigraphical studies in the LPWB, many of them initiated by BGS surveys, have contributed to an international effort to address these deficiencies. Historically, evolving graptolite assemblages have proved to be most useful means of dating the basin's dominant deeper water facies, and continue to be studied extensively (see Zalasiewicz *et al*., 2009, and references therein). Brachiopods and other benthic forms have, and continue to play their part in dating marginal and platformal successions (e.g. Holland *et al*., 1963; Holland and Bassett, 1989; Rushton *et al*., 2000; Davies *et al*., 2013) and have proved additionally important from a paleoenvironmental standpoint (see below).

However, much additional work is needed to resolve the significant obstacles to basin-wide and international correlation that remain. Our understanding of how the evolving assemblages of shelly taxa present in Silurian shallower water facies relate to the graptolite biozonation established in their deeper water counterparts is now greatly improved (e.g. Davies *et al*., 2013, 2016), but the cross correlation of Ordovician graptolite and benthic biostratigraphical assemblages remains incomplete. The impoverished and poorly preserved nature of the graptolite assemblages found in Marginal Belt and platformal successions remains problematical. Detailed work on Welsh graptolite assemblages has greatly refined the level of biozonal subdivision and permitted more precise international correlations. However, problems remain that stem from the acknowledged roles of provincialism and environmental factors on taxonomic distribution within LPWB and more widely (e.g. see Williams *et al*., 2003; Zalasiewicz *et al*., 2009, and references therein).

A more obvious obstacle to correlation is that large thicknesses of strata in the LPWB are devoid of biostratigraphically useful macrofossils. Advances in microfossil schemes offer hope that these may be able to 'fill in the gaps', and recent work on acritarch and, in particular, chitinozoan assemblages supports this (e.g. Mullins and Loydell, 2001; Vandenbroucke, 2005, 2008; Vandenbroucke *et al*., 2008a and b, 2009; Davies *et al*., 2013; Challands *et al*., 2014; De Weirdt *et al*., 2019). Conodont assemblages that have proved important internationally in dating carbonate successions are far less useful in for the predominantly clastic sedimentary facies of the LPWB. Amongst the studies of Welsh Ordovician assemblages documented in Rushton (2000) and by Molyneux *et al*. (2023), the work of Bergström (1987; also Ferretti and Bergström, 2022) is noteworthy. Silurian conodont findings, including those for the limestone-rich Silurian successions of the Midland Platform, are listed in Aldridge (2000) and by Davies *et al*. (2011; and references therein). Silurian spores continue to be relied upon heavily for the dating of Ludlow and Pridoli strata (see Hillier *et al*., 2024) and there are limited studies of earlier intervals (e.g. Burgess, 1991). At the time of writing, much of the basin fill remains unstudied from a micropalaeontological aspect; moreover, current microfossil schemes fail to provide the levels of biozonal resolution offered by graptolites. The use of geochemical analysis to aid both environmental interpretation and correlation has gained significant ground in Marginal Belt and Welsh Borderland successions even during the compilation of this report (e.g. Ray *et al*., 2019; Wang *et al*., 2024a). Again, its application to the deeper successions of the LPWB is largely untested, but exceptions include the investigations of Challands (2008), Vandenbroucke (2005), Snelling *et al*., (2011) and Melchin *et al*. (2018, 2023).

The role of sequence stratigraphy is discussed more fully below. Followings Woodcock's (1990) efforts at a basin wide sequence stratigraphical synthesis there has been limited further progress. Davies *et al*. (1997, 2013 and 2016) offer an analysis of early-mid Silurian successions in the South Wales Sub-basin and Ray (2010; also Davies *et al*., 2011) has assessed the sequence stratigraphy of the Wenlock of the Midland Platform. However, in general, the complex interaction of local tectonic with global events that shaped the fill of the LPWB presents an obstacle to such work (see Woodcock *et al.*, 1996), which the systems-based approach outlined below has sought to sidestep. Further advances on any or all of these research fronts will likely impact on the findings and recommendations of this report.

### 1.3.2 Map coverage of the LPWB

The plethora of local names that have found their way onto existing paper and digital BGS geological maps (Fig. 2) and into the BGS Lexicon (currently there are around 480 full or partial Lower Palaeozoic entries for Wales) partly reflects the history of geological map-making in Wales. Historically, BGS, and its precursors as the national geological survey, focused much of their efforts on revising the coverage for the resource- and population-rich coalfields of South and north-east Wales. Following the Primary one inch-to-one mile survey, completed in the mid-19th century, the geological map for much of 'Lower Palaeozoic Wales' was not revisited until late in the 20th Century (Appendix 1). In the absence of modern geological maps for large parts of the mid and north Wales, and with no immediate plans for their resurvey, interim or 'provisional' maps were issued periodically to replace the existing one-inch series. Most provisional maps were compiled from academic sources augmented by the findings of limited reconnaissance mapping. Of necessity, these lent heavily of already published stratigraphical schemes that were of differing age, limited geographical extent and variable quality. Since the mid 1970's, many of the BGS sheets covering the LPWB have been resurveyed. However, for many of these some form of 'rapid mapping' technique was utilised that placed a heavily reliance on traverse mapping and aerial photograph interpretation.

In many ways, the construction and release of BGS's digital geological map of Wales marked the first step towards standardising the terminology used for the LPWB stratigraphy and has proved a useful starting point for the current exercise. However, this digital product lays bare many of the boundary issues that exist between the different generations of mapping. Its office-based compilers were obliged to make assumptions about the lateral equivalence of differently named units that were not always correct; and, since its release, coding errors have also come to light. A key recommendation of this report is the need for a root-and-branch revision of this digital product.

# 2 Towards a new group-scale lithostratigraphy

## 2.1 INTRODUCTION

Much of the early outputs of BGS (and its precursors) in Wales sought principally to distinguish rocks of the same age, and such units continue to be the principal content of many regional and UK-wide maps. That there must be significant lateral changes in rock type and associated fossil assemblages was soon established and the role of much 19th Century mapping and fossil collecting largely focused on resolving such problems. It soon became apparent that the significant changes in fossil content used to date rock units commonly coincided with major changes in lithofacies and regional geological events. As issues linked to facies control and international diachroneity of faunas surfaced and the criteria used to define chronostratigraphical divisions were revised, the need for lithostratigraphical and chronostratigraphical divisions to be independent on one another became clear. Nevertheless, it is no accident that the bases of many of the chronostratigraphical divisions originally erected in Lower Palaeozoic Wales remain significant as modern lithostratigraphical boundaries. The original level adopted as the base of the Silurian in mid Wales is a good example (see BIII Systems Tract) (e.g. Jones, 1909, 1924; Davies *et al*., 2009).

## 2.2 SEQUENCE STRATIGRAPHY *VERSUS* LITHOSTRATIGRAPHY

The advent of sequence stratigraphy as means of analysing sedimentary successions brought the role of flooding events to the fore. By recognising such horizons it became possible to subdivide successions into a series of sedimentary slices that record the impact of these events, and the accommodation space they created (or destroyed), across a range of coeval depositional settings. Since flooding surfaces, including unconformities and correlative conformities, typically mark levels of abrupt change in lithofacies, many sequence and parasequence boundaries coincide with lithostratigraphical contacts.

Woodcock (1990), by utilising a rock preservation methodology, was the first to attempt a sequence stratigraphical analysis of the LPWB succession. His approach allowed him to recognise a hierarchy of sequence stratigraphical divisions which continue to have merit (see below). However, his methodology took less account of major sequence-defining eustatic events, or the marked facies changes they led to. Moreover, Woodcock *et al*. (1996), in their critique of the sequence stratigraphical approach to the Silurian of the LPWB, highlighted the complexities of applying sequence stratigraphical models to basins and depositional systems in which relative base-levels are controlled by a mix of eustatic and tectonic factors, and which experienced marked and diachronous changes in sediment provenance and subsidence regimes.

Nevertheless, regional omission surfaces (including unconformities) that serve to define the boundaries of major lithostratigraphical divisions, also represent sequence-defining flooding surfaces. In the context of this report, divisions defined by such lacuna feature in the shallower water successions of the Marginal Belt and Midland Platform. However, in seeking to aid interpretation of the basin fill, the temptation is then to rely on correlative conformities as a means of defining their deeper water lithostratigraphical counterparts – an approach adopted by Davies *et al*. (1997) for the Silurian succession of mid Wales. Certainly, the coincidence of flooding events, faunal renewals and abrupt changes in lithofacies is a feature of the original levels selected for the bases of many of the chronostratigraphical divisions originaly erected in the LPWB, including those for the Arenig, Llanvirn, Caradoc, Llandovery, Wenlock and Ludlow series.

Since the basal stratotypes for many of these chronostratigraphical units were placed at lithological contacts, it is unsurprising that many are now recognised as significant in a sequence stratigraphical context and as important boundary levels in lithostratigraphical scheme advanced herein.

Regional geological maps that show a group-level lithostratigraphy that seeks only to emphasise this sequence-based approach will differ little in style from those showing the original chronostratigraphical divisions. Sequence stratigraphy, whilst offering a powerful means of interrogating sedimentary successions, does not, in-and-of itself, offer the means for lithostratigraphical subdivision, particularly in a tectonically active basin (e.g. Woodcock *et al*., 1996). In utilising a form of ‘event stratigraphy’, the scheme advanced herein borrows much from the sequence stratigraphical methodology, but in seeking to establish rigorously lithostratigraphical definitions, differs both conceptually and in practice (see below).

## 2.3 DEPOSITIONAL SYSTEMS

A useful product of the facies analysis undertaken as part of sequence stratigraphical studies is the concept of **depositional systems** (see Galloway, 1998). A depositional system is a three-dimensional body of rock that encloses a set of sedimentary facies (a facies association) that can be linked to a particular environmental setting and can be applied at various scales. As a relevant example, a large-scale deep-water system can comprise separate slope-apron and sandstone lobe systems which, in turn, enclose smaller scale subsystems.

**Volcanic systems** reflect a rather different set of driving mechanisms and processes, but that still lead to the formation of three-dimensional – commonly highly complex–- bodies of rock that encompass the products of individual volcanic centres including both their eruptive and intrusive components. Pyroclastic deposits that have been deposited and reworked by sedimentary processes are clearly hybrid in character. The complex interdigitation of volcanic facies with enveloping sediments presents a very real conceptual and practical problem that requires a pragmatic approach to system definition and mapping (see below). The intrusive components of the LPWB's volcanic systems are excluded from this account.

By enclosing rock units of closely related facies and recognising boundaries between adjacent facies associations, volcanic and sedimentary systems serve as the building blocks for a detailed architecture for the basin fill. In doing so, they offer a route to a lithostratigraphical classification that seeks to establish a regional hierarchy of group and sub-group scale divisions. More pertinently, many already mapped lithostratigraphical boundaries mark the levels of significant lithofacies changes that can be used to define system boundaries. Davies *et al*. (1997) adopted this approach in erecting their sedimentary architecture for the late Ordovician-Silurian succession of the southern sub-basin. Rushton and Howells (1998), though they did not label it as such, effectively used a systems-based approach to construct their architecture for volcano-sedimentary Arenig to Caradoc succession of North Wales and, by doing so, were able to refine its lithostratigraphy. This report seeks to extend this systems-based approach to the entire fill of the LPWB and to flanking Midland Platform successions.

## 2.4 MAIN TYPES OF DEPOSITIONAL SYSTEM IN THE LPWB

The main systems and system hierarchies recognised herein are described in Table 3. The entire basin fill and its contiguous correlatives could be said to constitute a **Welsh Basin-Midland Platform Marine Mega-system**. Within this, there is a clear case to distinguish **volcanic systems** from **sedimentary systems**. Here the latter are argued to be subdivisible into **deeper water systems** and **shallower water systems** based on their sedimentary facies and faunas. As obvious as this appears, there are real challenges when seeking to erect and apply objective criteria for this depth-related differentiation (see Fig. 7; Text Box 2).

**Text Box 2. Depth-based systems:** Application of the depth-based 'deep-water' and 'shallow water' classification for the depositional systems of the LPWB and Midland Platform requires some qualification. Any attempt to use absolute depth in ancient sedimentary basins is problematic. Depth designations are nearly always relative and based on secondary lines of evidence principal amongst which are lateral changes in sedimentary lithofacies, fossil assemblages, including trace fossils, and sedimentary structures (see Fig. 7). Work on Ordovician and Silurian benthic and pelagic fossil communities in Wales and the Welsh Borderland has allowed some authors to speculate on absolute depth ranges. The association of blind benthic with large-eyed pelagic trilobites in late Arenig rocks in Pembrokeshire suggested to Fortey and Owens (1987) that deposition occurred at a depth of 300 m or more 'just below the critical depth for the penetration of light' (Owens, 2000). Fortey (2006) identified a comparable Caradoc atheloptic assemblage from the graptolitic Mydrim Shales Formation (Drefach Subgroup). In contrast, Owens (2002) viewed the greater proportion of sighted trilobites preserved in coeval Llanfawr Mudstones Formation of the Builth Inlier as consistent with a water depth in the range 150-200 m.

The graptolitic mudstones of the LPWB, of both Ordovician and Silurian age, have widely been assumed to record deep conditions (e.g. Zeigler *et al.*, 1968). Fortey (2006) certainly viewed his Mydrim Shales Formation trilobite assemblage as a 'deep-water' fauna. However, he also argued that reduced oxygenation levels explained the absence of similar trilobites from the otherwise black, graptolitic mudstones of the host formation. It follows that the latter, and like facies throughout the Drefach Subgroup, need not record accumulation beneath a significantly greater depth of water. Hurst *et al.* (1978) suggested that the *Visbyella trewerna* Benthic Community present in laminated and graptolitic Wenlock mudstones (Builth Mudstones Formation), and a successor to the Llandovery Marginal Clorinda Community of Cocks and Rickards (1968), could have colonised substrates as deep as 1500 m, but acknowledged its likely prevalence in much shallower settings.

The host facies of both these Caradoc and Wenlock examples formed outside the realm of widespread turbidite accumulation. In both cases, deposition occurred in offshore settings where sedimentary features and faunas owed as much to the muddy nature of the substrate and/or low levels of oxygenation, as to water depth. In both, lateral facies transitions allow them to be viewed as the distal components of shallow water sedimentary systems. Some may find objectionable the labelling of facies that formed in depths of 300 m, or more, as 'shallow water', but this simply illustrates the crude binary nature of the classification used herein.

Conversely, evidence of protracted and widespread deposition by mass flow (slumps, debrites, turbidites) and hemipelagic processes, in settings that largely precluded colonisation by shelly benthos is commonly seen to offer a practical indication of deep-water conditions (Fig. 7). Yet, such criteria offer no indication of absolute depth. There were also settings, particularly in the early Arenig rift sub-basins and in the vicinity of Caradoc volcanic edifices, where mass flow deposits accumulated adjacent to shallow water sites and likely under only modest water depths. It is to sidestep such semantic issues that the concept of mixed depositional systems is employed (see text).

In the LPWB, as elsewhere, the presence of a predominantly pelagic fauna, dominated by graptolites (Plate 2), has previously underpinned widespread usage of the term 'graptolitic facies' as a synonym for deep and basinal and to contrast with shallower 'shelly facies'. The colonising depth of shelly benthic communities is implied to be a useful approach in differentiating shallow from deep. However, the levels of oxygen in bottom waters also influenced the position of this level in ways unrelated exclusively to depth. Moreover, the depth of colonisation changed with time as new benthic communities adapted to deeper conditions appeared, but also as forms, notably blind and poorly sighted trilobites, that had previously been dominant in deeper distal settings were displaced or became extinct. In addition, textures and trace fossils show that, with the exception of those that characterise the shallowest facies and settings, the distribution of many soft-bodied, bioturbating organisms (ichnofauna) was less constrained by depth and palaeogeography than by levels of bottom-water oxygenation. Fluxes in salinity and linked environmental factors were undoubtedly also influential.

As we have seen, the terms ‘basinal’ and ‘shelfal’ come with their own misconceptions and classification baggage. In this account, it has seemed important to move away from the subjective approach that has seen all facies in particular locations labelled according to these arbitrary physiographical terms. Yet, as Figure 7 makes clear, few sedimentary and faunal features are unequivocally diagnostic of deep settings. Deep-water systems can reasonably be characterised as constructed, in the main, from mass-flow (turbidites, debrites) and hemipelagic components. Yet turbidites linked to storm and river flood events and to instability on delta fronts and steep, fault-generated gradients can also occur in facies for which other criteria imply shallow water affinities. The analysis of Marginal Belt and Midland Platform facies by Benton and Gray (1981) and Tyler and Woodcock (1987) are particularly pertinent in this context. Periods of sustained anoxia and reduced sedimentation also saw hemipelagic mudstones accumulate widely in such settings (Figs 7, 8). These difficulties point to the pragmatic need to weld objective lithological and faunal criteria to the palaeogeographical setting envisaged at the time of accumulation. Thus, it is possible to view facies that in the past have labelled ‘deep’ (e.g. Drefach Subgroup), but that accumulated astride intra-basinal highs, on sub-platforms and across the Marginal Belt, as the distal components of a shallow water facies continuum (see below). Fortunately, for the most part, mapped stratigraphies provide the means to apply this pragmatic binary (deep, shallow) classification on the ground and, in so doing, underpin the lithostratigraphical hierarchy presented herein. However, there exist units in which such differentiation is seen as either impractical, or where mapped divisions fail to capture it. These **mixed systems** were important components of the basin fill at certain times and in particular settings during its accumulation. Distinctive facies and condensed successions characterise **intra-basinal high systems**; and **terrestrial systems**, that came to dominate during the accumulation of the ORS Supergroup, are also present as localised units within the Welsh Basin-Midland Platform Marine Mega-system. The hypothetical form and relationships of the depositional systems outlined below are illustrated in Figure 8.

### 2.4.1 Deep-water systems

Davies *et al*. (1997) recognised different categories of deeper water system in the late Ordovician to Silurian succession of mid Wales. Here, these categories are applied more widely to the LPWB fill. Thus, **slope-apron systems** comprise wedge-shaped accumulations of turbiditic and hemipelagic mudstone that thin away from more elevated settings and locally enclose lenticular coarse-grained turbidite subsystems. Packets of strata that record deposition under oxic bottom conditions alternate with anoxic facies (Plate 3) in patterns that commonly appear to reflect eustatic events. During other periods, tectonically generated and fault confined **sandstone-lobe systems** invaded the basin rapidly building successions that locally exceed 2 km in thickness. The waxing and waning of sediment supply to such systems and their lateral migration underpin the recognition of component subsystems.

Steeper gradients, generated principally during periods of fault reactivation, developed periodically along the basin's margins and the flanks of areas within the basin prone to uplift. Both were settings susceptible to submarine mass-wasting and instability. The associated condensed successions and resulting slides and piles of slumped strata and debritic deposits, including huge olistoliths, comprise **slope** and **foot-of-slope systems**. In practice, the facies that reflect these processes and settings, though recognisable as members or formations, are included lithostratigraphically within groups that comprise enveloping systems. Slides and slumps associated with shallow water ramp and delta fronts, though they may terminate in deeper settings, are excluded (Fig. 8).

### 2.4.2 Shallow water systems

Intergradational shallow water system characterise the basin's Marginal Belt and the platform to the east and south, but for long periods also extended on to intra-basinal highs and flanking sub-platforms. Those of Ordovician and Silurian age differ greatly in character. The former are dominated by dark mudstone facies with mixed trilobite and graptolite faunas; limestone and sandstone facies are subordinate. With the exception of laminated distal facies (e.g. Builth Mudstones Formation), graptolites are rare in the bioturbated sandstones and mudstones that dominate Silurian shallow water systems. Calcareous lithologies including reef and shoal-hosting limestone facies are a feature of the Silurian successions on and bordering the Midland Platform.

Numerous studies, focussing in particular on brachiopod and trilobite fossil communities of different ages, have been shown to provide critical insights into the influence of changing water depths and sea floor conditions (e.g. Ziegler *et al*., 1968; Williams *et al*., 1981; Hurst, 1975 and *et al*., 1978; Watkins, 1979; Atkins, 1979; Cocks *et al*., 1984; Fortey and Owen, 1987). Many studies of Silurian benthic communities are detailed in Boucot and Lawson (1999). Trace fossil assemblages reveal much about bottom water oxygenation levels and/or rates of sedimentation in both deep and shallower settings of the LPWB (e.g. Challands *et al*., 2009; Melchin *et al*., 2023; Hillier *et al*., 2024).

It has long been recognised that their faunas make it feasible to distinguish proximal from distal shallower water facies. Working in the Llandovery area, Davies *et al*. (2013) use the terms topset, forset and bottomset facies as part of a clinoform depositional model. However, the labels inner, mid and outer ramp may better reflect the gross wedge-shaped geometry of some Marginal Belt successions and the intergradational nature of their facies. Rapid lateral changes in facies testify to the relative steep depositional gradients that characterised these **clastic ramp systems**. Ramp systems occur anchored to fault-located axes of uplift (e.g. Cwm Rhuddan Group), or seaward of extensive blanket systems (e.g. Builth Mudstones Formation), and in both cases transition into deeper slope apron systems. Also prevalent, notably during the Wenlock and Ludlow, are laterally extensive successions of progradational facies that describe the input and reworking of sediments supplied by south-westerly sourced deltas. Ramp-like depositional profiles were again a feature of these **clastic delta systems**. Rhuddanian facies of the Woolhope and Usk sub-basins that are speculated to be of fan delta origin are included in this category. Deltas supplied by molasse sediment from the north were a feature of the late Ludlow and (?)Early Pridoli.

In contrast, at other times offshore muds and nearshore sands accumulated across wide regions of the Marginal Belt and adjacent platform to form low-gradient **clastic blanket systems**. The deeper and shallower components of such systems are typically highly intergradational, but at some levels it serves to distinguish **sand-prone blanket systems** (or subsystems) from their mud-dominated offshore counterparts. Such sandy systems record deposition by littoral and near shore sandbodies and on storm-influenced shorefaces and host distinctive shallow water shelly and trace fossil suites (Plate 4). Basal transgressive sandstones are a common feature of many LPWB systems, however, there were periods and settings that promoted the accumulation of thick and extensive, group- and subgroup-scale sand-prone packages. Though grossly transgressive, these larger scale systems, exemplified by the Castell Powys Group and Dinefwr Subgroup, include the regressive components of subordinate parasequences. In such systems, marked lateral and vertical variations in sandstone content testify to deposition across a range of proximal to more distal shoreface settings. Typically, sand-dominated near shore facies pass laterally and vertically into more muddy intervals that record accumulation under deeper conditions. However, common sharp-based and graded sandstone beds show that deposition remained within the range of storm emplaced sheet sands.

In contrast, **mud-prone blanket systems** and subsystems appear to offer a record of sustained deposition under offshore conditions that were largely below or beyond the impact of storms. At their seaward (basinward) limits, some such systems appear to have terminated abruptly across steep fault-generated gradients associated with slope and foot-of-slope systems. The mid-Ordovician Drefach Subgroup provides an example. At other times, they passed seamlessly into ramp and proximal slope apron systems located along sub-basin margins. These were typically periods when mud-prone blanket subsystems formed a subordinate component of an important category of mixed system (see below).

Shallow water facies that characterise Ordovician and Silurian successions of the Midland Platform and located to the east and south of the contiguous Church Stretton and Benton-Johnson fault zones and that outcrop as inliers in the Welsh Borderland, at Usk, Cardiff and in south Pembrokeshire, include the thickened successions preserved in a series of intra-platform sub-basins. The Cressage-Cardington, Onny and Ludlow sub-basins accommodated Caradoc facies (e.g. Bowder-Hicks *et al.*, 2002); those at Skomer, Usk and Woolhope are known to have been active during the early Silurian (e.g. Hillier, 2002; Butler *et al.*, 1997). In the case of the latter, it seems advisable to distinguish these sub-basin successions from the fossiliferous, shoaling upwards, limestone-bearing **calcareous blanket system** that accumulated more widely across the platform, and inner parts of the Marginal Belt, during the Wenlock and Ludlow.

These various shallow water systems record the impacts of the same tectonic and eustatic events that were influential in shaping coeval deeper water successions. It is notable that many periods of anoxic facies deposition in deeper settings equate with facies that record marine transgressions and episodes of deepening across the basin's Marginal Belt and the platform beyond (Davies *et al*., 2016). Regressive episodes are marked by coarser-grained facies containing shallower fossil assemblages and, in proximal Marginal Belt and platformal settings where they commonly culminated in emergence, by extensive and locally compound non-sequences. Periods when tectonism promoted enhanced levels of subsidence and a decoupling from eustatic events are also evident (Woodcock *et al*., 1996).

### 2.4.3 Mixed systems

Many of the sedimentary systems recognised above exhibit some level of facies mixing at their vertical and lateral interfaces. However, it is useful to recognise three distinct categories of mixed system as the basis for defining some key lithostratigraphical divisions.

In the first instance, there are mixed systems where facies that display the characteristics of deep and shallower conditions pass seamlessly into one another over such short vertical and lateral distances that their separation into separate depth-related systems is impractical from a map-making perspective. Formational nomenclature, particularly where it is erected in areas that are geographically isolated from one another, may identify the end members of such a continuum, but there are many areas where existing nomenclatures fails to do so. In either case, there is a current need for inclusion in the same group. Such systems are predominantly siliciclastic and recognised as **mixed clastic systems**, though they may include locally significant limestone marker units. Mixed systems of this type were a significant feature during the early Ordovician evolution of the LPWB, when the later differentiation of deep basin from shallower Marginal Belt settings was incomplete and rifting promoted and accommodated rapid changes in water depth (e.g. Brenchley *et al*., 2006b, fig. 3.23).

**Mixed volcano-clastic systems** that seek to embrace the transitions between volcanic and sedimentary facies in the vicinity of mainly Ordovician eruptive centres, notably in North Wales, form an additional practical category. In addition to compositional mixing, the rapid bathymetric variations linked to both volcanic up-doming and the build-up of the volcanic piles themselves were influential during the development of these systems. The single Silurian example is associated with the south Pembrokeshire Skomer Volcanic Group. In contrast to volcanic systems (see below), in mixed volcano-clastic systems the proportion of sediment derived from terrigenous source areas typically matches or exceeds volcanic components. Moreover, the later principally comprise material that has been reworked by sedimentary processes; water lain tuffs that accumulated some distance from sites of active eruption only arguably represent primary eruptive products. Self-evidently, mixed volcano-clastic systems have clear genetic links with and commonly display vertical and lateral transitions into contemporary volcanic systems and their centres of eruption.

Of significance also are times when facies and fauna indicative of deeper and shallower setting exhibit highly gradational and seamless passages into one another over such wide areas that defining and mapping palaeogeographically significant boundaries is difficult. The Ashgill Corris Group and Telychian Trannon Group both provide examples where the fusing of shallower clastic blanket facies with ramp and deeper slope apron facies resulted in the regional accumulation of oxic mudstones throughout the LPWB and across its margins. In recording episodes when such mixed mudstone systems appear to have achieved basin-wide extent, they justify distinction as **mudstone drape systems**. The oxic nature of these systems and the resulting impacts of extensive bioturbation were certainly important as factors that diminished the physical contrasts between facies of deep and shallower water affinity. A coincident reduction in the supply of arenaceous sediment and to the basin was evidently also factor. Although in both the cited examples, more sand-prone facies (subsystems) characterise proximal settings. The early development of these drape systems attests to an initial rifting phase that saw the creation of local sediment traps, but also of extensive regions of non-deposition and/or mass-wasting. Whereas their subsequent spread speaks to regional (likely thermal) subsidence as the dominant influence.

### 2.4.4 Intra-basinal high systems

Linear axes and dome-like regions that behaved repeatedly in a structurally positive way such that the successions that accumulated across them were significantly thinner and display features consistent with shallower conditions than those in adjacent or surrounding regions are identified as intra-basinal highs. Where recognised within the Marginal Belt, such features record differential movement on the internal fractures and fracture belts of the WBFS and served, in addition, to define the sub-basins that were also a periodic feature of this region. Notable examples include the Crychan and Pen-y-waun axes of the Landovery area, the possibly contiguous Builth High and a Welshpool High linked to the Severn Valey Fault system. The Llŷn, North Powys and North Pembrokeshire sub-platforms, in common with the more isolated Harlech Horst and Derwen Anticline (or Horst), were intra-basinal features acknowledged periodically to have shed material into these deeper settings (e.g. Smith *et al*., 1995). The distinctive shoal facies and condensed successions that periodically formed across these features are identifiable as **intra-basinal high systems**. Given their attenuated nature, such systems are typically viewed and mapped as subordinate elements of enveloping deep and shallower water systems. The late Caradoc Nod Glas Group may be a noteworthy exception. However, the accumulation of intra-basinal high facies commonly coincided with the development of mudstone drape systems and with periods of waning tectonism and reduced coarse clastic input, and in this regard the Nod Glas Group was no exception.

### 2.4.5 Terrestrial systems

These systems came to dominate during the Late Ludlow (Ludfordian) to Devonian period of ORS Supergroup deposition. However, the deposition of calcrete-bearing red-beds in coastal plain settings that were prone to draining and emergence (e.g. Davies *et al*., 2008; Hillier *at al*. 2011) interrupted marine deposition in south-west Wales as early as the Gorstian. Such facies, represented by the Trichrug, Red Cliff and Albion Sands formations, are viewed as early components of the ORS Supergroup (see Barclay *et al*., 2015; Hillier and Williams, 2004).

Earlier terrestrial facies underlie and interfinger with transgressive marine facies in some rifted Arenig settings (e.g. Traynor, 1990) and at the base of platformal Llandovery successions (e.g. Butler *et al*., 1997). The topography generated by Llanvirn and Caradoc volcanic centres briefly also created sites of preserved subaerial sediment accumulation.

### 2.4.6 Volcanic systems and rocks

Volcanic systems sit outside the sedimentary system hierarchy. Each individual system has links to a major eruptive centre. The latter were sited either within or along the margins of the LPWB and were active principally during the early to mid-Ordovician. Volcanic systems are characterised by the dominance of primary and proximal erupted products including lavas, ash flow and air fall tuffs and vent agglomerates and volcanogenic debris flows. Abundant, high-level intrusions are a ubiquitous feature of their modern outcrops. The main phases of vulcanism in the LPWB had links to regional tectonic events (Figs 3-5), but the growth of volcanic systems was largely (though perhaps not exclusively) independent of the processes that shaped coeval sedimentary successions. Sediment shed from volcanic edifices would clearly have been affected by widespread base level changes, but the dynamics of the volcanic centres themselves were likely always the dominant control on the distribution and preserved geometries of primary volcanic and vent-proximal volcaniclastic facies.

On a technical note, sedimentary units that are interbedded with volcanic successions should be viewed as components of surrounding depositional systems. However, for practical reasons it has been common practise to recognise them as subordinate units within their enveloping volcanic systems. In erecting a new system-based lithostratigraphy for the LPBW, pragmatism will again be needed to determine when and where this practice should be maintained. The corollary is also true and arguably of greater significance. Where lavas and more commonly tuffs accumulated at some distance from their sites of eruption, and subsequent erosion and tectonism now leaves their outcrops isolated and unrelatable, or where eruptive centres were small in scale and only briefly active, it makes practical sense to include such volcanic units with their enclosing sedimentary systems and groups. This approach takes on added importance where such units have been employed as marker horizons that, as named beds, members or formations, have been relied upon for the subdivision of their host successions. Such practice is exemplified in mixed volcano-clastic systems, however, tuff layers, including bentonitic clay bands, comprise a minor component in a range of deep and shallow water systems of both Ordovician and Silurian age.

All the volcanic groups present within the study region are listed below. There are aspects of Rushton & Howells' (1998) account of the stratigraphy of north-west Wales that are revisited here, but their nomenclature for the volcanic rocks of that region is unchallenged and unnecessary to duplicate here. The following account lists only Lower Palaeozoic volcanic formations and members seen in other parts of Wales and not dealt with in that report.

## 2.5 CONCEPT OF SYSTEMS TRACTS

The **systems tract** concept had its origins in the study of seismic sections that allowed the recognition of sets of laterally contiguous depositional systems bounded by regionally recognisable event horizons (e.g. Brown and Fisher, 1977). It was self-evident that these bounding surfaces would be identifiable in surface exposures. Because many such event surfaces are recognisable as unconformities and correlative conformities, system geometries and distributions can typically be attributed to movements in (normally marine) base level and to the creation, or destruction of sediment accommodation space. The recognition of transgressive, high-stand, regressive and low-stand systems tracts has become one of the building blocks of the sequence-based approach to stratigraphical analysis (see review by Catuneanu, 2017). Sequences defined using such analysis are commonly believed to offer a record of eustatic sea level movements and their forcing factors (e.g. Vale *et al*., 1977).

However, the systems tract model can equally be applied to sets of depositional systems that evolved in response to regional tectonism and dependant changes in rates of subsidence and sediment supply. Systems that evolved when such regional forcing factors were dominant are recognised as **tectonic systems tracts** (e.g. Prosser, 1993; Woodcock *et al*., 1996). Even during periods when eustatic influences are dominant, regional subsidence and epeirogenesis, including active faulting, act to accommodate changes in sediment and hydrostatic load such that the differentiation between eustatic and tectonic tracts is seldom clear cut (Davies *et al*., 2016). Since the principal aim here is to establish a pragmatic lithostratigraphical framework, it has proved beneficial to loosen the ties to sequence stratigraphy and to apply the term systems tract in its broader and original sense.

Unsurprisingly, many of the boundaries of the systems tracts described below record the impact of abrupt changes in marine base level and constitute sequence boundaries in the sequence stratigraphical sense (see Woodcock, 1990, and *et al*., 1996; Davies *et al*., 1997, 2016). But several of the tract boundaries do not, rather they reflect the impacts of events of varying origin, in some cases compound in nature, that each promoted a long-term and widespread **paradigm shift** in the composition and/or distribution of sedimentary lithofacies and their accompanying faunas, throughout the report region (Fig. 5). Eight such tracts are recognised, four of post-Tremadoc Ordovician age and four principally of Silurian age (Table 4). Part 2 sets out the defining criteria for these systems tracts and assesses the key events and processes that shaped them.

Self-evidently, the boundaries of these tracts are also system boundaries and, hence, the boundaries of the newly erected groups and subgroups. The boundaries between systems within each tract are, by definition, diachronous, but the system tract boundaries themselves should not be assumed to represent synchronous time-limes, and many do not. Even events of global reach likely progressed at different rates across the faulted template that was the LPWB, hence, the marked facies changes used to recognise tract boundaries, though they may record the impacts of the same erosional or flooding episode, must also be diachronous – and in some cases markedly so. Critically, the bases of some tracts record the progress of migratory facies changes that reflect diachronous changes in subsidence regime and/or rates of sedimentation. Such boundaries emphasise clearly the conceptual differences of the systems tract approach adopted here, to classical sequence stratigraphical analysis.

Volcanic systems associated principally with the pre-Ashgill rocks of the LPWB serve to compartmentalise many local successions into alternating intervals of volcanic and sedimentary rocks. Sites of vulcanism evolved in response to igneous forcing mechanism that operated largely independently of those shaping coeval sedimentary successions and there is no *a priori* reason why volcanic system boundaries should align with sedimentary systems tract boundaries. That in many cases they, may reflect the over-riding role that regional tectonism played in shaping the basin's succession and the evolution of its volcanic centres. But it may principally talk to the practicalities of mapping and the use of contacts between dominantly sedimentary and dominantly volcanic successions as defining levels.

The systems tracts as conceived here utilise an 'event stratigraphy' to enable a dynamic group-scale lithostratigraphical classification that adopts the strengths and *rasion d'etre* both of earlier chronostratigraphical classifications and of the systems approach embodied in sequence stratigraphical analysis. It is aimed at erecting a lithostratigraphical classification that, whilst remaining pragmatic, veers away from the lithodemic in favour of one that facilitates insight into the geological events and processes that shaped the sedimentary successions of the LPWB and Midland Platform. In focussing on these fundamental changes and facilitating their interrogation, the proposed scheme might be seen to depart from objectivity. However, whilst many new group names are proposed and opportunities to rationalise nomenclature are pursued, in only a few instances does the new classification fail to utilise existing mapped boundaries.

### 2.5.1 Tract nomenclature

In addition to the sequential alphanumeric labelling system used for the tracts (AI, AII, etc), the use of a parallel chronostratigraphical method of labelling (see Table 4) serves to locate the tracts within the established stratigraphical framework for the LPWB. Certainly, many of the tract-defining levels coincide locally with lithological contacts that have been used in the past to define chronostratigraphical divisions. However, the tracts are not chronostratigraphical entities either in concept, or by definition (see above). Recent work has also seen the defining criteria and even the names used for many chronostratigraphical units in the study region change, so that they no longer align precisely with historical levels. Hence, the series labels are not in every case precise in terms of modern definitions.

### 2.5.2 Tract Assemblages

The eight systems tracts fall into three overarching **tract assemblages** that reflect the major phases in the basin's development. **Tract Assemblage A** encompasses the early to mid-Ordovician **rifting and volcanic phase** of the basin's evolution; **Tract Assemblage B**, the early **post-volcanic phase** that spanned the late Ordovician and early Silurian, during which thermal subsidence and eustatic forcing grew in dominance; and **Tract Assemblage C**, a **collision and post-collision phase**, which encompassed the LPWB's response to Iapetus closure and its transition into a molasse-accommodating foreland basin.

### 2.5.3 Mega-sequences and supergroups

Woodcock (1990), based on his rock preservation curve, perceived a sequence stratigraphical hierarchy that included the 'Dyfed', 'Gwynedd' and 'Powys' supergroups as subdivisions for the Cambrian to mid Devonian succession in Wales. He viewed this three-fold scheme as reflecting major volcano-tectonic episodes in the evolution of the LPWB and its fill. The 'Dyfed Supergroup' comprised all the Cambrian and much of the Tremadocian and is not considered further in this report. The base of the 'Gwynedd Supergroup' was principally defined by the regional unconformity that underlies Arenig rocks throughout Wales, although he also included in it the Tremadocian volcanic rocks of Rhobell Fawr. The base of the 'Powys Supergroup' was taken at the base of the Ashgill Series. Woodcock (1990) believed this marked a regional 'lacuna' recognisable throughout the basin and linked to its transition from a depocentre influenced by Ordovician subduction-related volcanism to one controlled by plate collision and strike-slip tectonics. The top of Woodcock's 'Powys Supergroup', located within the Old Red Sandstone, was taken at the major mid-Devonian Acadian unconformity in Wales (see above).

The Gwynedd Supergroup has merit in terms of the scheme advance herein, but by including lithofacies that range from deep marine to fluvial red beds, it is difficult to view the Powys Supergroup as having lithostratigraphical integrity. Moreover, the ORS component of this supergroup has subsequently been included in the Old Red Sandstone Supergroup of Barclay *et al*. (2015). Woodcock's (1990) divisions, as recognised by Verniers *et al*. (2002), more accurately represent tectono-sedimentary mega-sequences and continue to have merit in that context. Thus, the supergroups, groups and sub-groups defined herein can be viewed as a hierarchy of more strictly lithostratigraphical components that make up the newly labelled **Gwynedd Mega-sequence** and the lower part of the **Powys Mega-sequence**.

The role and significance of more strictly lithostratigraphical supergroups is of questionable relevance in terms of map-making. It risks creating divisions that dimmish the detail available on modern chronostratigraphical maps and that inhibit rather than assist interpretation of all but the broadest plate tectonic scale. However, the newly recognised assemblage, system and lithostratigraphical hierarchy permits erection of the two higher-level divisions presented in this account - the Preseli Supergroup and Hafren Supergroup (see Part 2). Each displays a distinctive suite of lithofacies formed in response to separate tectono-sedimentary episodes that affected the Arenig to (?)Early Pridoli marine successions of the LPWB and its adjoining regions (Fig. 5).

The newly named Preseli Supergroup encompasses the volcanic-bearing Ordovician systems recognised as Tract Assemblage A and equates stratigraphically, if not in concept, with the Gwynedd Mega-sequence, although it excludes strata of Tremadoc age. It records the marked change in the tectonic configuration of the LPWB, from an intra-arc to back-arc extensional basin setting (Figs 3-5). The base of the supergroup, and of the tract assemblage it equates with, is taken at the unconformity that typically defines the base of the Arenig throughout Wales. The subsequent marine transgression was of global extent (Fortey, 1984; Ross and Ross, 1992), but its diachronous progress in Wales reflects the progressive drowning of fault-controlled sub-basins and their margins. Arenig strata overlying the unconformity range from Moridunian to Whitlandian in age (Fortey *et al*., 2000, and references therein),and overstep Tremadocian rocks to rest on a range of Cambrian formations. A combination of subsidence and eustasy resulted in the marked, but likely diachronous facies changes, first manifest in the late Abereiddian, that underpin the supergroup's division into the AI (Arenig-early Llanvirn) and AII (late Llanvirn-Caradoc) systems tracts. In North Wales, the boundary between these tracts coincides with a widespread hiatus - the Mid-Ordovician (or Sub-*gracilis*) Unconformity. The Preseli Supergroup includes all the volcanic systems that mark the location of Arenig to Caradoc back-arc eruptive centres (Kokelaar *et al*., 1984). Its sedimentary rocks include a range of mixed and deep-water systems in north and south-west Wales. Shallower water systems characterise the Marginal Belt and the coeval successions of the intra-basinal North Powys and North Pembrokeshire sub-platforms. In the Welsh Borderland, east of the Church Stretton Fault Zone, exposed Preseli Supergroup rocks are limited to those introduced by the *gracilis* Biozone transgression and preserved in down-faulted sub-basins.

The Hafren Supergroup records the post-volcanic evolution of the basin and of cycles of marine sedimentation that were strongly influenced by external drivers, both eustatic and plate tectonic (Figs 3-5). It comprises a series of deep-water slope-apron and sandstone lobe systems, as well as the shallower systems of the Marginal Belt and the adjoining platform, including the successions of intra-platformal sub-basins. The base of the supergroup is taken at the onset of basin-wide facies changes that followed the cessation of back-arc vulcanism and record Ashgill re-ventilation. In taking the base of the ORS as its top, the Hafren Supergroup differs significantly both stratigraphically and conceptually from the Powys Mega-sequence. The recognition of tract assemblages B and C permit subdivision of the Hafren Supergroup into lower and upper parts.

These supergroups and tract assemblages provide the final elements of the new classification shown in Table 4. Figures 9 and 10 show how the newly defined systems tracts and their component sedimentary systems permit the construction of a schematic basin-wide architecture for the LPWB and Midland Platform, which informs a new group- and subgroup-scale lithostratigraphy for their post-Tremadoc to (?)early Pridoli successions. Individual systems appear naturally to equate with lithostratigraphical groups, and their mapped facies and subsystems to sub-groups, formations and/or members. These figures underpin the following account. Figure 10 shows the relative positions within the new scheme of detailed local lithostratigraphical architectures discussed in Parts 2 and 3.

### 2.5.4 Rationalising of nomenclature

Despite the voluminous nomenclature that exists for the LPWB succession it is inevitable that new names need to be introduced to produce a group-level lithostratigraphical framework in which existing terms can be rationalised. Whilst this is not ideal, it avoids the confusion that would result from adapting the nomenclature of earlier schemes, including the tectono-stratigraphic terms introduced by Woodcock. To acknowledge their continuing usefulness as lithostratigraphical divisions, many previously named groups have been redesignated sub-groups. Importantly, any new nomenclature advanced herein has sought wherever possible to utilise boundaries already shown on BGS maps. Thus, though changes to the names of units may be recommended, there exists the means easily to apply them to existing maps particularly within a digital context. That said, there remain some areas that will require modern mapping, if the findings of this report are to be followed (see Part 4).

Practical obstacles determined by the physical distribution of outcrops remain. An accurate assessment of a large portion of the basin's Ordovician stratigraphy awaits extensive subsurface investigations of deeply buried successions beneath mid Wales. More problematical are areas from which Silurian successions have been eroded as for much of Llŷn, Snowdonia and large parts of south-west Wales. For example, the separation marked by the influential Conwy Valley-Llanelidan Fault System between outcrops of predominantly deep-water Silurian systems, to the east and north, and mixed volcano-sedimentary Ordovician systems to the west and south implies that a simple stacking of the two successions is unlikely to be palinspastically realistic. Caveats of significant uncertainty that stem from such problems are compounded by those linked to the wide variations in age and quality of mapping and associated stratigraphical schemes (Appendix 1). Nevertheless, the new systems-based architecture provides a model for the LPWB fill and its bordering successions tailored to the aims of erecting a hierarchical, group-focussed lithostratigraphy for their current outcrops.

Rushton and Howells (1998) were the first to produce a lithostratigraphical synthesis for part of the LPWB, detailing the Tremadocian to Caradoc rocks of the region between the Menai Strait and the Llanderfel Syncline east of Bala. Their synthesis placed much emphasis on the region's volcano-tectonic stratigraphy. It essentially recognised a series of volcanic systems linked to eruptive cycles and to volcanic centres that appeared at different places at different times. Each of these separate systems was given group status. Less emphasis was given to the enveloping sediments other than where they inter-tongue with local volcanic successions. They review the past nomenclature used for these rocks. They included most sedimentary formations not intimately associated with volcanic sites, including those volcanic and volcaniclastic formations that had no obvious affinity with the major eruptive centres, in a new all embracing 'Ogwen Group' (Rushton and Howells, 1998, fig. 2).

Although volcano-tectonic events can be readily identified in Rushton and Howells' (1998) synthesis, the sedimentary facies changes that reflect the impacts of eustatic rises in sea-level and/or intra-basinal tectonics are underplayed. The volcanic groups of Rushton and Howells (1998) are largely retained in this report, however, their concept of a largely sedimentary 'Ogwen Group' has been abandoned (see Part 3).

The subdivision and nomenclature of Tract Assemblage A (Preseli Supergroup) largely reflects the impact of volcanic centres and associated tectonism on this part of the succession. The new group and sub-group nomenclature advanced herein attempts a regional synthesis. However, isolated outcrop patterns and the localised nature of successions linked to individual volcanic centres appear to offer insurmountable obstacles to refine further the current level of formational and member subdivision. Improved dating may offer a route to future rationalisation.

In contrast, the significance of well-dated base levels events later in the Ordovician and throughout much of the Silurian (Hafren Supergroup), has allowed a robust event framework to be erected and, in turn, permitted far greater rationalisation of nomenclature at the formational level. The extended use of certain names, the abandonment of others and, in certain cases the erection of new terminology, is recommended as a first step towards standardising the nomenclature for the Welsh Silurian succession. However, it is recognised that much work is still necessary before this ambition can be fully realised, particularly in those parts of Wales where few modern studies have been undertaken. For both supergroups, the report identifies areas where future research may be productive. The following assessment of each systems tract has sought to differentiate discussion pertaining to its base, from that relating to system nomenclature and tract evolution, though there are cases where this distinction has proved impracticable.

# Part 2 – Systems tracts, groups and subgroups

## 1 Tract Assemblage A (Preseli Supergroup)

This tract assemblage formed in the wake of the Penobscotian deformation that established the foundations of the LPWB (see Waldren *et al*. 2014; Schofield *et al*., 2020). The impacts of rifting linked initially to the ongoing separation of Eastern Avalonia from Gondwana and then to the subduction the Iapetus oceanic crust dominated the basin's early development. The extensive vulcanism that was a feature of this tract assemblage occurred in a back arc, marginal basin setting (e.g. Kokelaar *et al*., 1984; Howells *et al*., 1991). Global events, notably deepening episodes, also played their part in shaping the development of the Preseli Group's systems tracts (Fig. 5). Ordovician faunas in Wales initially shared much in common with Gondwana's Rheic Ocean margin, but subsequently developed their own identity (Cocks and Torsvick, 2021). Figure 1B shows the distribution of rocks assigned to the Preseli Supergroup and Figure 11 the principal structural and palaeogeographical features that influenced the development of tract assemblage. Linear, in part fault-defined, depositional troughs were a focus for deposition in pre-Caradoc times. The influences of sub-platforms on Llŷn, in north Pembrokeshire and north Powys and of components of the Derwen-Berwyn Axis were revealed as the North and South Wales sub-basins gained definition as sites of enhanced subsidence and deeper water deposition.

### 1.1 AI SYSTEMS TRACT (ARENIG-EARLY LLANVIRN)

Rocks assigned to this systems tract crop out extensively in North Wales, in the Pembrokeshire to Carmarthenshire region of South Wales, and in the Builth and Shelve inliers. The tract, see Figures 7 to 9, is characterised by rapid lateral and vertical variations in lithofacies and by localised lithostratigraphical nomenclatures that reflect the early compartmentalisation of the LPWB region by active faulting. This, together with the rapid passage between shallower and deeper water facies, is reflected in the recognition of a set of mixed depositional systems. Discrete volcanic systems mark the location of eruptive centres active during the late Arenig to Llanvirn phase of regional vulcanism, and the products of this activity are also widely represented by tuffs and volcanoclastic levels interbedded with the tract's sedimentary rocks. See Figures 9 to 11.

*Base* - The sub-Arenig, post-Penobscotian unconformity widely recognised in north and south Wales, and in the Welsh Borderland, marks the well-defined base of this systems tract and of the Preseli Supergroup. The basal surface cuts across units of Tremadoc and Cambrian age and is locally overlain by transgressive sandbodies, including the Garth Grit and its correlatives in North Wales, the Ogof Hên Formation and its correlatives in South Wales, and the Stiperstones Quartzite Formation of the Shelve Inlier (Fortey and Owens, 1990). These units collectively describe the drowning of these regions during the Moridunian global marine transgression. However, they occur in proximity to sites where the earliest preserved transgressive deposits date from the Whitlandian or Fennian, for example the St. Tudwald's Sandstone Formation of western Llŷn and the Pembrokeshire Abercastle Formation, occurrences which illustrate the impacts of Arenig rifting and the highly diachronous nature of the AI Systems Tract base.

Kokelaar (1988) and Pratt *et al*. (1995) argued that there were sites in North Wales that preserved a conformable contact between Tremadoc and Arenig facies, but more recent biostratigraphical studies have shown that nowhere in Wales and the Welsh Borderland is a complete Tremadoc succession believed to be preserved (Owens *et al*., 2000; and references therein). Fault compartmentalisation appears to have played a key role in differentiating the impacts of the Penobscotian deformation, uplift and erosion.

*Nomenclature & evolution* – Given the widely separated outcrops of AI System Tract rocks, with intervening major faults and the recognition that accumulation took place in sub-basins that were to a degree isolated from one another, there is a strong argument to give each outcrop area group status (Fig. 11). Successions which display rapid transitions between deeper and shallower components in south-west Wales, including those that accumulated within the embryonic Whitland-Llandeilo Sub-basin, are assigned to a mixed, in part volcano-clastic system here designated the **Foel Cwmcerwyn Group**. Deposits of that principally accumulated and were preserved in a sub-basin that extended between the Shelve and Builth Inliers are assigned to a discrete **Shelve Hill Group**. The northern counterpart to these mixed systems, in which turbiditic facies are more prevalent, but currently defined formations include both shallow and deep-water facies components, is here recognised as the **Cadair Idris Group**. All these new divisions take their names from topographic prominences within their type areas (see Part 3).

In these groups, overlying their basal sandstones, are varied successions in which a spectrum of shallower facies pass upwards into deeper, mud-dominated offshore and locally turbidite-bearing sediments. Volcanic rocks, though subordinate, are significant at certain levels and volcaniclastic contamination is widespread. An overall upward-fining trend accords with an ongoing transgressive deepening, however, rapid vertical and lateral changes in facies and thickness reflect accumulation within fault-controlled troughs and the diachronous onlap of intervening bathymetric highs. Different facies commonly yield distinctive, environment-specific

**Text Box 3 - Nant Ffrancon Subgroup:** Facies that characterise the bulk of the Allt Lŵyd Formation of the Cadir Idris, Harlech Dome and Llŷn areas appear not to extend into northern Snowdonia and the Bangor area. There, most Arenig-age strata form part of a thick mud-prone succession that ranges upwards into the lower Caradoc. Believing this to be lithostratigraphically indivisible, Howells *et al*. (1985) introduced the term Nant Ffrancon Formation. In upgrading this to the Nant Ffrancon Subgroup, Howells and Smith (1997) and Rushton and Howells (1998) recognised the need to accommodate the laterally equivalent Allt Lŵyd Formation and Arenig divisions in the Aberdaron and St. Tudwal's areas (Gibbons and McCarroll, 1993; Young *et al*., 2002) (see Fig. 13). Howells *et al*. (1985) included a basal Moridunian sand-prone interval in their Nant Ffrancon Formation, but Rushton and Howells (1998) subsequently viewed this as a local representative of the Allt Lŵyd Formation. Whether there is,or ever was a physical link between this northern development and facies of the formation's type area is uncertain and a case can be made to recognise the Bangor district unit, here designated the Graianog Sandstone Member (see text), as a separate formation.

Rushton and Howells were also aware that, in successions where it can be recognised, the presence of the Mid-Ordovician Unconformity offered a strong argument for subdivision of younger parts of the subgroup. In these successions, strata of early Caradoc age (*gracilis* Biozone) sit on a range of older rocks and strata of Llandeilian age (*teretiusculus* Biozone) are missing. The unconformity underpins the recognition of separate AI and AII systems tracts in North Wales (see text). However, in its northern Snowdonia type area (Plate 5), the Nant Ffrancon Subgroup is reported to host a complete sequence of mid-Ordovician graptolite biozones. H. Williams (1927), D. Williams (1930) and Greenley (1944) all report *teretiusculus* Biozone faunas. Subsequent work has called this into question (e.g. Young, 1991; Molyneux *et al*., 2023). A cryptic non-sequence may continue to be present some speculating that such break may exists in the Bangor area beneath the age disputed Llandegai Ironstone Member (see Trythall and Young, 1993). However, it is feasible that the thick mudstone succession seen in northern and eastern Snowdonia formed in a setting where no such omission occurred, that lay beyond the reach of slide excision, melange emplacement and mass wasting seen to the south and west.

In their work on this succession, H. Williams (1927) and his brother D. Williams (1930) recognised lithological differences between what they conceived of as chronostratigraphical divisions. They labelled a lower interval of structureless blue-black mudstones, now known to include rocks of both Arenig and Abereiddian age, the Maesgwm Slates. It was from the lower part of the overlying succession of more strongly laminated Glanrafon Slates that these authors report possible *teretiusculus* and *gracilis* Biozone assemblages. These graptolitic levels may offer evidence for the late Llanvirn to Caradoc deepening episode seen in South Wales and allow the line drawn between the separate slate units (H. Williams, 1927; D. Williams, 1930) to be adopted as the local proxy for the AI-AII systems tract boundary. Shackleton (1959) also recognised the Maesgwm Slates in the Cwm Pennant area. Despite BGS' failure to adopt these divisions, the line drawn between them by these earlier authors was utilised by Campbell *et. al*. (1988, fig. 2) when plotting the base of the Caradoc in northern Snowdonia. Definitions have since changed, but the implication is that the latter closely aligns with the base of AII Systems Tract throughout this northern region. In the context of this study, it would identify the contact between the local Cadir Idris and Eryri group successions (see parts 3 and 4).

The Maesgwm Slates succession of northern Snowdonia, by including some rocks that are the lateral equivalent of the Allt Lŵyd Formation and possibly preserving a conformable upper contact, may represent a more complete succession of the newly erected Criccieth Formation (Fig. 15), in place of which, having precedence, it is a potentially better name. The Glanrafon Slates, by including strata since assigned to the Cwm Eigiau Formation and to volcanic divisions of the Llewelyn Volcanic Group, is no longer acceptable. If the northern Snowdonia succession proves divisible, the lower mudstone-dominated parts of the former 'Glanrafon Slates' will form part of the new Porthmadog Formation. Future allocation of separate parts of the Nant Ffrancon Subgroup succession in northern Snowdonia to separate systems tracts and groups would underline the case for it to be abandoned. Howells *et al*. (1978) acknowledge the validity of the Maesgwm Slates as a division of its type succession. However, an assertion that the Maesgwm and Glanrafon Slates are indistinguishable in the region north-east of Nant Ffrancon underpinned their decision not to employ them on published maps (BGS, 1985, 1997). Pending reinvestigation use of the term 'Criccieth and Porthmadog formations undivided' may be required in this region.

trilobite and brachiopod faunas as well as graptolites. In the mixed system that comprises the Foel Cwmcerwyn Group, these complexities are reflected in the range of formational nomenclature applied to different facies in different areas and fault blocks (e.g. Brenchley *et al*., 2006b) (see Part 3). However, BGS maps covering large sectors of the Foel Cwmcerwyn Group outcrop do not differentiate such facies-based divisions and loosely biostratigraphical terms remain in use, notably the Tetragraptus Shales. Pending the remapping of these areas, the **Trifleton Subgroup** and **Eastern Cleddau Subgroup** (new name; see below) have been erected as temporary devices for early Arenig and late Arenig-earliest Llanvirn rocks respectively.

The succeeding parts of the systems tract in south-west Wales comprise an extensive succession of distal, mud-prone Abereiddian facies (Aber Mawr and Abergwilli formations). However, within the easterly confines of the Whitland-Llandeilo Sub-basin near Llandeilo, volcaniclastic and feldspathic sand deposition records the mid-Llanvirn (lower *murchisoni* Biozone) emergence, or unroofing of a nearby volcanic edifice (Williams, 1953; Williams *et al*., 1981; Wilcox and Lockley, 1981; Schofield *et al*., 2009a). The nomenclature of these rocks requires revision (see Text Box 4). The isolated and poorly exposed early Llanvirn succession seen in south Pembrokeshire can only questionably be included in the Foel Cwmcerwyn Group.

In north-west Wales, Rushton and Howells (1998) recognised the potential of the Mid-Ordovician Unconformity (see AII Systems Tract) to act as a major lithostratigraphical boundary yet chose not to utilise it when erecting their Nant Ffrancon Subgroup (see Text Box 3). Where the unconformity is most clearly developed it allows recognition of the Cadair Idris Group for the underlying Arenig to Llanvirn succession. The term is also used in place of the Aberdaron Bay Group erected by Gibbons and McCarroll (1993) for the succession of western Llŷn. In parts of Snowdonia where the Mid-Ordovician hiatus is unreported, a possibly intact succession of the former subgroup may span the AI-AII systems tract boundary interval (see Text Box 3).

Contemporary late Arenig-early Llanvirn volcanic systems identify the main Preseli Supergroup eruptive sites. Associated with the Cadair Idris Group is the **Lower Aran Volcanic Group** (adapted name; see below). Sites where the latter rest on pre-Arenig formations (see Rushton and Howells, 1998) testify to the eruptive excision of early AI Systems Tract strata at the onset of Llanvirn vulcanism (Fig. 15). Linked to the Foel Cwmcerwyn Group are the **Sealyham Volcanic Formation**, the Ramsey Island **Carn Llundain Volcanic Formation** and the **Fishguard Volcanic Group** (Plate 6). The **Builth Volcanic Group** and **Stapeley Volcanic Formation** (upgraded name) interdigitate with Abereiddian levels of the Shelve Hill Group. The top of the AI Systems Tact marked the shut-down of its major volcanic centres at Fishguard, Builth and Shelve, and the termination of widespread vulcanism in South and mid Wales.

Active faulting was a key factor in controlling development and preservation of AI System Tract facies. In South Wales, the Bronnant, Llanglydwen-Cwm Cynnen and Penfordd fault belts strongly influenced Foel Cwmcerwyn Group deposition and preservation. The thick and intact successions of the latter, seen in north Pembrokeshire and east Carmarthenshire, including those linked to the Whitland-Llandeilo Sub-basin, contrast with the attenuated and incomplete succession preserved over the Haverfordwest Tilt-block located to the south of the evidently active Roch-Egremont and St. Clears fracture belts. The Musselwick Fault was likely influential in the Marloes area further south. The fault-bounded Builth-Shelve Sub-basin, defined to the east by an emergent Long Mynd Horst, was influential in the preservation and accommodation of Shelve Hill Group successions. Cave and Hains (2000) associated the western margin of the sub-basin with the Severn Valley Fault Belt.

The Cadair Idris Group of North Wales describes a similar picture of initial, rift-influenced complexity. Transgressive Moridunian sandbodies compare with those seen in the south, but astride some adjacent fault blocks the accumulation of preserved deposits appears to have been delayed, locally until Fennian times (e.g. Rushton *et al*., 2000). Rapid Arenig lateral facies variations observed in the successions that flank the Harlech Dome show that significant control was exercised by structures linked to the RFZ and Bala Lineament (e.g. Kokelaar, 1988) with Fitches and Campbell (1987) and Traynor (1990) recognising the role played by a series named horsts and grabens. Young *et al*. (2002; see also Gibbons and McCarroll, 1993) describe the impact of contemporary faulting on the Llŷn succession including the influence of an uplifted block in the St. Tudwal's area (Appendix 4). The Arenig succession in northern Snowdonia also differs from those to the south and west (Fig. 15). Most reconstructions envisage the Harlech region as an uplifted block and the site of nil or restricted deposition. The RFZ had links to the Fishguard Caldera and to the Cardigan-Fishguard Fault Belt (see Part 3) and appears to have been the focus of early Llanvirn vulcanicity and perhaps the site of a linear volcanic archipelago. In north-west Wales, the complex pattern of Arenig rifting evolved into the broader belt of subsistence and finer sediment accumulation recognised as the Snowdon Trough (Smith *et al*., 1995). This feature's easterly reach is unknown, but it extended into western Llŷn to include the Arenig site of Wig Bâch Formation deposition (Younge *et al*., 2002). The uplifted Harlech region and the adjoining Aran volcanic belt, by combining to define the southern margin of this early depocentre, imply that the Vale of Ffestiniog Lineament and elements of the Derwen-Berwyn Axis were already active (Fig. 12). Whether the Fishguard-Robell Fracture Belt traversed or bordered an embryonic South Wales Sub-basin, its deposits present at depth beneath the younger rocks of mid Wales, is unknown. AI Systems Tract rocks may record a period in the evolution of the LPWB that preceded this sub-basin's differentiation.

## 1.2 AII SYSTEMS TRACT (LATE LLANVIRN-CARADOC)

Rocks assigned to the AII Systems Tract are seen succeeding those of earlier tract in south-west, north-west and eastern mid Wales. However, they outcrop more widely including in north Pembrokeshire and south Ceredigion, the core of the Tywi Anticline including the Llanwrtyd Inlier, the Welshpool and Berwyn Dome regions, and in south Shropshire. The impacts of vulcanism and tectonic differentiation allow the recognition of shallow water, deep-water and mixed volcanoclastic systems and the earliest example of an intra-basinal high system. See Figures 9 to 11.

**Text Box 4. Ffairfach Grit and Llandeilo Flags:** Earlier studies of the Llandeilian type area sought, at least in part, to align named rock units with contemporary chronostratigraphical understanding. Williams (1953) and Williams *et al*. (1981) recognised the succession of sandy facies that they considered to be Llanvirn in age as the 'Ffairfach Group'. Within this, they acknowledge a prominent contact between a massive, poorly fossiliferous lower grit unit and an overlying, well bedded, heterolithic succession. They believed the boundary between the Llanvirn and Llandeilo series lay at, or close to the base of the overlying succession of interbedded limestones, sandstones and mudstones. It was as a label for these rocks that they confined the term 'Llandeilo Flags'. Schofield *et al*. (2009) assumed in error that the 'Ffairfach Group' was the equivalent of the 'Ffairfach Grit' of the Ammanford region (Strahan *et al*., 1907). Being unable to map the internal divisions of Williams (1953), they applied the term 'Ffairfach Grit Formation' to all the strata he had previously been included in the 'Ffairfach Group'.

Previously, believing it to be Llandeilian, Strahan *et al*. (1907) had used the label 'Ffairfach Grit' only for the basal grit division of what was to be called the 'Ffairfach Group'. They recognised the upper parts of the group as the 'Sandy Basement Beds' of an expanded 'Llandeilo Flags' succession (spelt Llandilo Flags). Faunal re-evaluations have since shown that the basal grit lies within the *murchisoni* Biozone and that base of the modern Llandeilian Stage lies neither at the base, nor top, but intersects the overlying sandy sequence (Owens, 2000; Ferretti and Bergström, 2022).

Willams *et al*. (1981) suggest that the basal grit unit and overlying pebbly facies formed during the same regressive episode. However, the bedded nature of the latter, the presence of cross-stratified units, of increased levels of bioturbation and a more abundant shelly fauna are consistent with the transgressive passage of upper shoreface conditions. The prominent contact between the pebbly rocks and the underlying grit, located in the upper part of the *muchisoni* Biozone (Owens, 2000), emerges as a strong local candidate for the base of the AII Systems Tract.

The recommendation here is to reinstate the stratigraphy envisaged by Strahan *et al*. (1907). They describe the lateral passage between late Abereiddian mudstones now included in the Abergwilli Formation and the lower grit unit of the Llandeilo area. It is for the latter, as a division of the Foel Cwmcerwyn Group, that the name Ffairfach Grit Formation should be reserved. The incorrect usage of Schofield *et al*. (2009) should be abandoned. Strahan *et al*.'s (1907) use of the term 'Llandeilo Flags' for the whole of the succession between the top of the grit and overlying graptolitic Caradoc mudstones is also seen as valid. However, the presence of internal divisions (see Part 3) necessitates the erection of a Llandeilo Flags Subgroup as part of the local Montgomery Group succession.

*Base* - The base of this systems tract in south and eastern mid Wales is marked by the impacts of a diachronous deepening episode that appears to owe its origin to a series of overlapping processes and events. In the intra-platformal sub-basins of the type Caradoc region, east of the Church Stretton Fault Zone, early Caradoc rocks ranging from Costonian to Harnagian in age (*gracilis* to *foliaceus* biozones) overstep Tremadoc and Cambrian strata. Such relationships have been widely attributed to a global deepening event commonly but inaccurately termed the '*gracilis* transgression' (see Bettley *et al*., 2001). In seeking to characterise the impacts of this large and prolonged Caradoc sea level rise on Welsh successions, many highlight the black graptolitic mudstone facies that widely typify this time interval. However, graptolitic facies deposition was already widespread within the developing LPWB prior to the Caradoc and, together with other facies boundaries, testifies to the earlier onset of base level rise.

Along the northern flanks of the North Pembrokeshire Sub-platform, graptolitic mudstones of distal aspect (Drefach Subgroup) onlap an unconformity at the top of the Fishguard Volcanic Group that is overlain locally by a bed of volcaniclastic conglomerate. Faunas from close to the diachronous base of the mudstone succession range from as early as the late Abereiddian (upper *murchisoni* Biozone) (see Bevins *et al*., 1992; Williams *et al*., 2003; Burt *et al*.; 2012). Drefach Subgroup facies that overlie the local representative of the Fishguard Volcanic Group (Llanrian Volcanic Formation) at Abereiddi Bay also range down into the upper *murchisoni* Biozone (Bettley *et al*., 2001) (Plate 2). South of the Llanglydwen Fault and throughout the Whitland-Llandeilo Sub-basin, coeval levels succeed burrow-mottled, trilobite-bearing early Llanvirn rocks (Abergwilli Formation) (Wilby *et al*., 2007). Any break in deposition that preceded largely intact north Pembrokeshire and west Carmarthenshire successions was minimal. In the Llandeilo area, where the Llanvirn rocks are noticeably coarser grained than to the west, it is the facies and faunas that enter abruptly above the Ffairfach Grit Formation that appear to mark the defining deepening episode (see Text Box 4). Only astride the Haverfordwest Tilt-block, where similar facies rest unconformably on AI Systems Tract formations assigned to the *artus* Biozone, was AII Systems Tract deposition was delayed until the Caradoc (Fortey *et al*., 2000).

Throughout this south-western region, the system defining deepening episode has been attributed to the widespread subsidence that followed the end of large scale vulcanism. Lower levels of the Llanfawr Mudstones Formation that unconformably overlie the Builth Volcanic Group and which yield late Abereiddian trilobites and graptolites, attest to a similar event affecting the Builth Inlier succession (Schofield *et al*., 2004). In the Shelve Inlier, the Betton Shale Formation appears to mark a coeval deepening episode that also post-dated local volcanic shutdown (Cave and Hains, 2001).

A commonly held view is that these various deepening profiles reflect local processes linked to the erosion and drowning of individual volcanic edifices. Taken together, they imply that a period of post-volcanic subsidence-initiated deepening throughout South and eastern mid Wales late in the *murchisoni* Biozone. This was overtaken and enhanced by the '*gracilis* transgression' and it was the latter that extended the system tract to the south of the Roch-Egremont fault system in Pembrokeshire and into the platformal sub-basins of the Church Stretton region.

Attention has also focused on the major Mid-Ordovician Unconformity that affects the Ordovician succession in North Wales (Smith *et al*., 1995; Rushton and Howells, 1998). Throughout much of this region, the earliest of AII Systems Tract deposits are of Caradoc age and overlie an extensive omission surface. In the areas affected by this event, much, and locally the whole of any pre-existing Arenig to Llanvirn succession was destroyed (Fig. 15). In several places, strata yielding probable *gracilis* Biozone graptolites overlie the hiatus surface (e.g. Zalasiewicz, 1992; Smith *et al*., 1995). Rushton and Howells (1998) show that preserved accumulation on Llŷn was delayed until the late Burrellian (late *foliaceus* Biozone), although there is evidence to dispute this (see Trythall and Young, 1993; Young *et al*., 2002). In the Cadir Idris region, the significant non-sequence affecting the Aran Volcanic Group, evident beneath the oolitic, early Aurelucian Fron Newydd Member, is believed to mark the impact of the same erosional episode (Pratt *et al*., 1995). In marking an interruption in the accumulation of Aran

Volcanic Group rocks, it permits division of the latter into lower and upper parts. The findings of Zalasiewicz (1992) confirm that such a break is also present in the Arenig region (Fig. 15).

The melange-like Saddle Point Member of the Fishguard succession has been linked to a coeval mass-wasting episode affecting the margins of the by then extinct Fishguard Volcanic Group caldera, implying that this was a widely felt tectono-sedimentary event (Davies *et al*., 2003; Burt *et al*., 2012). Here, local instability and mass-wasting persisted at least into the *foliaceus* Biozone. Yet, it is noticeable that intervals of undisturbed strata, recognised in Snowdonia as the newly named Penrhyndeudraeth Member and in the Fishguard area as the Castle Point Member (Plate 6), locally intervene between disturbed successions and underlying hiatus surfaces (see Smith *et al*., 1995; Burt *et al*., 2012).

This evidence of widespread omission was an additional factor that determined the local base of the AII Systems Tract. In North Wales, mass-wasting resulted in the widespread loss or non-deposition of strata that may have provided a record of the earlier intra-Llanvirn deepening episode seen in South and mid Wales. Only in northern Snowdonia and in the Bangor area is the base of the AII Systems Tract not identifiable on modern geological maps. There exists, nevertheless, linework available from other published sources that may identify the base of the systems tract in this region (see Text Box 3). That such linework is associated with a level that offers evidence for either the late Llanvirn deepening episode, or an omission event needs to be confirmed. Work accurately to establish the age and degree of synchronicity of various ironstone horizons and the presence of Llandeilian rocks, both disputed (see Trythall and Young, 1993), will inform decisions that may necessitate adjustments to the new nomenclature.

*Nomenclature & evolution* - Its base thus defined, the AII Systems Tract includes systems of mixed and both deep and shallow water aspect. The predominantly deeper water, turbiditic and graptolitic slope-apron facies that comprise the multi-sourced **Hengae Group**, here redefined, have a wide geographical range with outcrops in the Cadair Idris and Corris region of North Wales, in north Pembrokeshire and in the northern part of Tywi Anticline. The slope and foot-of-slope debritic facies, alluded to above, form a distinctive additional component of the Hengae Group successions in all these areas. A distinctive coarse-grained subsystem (Dinas Island Formation) is associated with the fault-controlled site of the former Fishguard Caldera (Davies *et al*., 2003).

The lithologically varied and laterally extensive **Montgomery Group** (new name) is recognised, with some qualification, as a shallow water clastic blanket system. Graptolitic mud-rich facies accumulated periodically in some distal Mongomery Group settings, but brachiopods and trilobites dominate the faunas of the more prevalent sedimentary facies that record accumulation in a spectrum of off-shore and shoreface environments. Northerly Mongomery Group successions are preserved in the Shelve and Builth inliers and occupy the core the Forden Horst. They also include those associated with the North Powys Sub-platform that crop out along the southern flank of the Berwyn Dome and in the cores of the Brogan and Guilsfield anticlines. Pre-Caradoc facies were confined to the west of a still active Long Mynd Horst, but the successions of the Cressage, Onny and Ludlow sub-basins testify to a more extensive Caradoc phase of Montgomery Group deposition (Cave and Hains, 2000). In many of these areas, the youngest levels of the AII Systems Tract are absent due to Shelveian and Hirnantian erosion (see below). Montgomery Group successions located west of the Severn Valley Fault Belt are incomplete beneath disconformable Nod Glas Group or BI Systems Tract facies. Only in the Ludlow Sub-basin, beneath unconformable BIII Systems Tract Llandovery strata, are Montgomery Group rocks of latest Caradoc (late Onian) age preserved (Bowdler-Hicks *et al*., 2002).

Southerly Montgomery Group successions crop out between Pembrokeshire and the Llandovery area and in the Llanwrtyd Inlier and include deposits that accumulated within the Whitland-Llandeilo Sub-basin. For the latter, the case to abandon the earlier label 'Ffairfach Group' for the easterly sand-prone Montgomery Group succession is set out in Text Box 4. The strata that succeed the system tract base in this area constitute the historical type succession of the 'Llandeilo Flags'. This is acknowledged in the erection of a **Llandeilo Flags Subgroup**, used in a way that follows Strahan *et al*. (1907), but that departs significantly from Williams (1953) and Schofield *et al*. (2009a). The subgroup ranges from latest Llanvirn to early Caradoc in age, but late Abereiddian to Llandeilian sand and pebble-prone facies (Garth Formation) sourced from eroding volcanic sites form a distinctive basal component in the east of the sub-basin. The more typical and more widespread sheeted facies of the Llandeilo Flags Subgroup, in common with Montgomery Group successions to the north-east, testify to sediment supply from a broad sector of the adjacent platform. An unconformable succession of comparable, but exclusively early Caradoc facies, rich in brachiopods and trilobites (Narberth Formation), occupies the lower levels of the reduced AII Systems Tract succession associated with the Haverfordwest Tilt-block. It is with some caution that comparable late Abereiddian to Llandeilian facies seen in South Pembrokeshire are also included in the Montgomery Group.

The succession of distal graptolitic mudstones with trilobite-bearing calcareous levels seen on the North Pembrokeshire Sub-platform and in adjoining parts of the Marginal Belt is recognised as the **Drefach Subgroup** (status amended). In westerly successions, these strata form the whole of a Montgomery Group succession that underlies conformable BI Systems Tract rocks (see below). The lower levels of this graptolitic succession pass eastwards into the coarser facies of the Haverfordwest Tilt-block and the western part of Whitland-Llandeilo Sub-basin (see above), but graptolitic Drefach Subgroup facies of mid to late Caradoc age extend as far as the Llanwrtyd Inlier. The Aber Richard Fault intervenes between the Hengae and Mongomery group successions in north Pembrokeshire, but the Llanwrtyd Inlier succession reveals a lateral transition (see Part 3).

A mixed volcanogenic clastic system in North Wales that was strongly influenced by its proximity to active Caradoc volcanic centres comprises the newly erected **Eryri Group** (new

**Text Box 5. Nod Glas Group:** This group is hybrid in character. The attenuated and incomplete successions astride the Derwyn-Berwyn Axis have all the characteristics of an intra-basinal high system. Yet, when placed alongside thicker developments to the north and south that also include its oldest levels, the group bears the hallmarks of a mudstone drape system. It differs from the latter in failing to gain basin-wide extent. Nonetheless, uppermost parts of the Hengae Group in South and east Wales (see Dinas Island and St. Cynllo's Church formations) and coeval levels of the Drefach Subgroup's Mydrim Shales Formation testify to a period, late in the Caradoc, when level of coarse clastic supply to the whole of the LPWB was diminished, and anoxic mud-prone facies were being widely deposited in both deep and shallower water

name). In its Snowdonia type area, finely laminated, locally graptolitic silty mudstones, dominate parts of the Eryri Group that were deposited prior to the impacts of mid-Caradoc vulcanism. Successions in southern Snowdonia including those of the Blaenau Ffestiniog slate belt everywhere succeed the Mid-Ordovician hiatus. This may not to be the case in the successions seen around Bangor and in the Nant Ffrancon (Plate 5), Nant Peris and Cwm Pennant valleys (see Text Box 3). Further south, Eryri Group mudstones blanketed the upper parts of the Aran Volcanic Group (e.g. Smith *et al*., 1995; Howells and Smith, 1997). Subsequently, alongside the spread of erupted material, shallower, brachiopod and trilobite-bearing sedimentary facies became more widespread with some coarser units, associated with volcanic islands, testifying to beach and fluvial processes (e.g. Howells *et al*., 1991). Volcaniclastic contamination was ubiquitous. The group also includes, as formations and members, volcanic units excluded from regional volcanic groups (Rushton and Howells, 1998). These include lavas linked to briefly active eruptive sites, as well as tuffs and tuffaceous levels deposited and redistributed some distance from their sites of ejection. Shallower water indicators are prevalent in the group's Berwyn Dome succession that, as well as volcanic material from the principal Snowdonia centres, includes the products of eruptions further east (Brenchley *et al*., 2006b). The lateral relationship between the Eryri and Hengae groups astride the Derwen Anticline are discussed more fully in Section 3 but offer evidence that the latter was acting as a facies divide. In the south of the Berwyn Dome, where its volcanic components become less prevalent and in what would otherwise be a gradational lateral passage, the Tanat and Cynllaeth faults combine to provide a practical boundary between the local Eryri and Montgomery group successions.

Late Caradoc rocks in North Wales to which the label 'Nod Glas' has been applied comprise a series of thin and attenuated successions that records the blanketing of local volcanic centres and attendant sedimentary successions by facies suggestive of anoxia and sediment starvation. These include black, hemipelagic, graptolite-rich mudstones and phosphate-rich limestones. The accumulation of such facies across both the North Powys and Llŷn sub-platforms and the Derwen Anticline has been seen to record an interregnum between the earlier mixed volcano-sedimentary systems of the Preseli Supergroup and the post-volcanic successions (Hafren Supergroup) that followed (see Brenchley *et al*., 2006b, p. 65). But this emphasis reflects a North Wales-centric view. Black graptolitic mudstone deposition had already been in progress in South Wales from late Llanvirn times (Drefach Subgroup) and gave way locally to Caradoc limestone facies (e.g. Castell Limestone and Mydrim Limestone formations) (Plate 7). Moreover, localised volcanic units seen in North Wales on Llŷn and in the Conwy Valley (e.g. Trefriw Tuff Member), and more widespread igneous intrusions including those seen in the northern Tywi Anticline succession at Baxter's Bank (Davies *et al*., 1997), show that volcanic shutdown was incomplete at the time of 'Nod Glas' deposition. The distinctive facies in North Wales are better viewed as the components of a discrete late Caradoc sedimentary interval that, at least in part, has the characteristics of an intra-basinal high system (see Text Box 5). In having physical links to both shallower water (Montgomery Group) and deeper (Hengae Group) systems, as well as the mixed Eryri Group system, these facies warrant designation as a separate **Nod Glas Group**. In the context of the LPWB, the latter clearly formed an integral, if terminal component of Tract Assemblage A. The dating and seemingly anomalous lateral relationships of the group in north-west Wales are assessed in Section 3. Nod Glas Group facies (Gwern-y-Brain Formation) seen in the Welshpool area (Brenchley *et al*., 2006b) may record the onset of a lateral passage into coeval Montgomery Group rocks.

A detailed lithostratigraphical analysis of the major Caradoc volcanic systems that interdigitate with AII Systems Tract deposits in North Wales, principally with the Eryri Group, is provided by Rushton and Howells (1998). The one significant change relates to the Aran Volcanic Group (Allen and Jackson, 1985). The latter, as currently defined, spans the Mid-Ordovician Unconformity (e.g. Pratt *et al*., 1995; Rushton and Howells, 1998). The presence of this hiatus, though its location in some outcrops is not obvious, requires the concept of a unified Aran Volcanic Group to be re-visited. Pending future investigation, division of the Aran volcanic succession into separate 'Lower' and 'Upper' group-scale components has pragmatic merit. Thus, significant AII Systems Tract volcanic systems include the early Caradoc **Upper Aran Volcanic Group** (adapted name), the mid-Caradoc **Llewelyn Volcanic** and **Snowdon Volcanic groups** and, on Llŷn, the **Upper Lodge Volcanic** and **Llanbedrog Volcanic groups** (see also Howells and Smith, 1997; Young et al., 2002). The volume of material erupted in the south and east Wales was not on a scale to warrant the recognition of group-scale volcanic systems. However, volcanic formations and members included in the AII tract's sedimentary systems testify to the output from briefly active volcanic sites (see Llanwrtyd Volcanic, Coed Duon Volcanic, Trelowgoed Volcanic, Hagley Volcanic and Wittery Volcanic formations). Tuffs and volcanic breccias linked to igneous intrusion and surface eruptions are also seen in the Breidden Hills (Cave, 2008). These volcanic components commonly serve as important marker horizons within their host successions (see Part 3).

Extensive areas of distal mud accumulation (Drefach Subgroup) and transgressive basal contacts testify to the role of rising base levels on the AII Systems Tract in South and mid Wales. However, a discrete phase of back arc transtension overtook such processes to initiate the changes associated with the tract's base in North Wales. The resulting Mid-Ordovician Unconformity was a compound feature. The merging of the Harlech Horst and Llyn Sub-platform created a region of widespread erosion linked to shoaling and emergence that also included sites of ferruginous ooid formation. In contrast, the omission seen along the flanks of these structurally positive regions testifies to mass-wasting and slide excision, followed by slump, olistolith and melange emplacement (Fig. 12). That there may have been subsidence-prone areas in northern Snowdonia that escaped both forms of omission is explored in Text Box 3. Whether mass-wasting or erosion in a shallower, uplifted setting was responsible for omission in the Arenig area is less clear. Certainly, early Caradoc up-doming and Upper Aran Volcanic Group vulcanism were soon to give topographical expression to this section of the Derwen Anticline from which the mud-prone Eryri Group sediments (Porthmadog Formation) that had begun to accumulate in the Snowdon Trough were initially excluded. The cessation of early Caradoc eruptions saw such facies to spread across this embryonic structural axis (see Part 3). This was before mid-Caradoc vulcanism and tectonics became the dominant controls on AII Systems Tract development throughout the north-west Wales region. New and revived fracture belts became the focus for magma intrusion, eruption and caldera collapse associated with centres on Llŷn and in Snowdonia (Upper Lodge, Llanbedrog, Llewelyn and Snowdon volcanic groups) (e.g. Kokelaar, 1988; Campbell *et al*., 1988; Howells *et al*., 1991; Young *et al*., 2002).

Omission linked to the Cardigan-Fishguard Fault Belt, the latter's role in confining sand-prone Hengae Group facies, the incomplete AII System Tract succession of the Haverfordwest Tilt-block and the opening of the south Shropshire half graben all testify the wider impacts of Caradoc transtension. Small volcanic centres had been active in South Wales during the Llandeilian, but it was the Caradoc that witnessed outpourings in the Berwyns, Shelve, Builth and Llanwrtyd areas. It was in the wake of early Caradoc tectonism that the principal structural components of the LPWB became fully established. The recognition of an extensive deep-water system provides the earliest clear evidence for a discrete South Wales Sub-basin (Fig. 12). Montgomery Group facies show that the North Pembrokeshire and North Powys sub-platforms and the Marginal Belt were serving to limit its extent. The depocentre in Snowdonia served briefly as a counterpart in North Wales, before the impacts of vulcanism became dominant (see Part 3).

Subduction of the Iapetus Ocean spreading ridge is widely cited as responsible for the shutdown of vulcanism in Wales late in the Caradoc. Brenchley *et al*. (2006b) suggest that, though vulcanism had not completed ended, it was the onset of differential thermal subsidence that promoted the changing basal relationships and pronounced lateral variations displayed by Nod Glas Group in North Wales. The crestal region of the intra-basinal Derwen-Berwyn Axis was a site of condensed deposition (see Part 3) and, likely in concert with the Harlech Dome, was operating once again to partition the LPWB into discrete sub-basins (Fig. 12). Thickness and facies changes within the Montgomery Group including those seen in the Shropshire sub-basins, those associated with the Severn Valley Fault System near Welshpool, and evident in the Llandeilo area and on the Haverfordwest Tilt-block show that, though the group achieved blanket-like coverage, deposition in shallower settings remained strongly influenced by extensional palaeotopography.

Throughout the development of the AII Systems Tract, links to the norther Iapetus Ocean were established and maintained, but a direct connection to the south and south-west with the Rheic Ocean, shown on some palaeogeographical reconstructions (e.g. Rushton, 2000), appears doubtful. Volcanic edifices undoubtedly acted as local sources for coarse volcaniclastic sediment, but the volumes of Hengae Group turbidites sourced from the south-west (Dinas Island Formation) and south-east (St. Cynllo's Church Formation), together with sand-prone facies of the Montgomery Group, imply that a more extensive sediment source area (Pretannia) was in place to the south (e.g. Bevins *et al*., 1992). This continued to supply coarse clastic sediment to adjacent regions until well into the *clingani* Biozone (*morrisi* Subzone). However, latest Caradoc facies, where they are preserved, testify to a period late in the tract's evolution, at a time of elevated global sea levels, when large parts of this source area were likely submerged (e.g. Woodcock and Strachan, 2012).

# 2 Tract Assemblage B (lower Hafren Supergroup)

The cessation of subduction-related vulcanism and an associated decline in rift tectonics initiated a period during which the impacts of thermal subsidence alongside global forcing factors became increasingly significant influences throughout the LPWB and across the Midland Platform. The Shelveian Orogeny that resulted from the collision of Eastern Avalonia with Baltica had significant local effects during the late Ashgill (e.g. Brenchley al., 2006b). It overlapped with oceanographic changes linked to the Late Ordovician Gondwanan glaciation (see Text Box 6; Fig. 5) the impacts of which in Wales, as elsewhere, were profound and widespread and had a legacy that lasted well into the Silurian (e.g. Pope and Steffen, 2003; Salzman and Young, 2005; Davies *et al*., 2009, 2016). Figure 1B shows the distribution of rocks assigned to the Hafren Supergroup and Figure 12 the principal structural and palaeogeographical features that influenced Tract Assemblage B's development.

## 2.1 BI SYSTEMS TRACT (PRE-HIRNANTIAN ASHGILL)

Rocks of this systems tract crop out widely throughout north, south and western Wales, but are absent to the east of a line connecting the Severn Valley Fault Belt, the Pen-y-waun Fault Belt and the Sawdde Fault, and also to the south the Old Red Sandstone unconformity in mid Pembrokeshire (Fig. 13). Profound facies changes typified by an abrupt transition from anoxic to predominantly oxic facies mark the base of this system tract and of the post-volcanic tract assemblage; and equally profound changes define its top. Though both sets of changes record key oceanic events associated with the Late Ordovician Glaciation (e.g. Armstrong *et al*., 2009; Davies *et al*., 2009, 2016), but arguably neither were linked to global flooding events (Fig. 5).

Differential, post-volcanic subsidence and regional plate tectonism also played their part in shaping the tract's early development and the subsequent destruction of its proximal components. The tract's suite of grossly similar, intergradational mudstone-dominated facies are included in a single basin wide depositional system. See Figures 9, 10 and 12.

*Base* - In deeper South Wales Sub-basin settings, where successions are intact, strongly burrow-mottled Ashgill rocks overlie graptolitic facies of the preceding tract in what is widely recognised as an intra-*linearis* Biozone transition at or close to the base of the Pusgillian (e.g. Williams *et al*., 2003). The base of the east Pembrokeshire and Carmarthenshire Sholeshook Limestone Formation and its correlatives marks this same event in south-west Wales (Zalasiewicz *et al*.,1995; Vandenbroucke *et al*., 2008b). However, throughout much of North Wales, and parts of south-west Wales, Ashgill facies enter above a non-sequence of varying magnitude; indeed it was the recognition of this hiatus, in the Bala area, that underpinned the subdivision of the former Bala Series into its modern Caradoc and Ashgill components (Bassett *et al*., 1966) and formed the basis for Woodcock's (1990) 'Powys Supergroup'. The youngest (latest Caradoc) levels of the underlying systems tract are reportedly also absent from these areas (Fortey *et al*., 2000). Here the earliest Ashgill rocks preserved date from either the Cautleyan, or as throughout much of Snowdonia and Llŷn, the Rawtheyan. In North Wales, condensed successions of limestone (e.g. Dolhir Limestone and Rhiwlas Limestone members) locally mark the bases of these incomplete Ashgill successions, their location testifying to the still active nature of the Derwen-Berwyn Axis. Molyneux *et al*. (2023) reject reports of Pusgillian strata along the flanks of the Berwyn Dome and near Welshpool (e.g. Brenchley *et al*., 2006b) that might otherwise contradict this view, though any break in these areas was perhaps minimal.

In addition, deep erosion initiated by the Shelveian deformation, and compounded by the impacts of the Hirnantian fall in global sea level (see Text Box 6), is reflected in the absence of any previously deposited Ashgill rocks from eastern Wales (see below). Consequently, the nature of any shallow water early Ashgill facies once deposited across the basin's eastern Marginal Belt and the adjacent platform is unknown. Only in Pembrokeshire and western Carmarthenshire, where the Pusgillian to Rawtheyan Sholeshook Limestone Formation is preserved, is there a representative of more proximal early Ashgill deposition. Even within this unit there are facies and faunas that Price (1980) viewed to be suggestive of slope and foot-of-slope settings. The Sholeshook Limestone has been widely reported to be separated from the underlying Caradoc succession by a non-sequence, but the work of Zalasiewicz *et al*. (1995) near Whitland has called this into doubt. An unconformity continues to be invoked to the north and west, where the limestone is absent and the Rawtheyan Slade and Redhill Formation rests on older levels of the local Caradoc (AII Systems Tract) succession. For these relationships, mass-wasting across parts of a still active Haverfordwest Tilt-block and embryonic Llanddewi-Velfrey Anticline offers a possible an explanation.

**Text Box 6. Timing and impacts of the Shelveian Orogeny:** The Shelveian deformation appears to have been a protracted event. Some authors recognise its early impacts on late Caradoc successions (e.g. Verniers *et al*., 2002) and others a conclusion during the Hirnantian (e.g. Cocks and Fortey, 2009). The impacts of the orogeny on the preservation of earlier Ashgill (BI Systems Tract) rocks across eastern parts of LPWB and the Midland Platform is outlined in the main text and this has been widely perceived to record a period of maximum impacts late in the Rawtheyan Stage (e.g. Toghill, 1992; Davies *et al*., 2009).

A pertinent question is: Where are the predicted products of the extensive erosion that accompanied Shelveian uplift? It is likely that any succession of early Ashgill rocks previously deposited to the east of the South Wales Sub-basin, at a time of falling global sea levels, was relatively thin. The faulted-control accumulation of late Rawtheyan coarse clastic subsystems along Tywi Anticline has been alluded to and these offer evidence of contemporary erosion. However, the effects of the deformation extended beyond the western limit of Ashgill preservation (Fig. 11), and it is angular unconformities between transgressive mid Hirnantian facies seen in the Llandovery and Welshpool areas that provide a minimum age (Davies *et al*., 2009; BGS, 2000a). That the early Hirnantian glacial maximum shoreline was established only a few hundred metres to the west of these localities suggests that there was link between the limits of deformation and the final position of the early Hirnantian regressive shoreline.

It emerges as likely that the bulk of the Shelveian erosion was accomplished during the Hirnantian, when, in the South Wales Sub-basin, the regressive portions of the Yr Allt Group offer evidence of exceptionally high rates of sedimentation, of widespread slumping and of coarse-grained subsystems advancing into the deepest parts of the basin. This mass transfer of material is consistent with the terminal impacts of tectonic uplift being exacerbated by rapidly falling early Hirnantian sea levels. The deformation saw earlier sub-basins sited within the eroded region, notably the Builth-Shelve and parts of the Whitland-Llandeilo Sub-basins, undergo inversion. In marked contrast to their earlier histories, they now evolved into persistently positive physiographical features active during the development of succeeding systems tracts (see below). As well as preventing the preservation of Ashgill sediments, it was principally this erosion that accounts for the absence of upper levels of the AII Systems Tract and, locally, earlier Lower Palaeozoic rocks, from large parts of the Marginal Belt and Midland Platform; and which created the surface that the post-glacial sea subsequently transgressed.

The base of the B1 system tract, therefore, offers contradictory evidence of origin. The transition from anoxic to oxic facies seen in deeper settings is commonly attributed to the early impacts of glacioeustatic regression (e.g. Brenchley *et al*., 2006b), whereas the contacts and facies seen in parts of Pembrokeshire and in North Wales show that tectonism delayed the onset of deposition. Two processes were possibly at work: 1) oceanic chemical and temperature changes that attended the early stages of the Late Ordovician glaciation; and 2) a protracted tectonic transition that saw areas prone to uplift during the preceding rifting regime only gradually succumb to the effects of crustal cooling and regional thermal subsidence. The former likely accounts for the abrupt oxygenation of the LPBW and spread of bioturbating benthos into even its deepest regions; the latter offers explanation for the diachronous spread of deeper water facies across regions of widespread omission in North Wales, and for the transgressive relationships of shallower water facies seen locally in the south.

*Nomenclature & evolution* - The delineation of discrete depositional realms in North and South Wales initiated during the earlier system tract initially continued during the early evolution of the Pre-Hirnantian Systems Tract. In North Wales, the widespread absence of early Ashgill strata from the axial region of the Derwen Anticline and from the successions of the Berwyn Dome, the Conwy Valley and Llŷn peninsula has been attributed to mass-wasting across an area that was largely starved of sediment. Woodcock (1990) The products of such erosion may form part of a more complete North Wales Sub-basin succession speculated to be present at depth below Silurian rocks to the east and north of the Conwy-Llanelidan Fault System. Local fault-determined omission in South Wales has also been noted.

However, these basal relationships paint a picture of misleading complexity for the story of BI System Tract deposition was one of widespread uniformity. The growing influence of thermal subsidence is reflected in the Cautleyan to mid Rawtheyan spread of intergradational mud-prone slope apron, distal ramp and clastic blanket systems throughout both sub-basin regions, including the North Pembrokeshire and North Powys sub-platforms, and the Marginal Belt. Subgroup- and formation-level divisions reveal the presence of deeper and shallower water subsystems, but their shared oxic features and the seamless nature of many of their transitions records the first development of a mixed, basin-wide, mudstone drape system and justifies inclusion in an all-embracing **Corris Group** (new name). Variations within this facies continuum, including the presence or absence of shell-bearing sandstone event beds, localised basal limestones and in situ benthic shelly faunas, allow the distinction of the **Llandrillo Subgroup** (new name), in North and northern mid Wales, from the turbiditic and hemiplegic **Tresaith Subgroup** (adapted name) slope-apron facies further south. The yet more southerly and easterly **Withybush Subgroup** (new name), in addition to the basal Sholeshook Limestone Formation, includes the sheet sandstone-bearing off-shore, outer ramp and upper slope-apron facies seen in parts of north Carmarthenshire, Pembrokeshire and Ceredigion (see Part 3). However, the complex interleaving and highly gradational lateral contacts of these Corris Group subdivisions must be emphasised. Thus, whilst they appear useful as means of labelling geographically isolated successions, they are likely more relevant as conceptual rather than mappable entities (see Part 3).

Anoxic slope apron facies in the upper part of the Tresaith Subgroup have been linked the global Boda Event (Fig. 5; Challands *et al*., 2009). The impacts of the overlapping Shelveian Orogeny, believed to mark the final docking of Baltica with Eastern Avalonia, appear to have been limited to eastern parts of the LPWB (Toghill, 1992). Here, in addition to initiating uplift, tilting and erosion, late Rawtheyan faulting affecting upper parts of the local slope-apron system (Tresaith Subgroup) created local traps for coarse-grained turbidite subsystems recognised as the Doldowlod, Bryn Nichol and Taliaris formations (Davies *et al*., 1997; Schofield *et al*., 2004, 2009a). The coeval advance of strongly bioturbated muddy sandstones (Cribarth Formation) and local deposition of shallow water limestones (e.g. Glyn Limestone and Meifod Limestone members) offer evidence of a late Rawtheyan regression affecting upper levels of the BI Systems Tract. Even so, the preserved succession offers little to suggest that large volumes of eroded material generated by Shelveian uplift were entering the LPWB at this time (see Text Box 6).

## *2.2* BII SYSTEMS TRACTS (EARLY-MID HIRNANTIAN)

It is the BII Systems Tract that encompasses the impacts in Wales of the global oceanographic changes that accompanied the Late Ordovician Glacial Maximum. Critically, since it affects distribution, these include those linked to the early Hirnantian drawdown in sea level, but also of the mid Hirnantian onset of post-glacial deepening. Both deep and shallow water systems comprise regressive and transgressive components. Rocks assigned to the systems tract succeed those of the preceding one in all areas of Wales where the latter crop out. However, along the northern and southern flanks of the Berwyn Dome and in the vicinity of Garth, Llandovery and Haverfordwest, transgressive BII System Tract rocks locally overstep early Hirnantian strata to form the sole representatives of the systems tract (see below). Telychian mass wasting accounts for the local omission of BII System Tract rocks elsewhere (Brenchley *et al*., 2006b). Global Hirnantian processes were responsible for major Late Ordovician extinction events. From shallower facies, in all their areas of outcrop, elements of the distinctive and historically important 'Hirnantia' shelly fauna have been reported. See Figures 9, 10 and 12.

*Base* – As throughout the world, the facies changes that record the impacts of Hirnantian sea level and climatic events were some of the most profound and abrupt witnessed within the LPWB. Their effects in the South Wales Sub-basin were particularly marked. There, where it is conformable, the base of the BII Systems Tract is marked by a sharp contact between strongly burrowed pre-Hirnantian facies and weakly or largely unbioturbated Hirnantian rocks. In deeper water successions, the bases of Garclwyd, Drosgol and Lower Garnedd-wen formations identify this relationship. The abrupt reduction in burrowing activity has been linked to the marked increase in rates of deposition and levels of turbidity that accompanied the onset of the glacio-eustatic regression. Perhaps as significant was the increasing isolation the South Wales Sub-basin and the attendant impacts on levels of oxygenation and salinity (e.g. Davies *et al*., 1997; 2009; Nicholls, 2019). Abrupt macrofaunal faunal changes record the coincidental onset of the extinction event.

The pronounced early Hirnantian fall in sea level saw the contemporary shoreline withdraw westwards so that all regions to the east of the Tywi Anticline became emergent and a site of deep erosion (Davies *et al*, 2009, 2011; James, 2014). Seaward of these emergent regions, regressive early Hirnantian facies are preserved, but landward of the glacial maximum shoreline any previously deposited regressive units were quickly denuded. Here, mid-Hirnantian rocks laid down during the early post-glacial maximum transgression overstep their regressive counterparts to rest on eroded levels of the BI Systems succession deformed during the Shelveian event (see below). In the South Wales Sub-basin, basal sandstones and conglomerates and locally disturbed mud-prone units largely barren of shelly macrofossils, but with distinctive trace fossil suites are a feature of these transgressive successions (e.g. Nicholls, 2019). The bases of the Cwm Clyd Sandstone and Portfield formations display such contacts.

The Derwen-Berwyn Axis was an important intra-basinal influence on the development and preservation of local BII Systems Tract facies and its impacts are reflected in differences between the Hirnantian successions of the South and North Wales sub-basins. The bases of separate shallow water sand bodies (Glyn Grit and Corwen Grit formations) mark the base of the BII Systems Tract in successions north of the Berwyn Dome. In the Conwy area, it is linked to the onset of coeval fan delta deposition (Conwy Castle Grit Formation).

*Nomenclature & evolution* - Facies that record both the early Hirnantian fall in sea level as well as the early (mid-Hirnantian) stages of the global transgression that followed are recognised and their contact marks a major sequence boundary (Davies *et al*., 2009). Formation level divisions only serve locally to distinguish these separate regressive and transgressive components. For now at least, the mapping widely available for these rocks largely fails to do so and the common practice in Wales has been to include and map them as a single combined lithostratigraphic entity. Though Davies *et al*. (2009) argue against this approach, it remains clear that the similarities of these separate components outweigh their differences when compared to the facies that precede and succeed them. Self-evidently, there is a strong case to recognise them as elements of a common systems tract that was dominated by the impacts of Hirnantian glacioeustasy (see Part 1) and having some of the highest eustasy index values seen in the LPWB (*sensu* Davies *et al*., 2016).

This then provides the background for recognising a series of groups that reflect the modifications wrought by Hirnantian glacio-eustasy to the preceding Coris Group system. In the South Wales Sub-basin, highly disturbed deep-water Hirnantian slope, foot-of-slope and slope apron systems (**Yr Allt Group)** are distinguishable from the shallower water ramp systems associated with its opposing flanks. To the north-west, the **Cwm Hirnant Group** (new name) has strong links to the Derwen Anticline and displays features consistent with mass-flow deposition on, or adjacent to steep gradients (e.g. James, 2014; Nicholls, 2019). The shallow water facies of the **Scrach Group** crop out in the Marginal Belt, around the northern closure of the Tywi Anticline and along southern parts of the North Powys Sub-platform. It is these shoal systems that locally preserve the globally distinctive Hirnantia Fauna and it was from an exposure in the type succession of the Cwm Hirnant Group, east of Bala, that this distinctive shelly assemblage, all be it likely transported, was first discovered (Elles, 1922). The broadly equivalent deeper and shallower counterparts in the North Wales Sub-basin are recognised as the **Conwy Group** (adapted and upgraded) and the newly named **Ceiriog Group** respectively. Brachiopod and trilobite-bearing transgressive facies that imply a connection to the open Iapetus Ocean, serve to distinguish both these northern units from their South Wales Sub-basin counterparts.

Epeirogenic faulting triggered by the abrupt changes in sediment and hydrostatic load that attended glacioeustasy was also an important factor in shaping LPWB Hirnantian successions (e.g. Schofield *et al*., 2004; Davies *et al*., 2016) (Text Box 6). The absence of late Rawtheyan strata from northern parts of the Derwen Anticline may, in part, record the impacts of Shelveian uplift, but the distribution and attenuation of early and mid-Hirnantian strata clearly testify to the active nature of the Derwen-Berwyn Axis, including the Bala Fault, during the BII Systems Tract's development (see Bassett *et al*., 1966; James, 2014). The impacts of Telychian mass-wasting (see below) destroyed any early-mid Hirnantian facies once deposited across the crestal region of the axis and prevents insight into the nature of any transition between the Cwm Hirnant, Scrach and Corwen groups. There seems little doubt that this was a site of widespread omission linked to emergence and/or shallow water scour (see Part 3). However, though it played an important role in isolating the region to the south, long-lived breaches in this structural barrier likely served to connect the South Wales Sub-basin to its North Wales counterpart and to the Iapetus Ocean beyond. It was via these, even at the time of maximum isolation, that the cosmopolitan Hirnantia Fauna gained access to the southern water body and the reworked assemblage seen at its Cwm Hirnant type locality was supplied (Fig. 13).

### 2.3 BIII SYSTEMS TRACT (LATE HIRNANTIAN-MID TELYCHIAN)

Outcrops of BIII Systems Tract rocks occur widely throughout mid and north Wales where successions of deep-water facies succeed their BII System counterparts. However, the tract's shallow water systems have a significantly greater geographical range than the earlier components of the Hafren Supergroup. Outcrops that flank the Shelve and Builth inliers, and seen in the Garth, Llandovery and Haverfordwest areas, testify to the presence of such rocks throughout the Marginal Belt. The extensive presence of a Midland Platform succession is revealed by outcrops in the Church Stretton and Ludlow districts, the Silurian inliers of south-east Wales and Welsh Borderland and the Skomer area of south Pembrokeshire. Subsurface data permit a fuller understanding of the distribution of these rocks (see below). The marked facies changes that were previously widely seen to mark the base of the Silurian in Wales remain significant as a systems tract defining level (see Part 1). However, alterations to the international criteria used to define the base of the Silurian mean that that the lowermost levels of the BIII Systems Tract are *de facto* late Hirnantian in age. Thermal subsidence and eustasy remained the dominant influences on systems tract development, but fault movements that affected deposition and preservation of facies, notably across the Marginal Belt and Midland Platform, record the ongoing role of contemporary tectonism in those regions. See Figures 9, 10 and 12.

*Base* - The base of this tract is one of the most widely recognised and mapped surfaces throughout the LPWB. In deeper water successions of the South Wales Sub-basin, the abrupt appearance of graptolite-bearing *persculptus* Biozone rocks (Mottled Mudstone Member) above barren, extensively slumped mid-Hirnantian facies is a readily recognised contact that has been extensively examined and described (e.g. Cave & Hains, 1986; Temple, 1988; Davies *et al*., 1997; Blackett *et al*., 2009) (see Figs 17-19). The corresponding level, in comparable facies, is readily identified in borehole core from sites in the North Wales Sub-basin near Conwy where it marks the base of the Bryn Dowsi Formation (Warren *et al*., 1984). The equivalent horizon in coeval outer Marginal Belt shallower water successions in South and mid Wales, as assessed by Davies *et al*. (2009, and references therein), is marked at different localities by the bases of the Ystradwalter Member, Bronydd Formation and St. Martins Cemetery Bed. Only along the northern and southern flanks of the Berwyn Dome is there some doubt as to its exact position within the complete, but poorly fossiliferous mudstone successions that succeed mid-Hirnantian transgressive sandstones. When better understood, it is likely that the base of a redefined Laundry Mudstone Formation will also serve to identify the local base of the BIII System Tract in the Welshpool area (see Part 3). In complete and conformable deep-water successions, the distinctive facies change has been seen to mark a critical point in the post-glacial evolution of the LPWB, when rising sea levels by establishing a fuller re-connection to the open ocean allowed the return of graptolites to the water column and bioturbating benthos to the sea floor. Davies *et al*. (2009) recognised this as a re-ventilation event. However, the return of normal oceanic conditions following the Hirnantian glacial episode and its associated extinctions involved changes to a range of previously injurious chemical and/or nutrient-related factors (e.g. Delabroye and Vecoli, 2010; Harper *et al*., 2014).

In contrast to these conformable successions, the BIII systems tract base in western regions relationships followed an interval of erosion. Basal shallow marine and locally fluvial conglomerates and sand-prone facies rest unconformably on deformed Lower Palaeozoic and older rocks. They testify to the diachronous burial a complex topography inherited from Ashgill erosional events but sustained in part by active faulting (Fig. 9). In the Welshpool region, the strongly diachronous base of the Powis Castle Conglomerate Formation records the Rhuddanian and early Aeronian progress of the post-glacial deepening event across the North Powys Sub-platform and reveals the active nature of the Severn Valley Fault Belt (Cave, 2008). Surface and sub-surface data reveal the complex pattern of inundation across the Marginal Belt and adjacent Midland Platform. The local bases of the Pentamerus Sandstone and Folly Sandstone formations record the late Aeronian to early Telychian onset of BIII Systems Tract deposition on tectonic blocks in the Shelve, Wrekin, Pedwardine and Presteigne areas. The base of Trecoed Sandstone Formation marks the late Aeronian onset of deposition along the western flank of the Builth High. The Derwyddon Formation began to accumulate in the east of the Llandovery area across the Pen-y-waun Axis during the *convolutus* Biozone (Davies *et al*., 2013). Much further east, in the Malverns and Abberlys inliers, the base of the Cowleigh Park Formation reveals the regional extent of these late Aeronian transgressive facies. Such occurrences have promoted the concept of an 'Upper Llandovery Unconformity' but are misleading (see Text Box 7). Subsurface data suggest that a wide area of the central Marginal Belt and the adjoining Midland Platform is underlain by a BIII Systems Tract rocks that are significantly older. The base of the reddened, in part terrestrial Fownhope Formation record the Rhuddanian onset of BIII Systems Tract deposition in the Woolhope Sub-basin (BGS, 2000b).

Exposures in Huntley Quarry (Huntley Quarry Volcanic Member) reveal the southerly range of these rocks in the May Hill Inlier.

*Nomenclature & evolution* – With the Telychian destruction of any BIII System Tract facies once deposited across the Derwen - Berwyn Axis, any evidence of linkage between the northern and southern sub-basins has been lost. Strong similarities between the two deep-water successions implies that the late Hirnantian to Llandovery global transgression may have re-established strong links between the sub-basins. However, evidence of a southwards coarsening of facies on its northern side (Warren *et al*., 1984), and of its local incision (Foel Ddu Canyon), points to the continued presence of some part of the Derwen Anticline as a topographic feature. The degree to which this was tectonically active remains questionable (see below), but its continued impact has been persuasive in recognising the late Hirnantian to Aeronian successions seen to the north and south as belonging to geographically separate systems.

In the South Wales Sub-basin, the name **Pont Erwyd Group** of Jones (1909) is reinstated for widely outcropping deep-water slope-apron facies (Plate 8) (note use of Jones' original spelling in place of the modern Ponterwyd). However from this, oxic slope-apron facies of largely Telychian age are excluded (see below; Fig. 17). The South Wales system of shallower bioturbated facies with distinctive benthic faunas includes the ramp or fan delta **Cwm Rhuddan Group** and the strongly diachronous transgressive sand-prone blanket facies of the **Castell Powys Group**, both newly named (Figs 18, 19). The stratigraphical affinities of tectonically influenced, Rhuddanian to ?mid-Telychian, sand-rich, fluvial and marine successions preserved within the confines of the intra-platformal Woolhope and Usk sub-basins are assessed more fully in Parts 3 and 4. The case to view these rocks as a separate group has been resisted and they are here recognised as a proximal division of the Castell Powys Group. The existing term for these strata (e.g. BGS, 1988, 2000b) is modified and downgraded to the **May Hill Sandstone Subgroup**. The sedimentary units that interdigitate and cap the **Skomer Volcanic Group** in the eponymous south Pembrokeshire sub-basin represent a transgressive mixed volcano-clastic subsystem here recognised as the Cable Bay Formation (new name).

A subsystem-scale interval of sustained coarse-grained turbidite deposition enclosed within the Pont Erwyd Group is recognised as the **Caban-Ystrad Meurig Subgroup** and finds mapped expression as the geographically isolated Caban Conglomerate and Ystrad Meurig Grits formations (Plate 9). Together these units define a belt that was in receipt of coarse clastic sediments throughout the system tract's development. The supply of easterly sourced sediment persisted into the early Telychian (Davies and Waters, 1995) such that the subgroup crosses the boundary event level for the base of the CI Systems Tract recognised in enveloping slope-apron successions (see below) (Fig. 9). Though seemingly contradictory, this relationship accords with the presence of coeval Castell Powys Group sand-prone facies in source areas to the east. Other coarse clastic units within the Pont Erwyd Group, unrelated to the Caban-Ystrad Meurig Subgroup testify to similar relationships (see Part 3). The 'Claerwen Group' of Davies *et* *al*, (1997) has been widely used for the succession of predominantly oxic Aeronian to early Telychian slope-apron facies on BGS maps of the South Wales Sub-basin. In a decision that many may feel to be contentious, the term Clearwen Group is no longer viewed as fit for purpose (see CI Systems Tract).

In the North Wales Sub-basin, the relationships between deeper slope-apron facies closely comparable to the Pont Erwyd Group and shallower facies that host benthic faunas remain unclear (see Part 3). Pending a better understanding, pragmatism warrants their inclusion in a mixed depositional system here recognised as **Capel Garmon Group** (new name).

The continuing influence of the Derwen-Berwyn Axis has been alluded to, but otherwise the late Hirnantian-late Aeronian deep-water slope-apron systems of the both the North and South Wales sub-basins have been seen to testify to deposition during a period of relative tectonic quiescence and of strong eustatic influences (Woodcock *et al.*, 1996). The alternation of oxic and anoxic slope apron facies describes the pulsed and protracted nature of the post-glacial maximum deepening (Davies *et al.*, 2016). Conglomerate-lined channels and migratory sandy turbidite lobe deposits evolved in concert with these external events (e.g. Davies and Waters, 1995; Schofield *et al.*, 2009b).

The Cwm Rhuddan and Castell Powys groups record the accumulation and spread of shallow water facies across the Marginal Belt and Midland Platform from late Hirnantian to Telychian times. The dates obtained from surface exposures were initially seen to offer a record of eastward progression across an irregular, but essentially passive surface installed by Shelveian and Hirnantian erosion. Rhuddanian and early Aeronian deposition was viewed as confined to the west of the Pontesford Lineament (Ziegler *et al.*, 1968). More recent studies, including subsurface investigations, reveal the transgression of a deeply corrugated and embayed topography strongly influenced by contemporary faulting (e.g. Cave and Hains, 2001; Cave, 2008; Butler *et al.*, 1997; Davies *et al.*, 2013; Ray *et al.*, 2021) (Text Box 7; Fig 16).

Local uplift within the Marginal Belt and outer platform promoted sites which resisted successful inundation until *guerichi* Biozone times, and there were sites associated with the Church Stretton Fault Zone from which BIII System Tract facies were either excluded, or denuded altogether (e.g. Cocks and Rickards, 1968; Ray *et al.*, 2021). The Severn Valley Fault Belt, Shelve-Long Mynd High, Builth High, Pen-y-waun Fault Belt and Carmarthen High display stratigraphical relationships that reveal their active nature (e.g. Cave and Hains, 2001; Davies *et al.*, 1997, 2013). Collectively, these features show that the inverted Builth-Shelve and Whitland-Llandeilo sub-basins comprised an archipelago of periclinal shoals and islands available to be drowned by rising post-glacial sea levels. However, with the exception of the Long Mynd Horst and other upfaulted blocks of Neoproterozoic rocks (e.g. Johnson, 1998; Ray *et al.*, 2021), few of these features exhibited steep flanking gradients and significant topographic relief. Castell Powys Group successions testify, not to their passive burial, but to the onlap of sites that were sustained by synsedimentary tectonism.

**Text Box 7. Concept of an Upper Llandovery Unconformity:** The system tract credentials of late Aeronian to early Telychian sandstones that crop out within the Marginal Belt and across the Midland Platform are problematical. Jones (1925, 1949), working on what was to become the Type Llandovery succession, recognised such strata as belonging to an upper, or 'C' division of the series. He associated this interval with the appearance of *sedgwickii* Biozone graptolites and established that it was these levels that overstepped earlier Llandovery divisions to rest on Ordovician rocks. It became widely accepted that Llandovery successions throughout much of eastern mid Wales and the Welsh Borderland overlay this so-called Upper Llandovery Unconformity. Subsequent studies significantly refined Jones' (1949) stratigraphical model and dating of the Type Llandovery succession (e.g. Cocks *et al*., 1992; Davies *et al*., 2013). However, the belief that late Aeronian transgressive events were responsible for the inundation of previously emergent structural axes and extended the reach of Llandovery marine facies across much of the Midland Platform remained largely unchallenged (compare Zeigler *et al*., 1968 and Cherns *et al*., 2006).

Attenuation and omission identify sites within the Marginal Belt that were tectonically active throughout the Rhuddanian and Aeronian. Their submergence, during the late Aeronian to early Telychian, followed an interval during which the impacts of regional tectonism and global marine regressions combined to promote widespread emergence and erosion. Evidence for contemporary tectonism is well seen in the Builth and Garth areas and west of Welshpool, where uplift created areas of pre-late Aeronian denudation (see Schofield *et al*., 2004). Such stratigraphical patterns and events appear clearly to favour the lithostratigraphical grouping of late Aeronian to early Telychian sand-prone transgressive facies with the succeeding mud-prone succession. It allows both to be viewed as offering evidence for a progressive deepening across the region. Recent BGS stratigraphical reconstructions, as depicted by Cave and Hains (2001, fig. 16), Schofield *et al*. (2004, fig. 2) and Cave (2008, fig. 6), endorse this view. In the context of this report, they appear to support the inclusion of the transgressive sandstones within the CI Systems Tract.

However, the work of Davies *et al*. (2013, 2016) has shown that the 'Upper Llandovery Unconformity' of the Type Llandovery area conflates the impacts of multiple erosional episodes and that the pattern of overstep shown, for example, by Schofield *et al*. (2004) is overly simplistic. Moreover, subsurface discoveries show that pre-late Aeronian rocks are more widely present than previously supposed. Graptolites recovered from boreholes testify to the partial inundation of areas in the vicinity of the Long Mynd during the mid-Aeronian *convolutus* Biozone, and likely earlier. This contrasts with the nearby Shelve and Wrekin areas where some basal sandstones date from the *guerichi* Biozone (Cocks and Rickards, 1968; Loydell and Cave, 1996; Cave, 2008). Seismic and borehole investigations in the Woolhope and Usk areas (Butler *et al*., 1997) demonstrate the presence of concealed intra-platformal sub-basins that host thick Rhuddanian to Aeronian successions (Fownhope and Huntley Hill formations). Such findings show that 'tectonic topography' remained influential into the Telychian, but also that BIII Systems Tract rocks of pre-late Aeronian age are far more widespread across the Marginal Belt and western parts of the Midland Platform than surface exposures alone suggest (Figs 9 and 12; see Text Box 13).

The concept of an 'Upper Llandovery Unconformity' emerges as simplistic and its role in defining the base of the CI Systems Tract problematical (see Part 4). Transgressive 'Upper Llandovery' facies clearly record a significant regional flooding event; one that was successful in drowning previously resistant axes of uplift and greatly extending the range of Llandovery deposition (Fig. 12). But these rocks can be viewed as the youngest levels of an onlapping Marginal Belt and Midland Platform succession that includes older concealed components. Much of this region may have remained tectonically buoyant compared to the subsidence-prone Woolhope and Usk sub-basins south of the Vale of Neath Disturbance, but it evidently lay within the reach of contemporary transgression. However, it likely also experienced multiple phases of emergence and erosion notably in response to Aeronian regressive episodes and its concealed succession is likely incomplete (see Butler *et al*., 1997). Certainly, it was the onset of subsidence associated with the Telychian CI Systems Tract that allowed the late Aeronian and to early Telychian components of this onlapping succession widely to escape such erosion, but their sedimentary alignment is clearly with the earlier (BIII) systems tract.

As such, this island belt was ineffective as a barrier to marine incursion further east, where Rhuddanian to early Aeronian shallow water BIII Systems Tract deposits are, or certainly were more widespread in areas of concealed stratigraphy (see Part 3). The thick May Hill Sandstone Subgroup successions in the Woolhope and Usk sub-basins testify to sites of fault-bounded subsidence. The Skomer Sub-basin and the complimentary Benton Horst were active features in south Pembrokeshire (Powell, 1989). This structural architecture shows that the Marginal Belt of the South Wales Sub-basin, and the adjacent platform to the east and south lay within reach of an extensional (or transtensional) regime linked to Rheic Ocean subduction. It was this that promoted the eruption of the Skomer Volcanic Group and activity at other volcanic centres, including in the Huntley Quarry area (Butler *et al*., 1997; Woodcock and Strachan, 2012). That these regions were those in Wales and the Welsh Borderland most impacted by the Shelveian event implies an ongoing link to the tectonic episodes affecting 'Far Eastern Avalonia' documented by Vernier *et al* (2002). Late Hirnantian to Aeronian BIII Systems Tract facies of the Marginal Belt and outer Midland Platform emerge as having mixed tectonic and eustatic credentials. Whilst tectonism strongly influenced thickness, distribution and preservation, contemporary eustatic events, in common with the Pont Erwyd Group, also had recognisable impacts (Davies et al., 2016). However, the eustatic credentials of depth-related faunal variations seen in Castell Powys Group facies of Telychian age (see Ziegler et al., 1968) remain unproven. Contemporary CI Systems Tract deposition has been linked to a significant weakening of global influences (see below). Such decoupling may have been a long-term feature of the intra-platformal, subsidence-prone sub-basins that host the May Hill Sandstone Subgroup (see discussion in Part 4).

# 3 Tract Assemblage C (upper Hafren Supergroup)

A further set of profound changes overtook the LPWB during the latest Aeronian to early Telychian as it responded to a key phase in the closure of the Iapetus Ocean and the collision of Eastern Avalonia with the northern supercontinent of Laurentia. Tectonism, affecting basin and platform settings alike, promoted a decoupling from eustatic influences and the transition into a tectonic systems tract (Woodcock *et al*., 1996; Davies *et al*., 1997). These changes were also marked by a long-term shift in the provenance of sediment being supplied to the LPWB. Though regions bordering its sub-basins continued to deliver material, huge volumes of far-travelled, compositionally distinct, sand-grade detritus now entered the South Wales Sub-basin via putative deltas to the south-west (e.g. Wilson *et al*., 1992; Clayton, 1994; Smith, 2004). This sediment's chemistry and mineralogy imply that an early effect of plate collision was to uplift an extensive source area located within the Avalonian province (e.g. Ball *et al*., 1992; Morton *et al*., 1992; Woodcock *et al*., 1996). Initially located some distance to the west or south-west of the LPWB, this emergent region likely developed links to early regions of inversion in the west of the basin and to Pretannia, the cryptic southerly land region which later also gained prominence as a region of sediment supply (Cherns *et al*., 2006).

Intra-basinal and basin-bounding faults became increasingly active in directing and accommodating this collision-related detritus. Structurally positive intra-basinal areas experienced intervals of reduced sedimentation and locally extensive mass-wasting. Marked differences periodically re-appeared between the northern and southern sub-basin successions although green, predominantly oxic slope-apron systems established in both were able to merge during the late Telychian. Much of the Midland Platform experienced rapid subsidence and went on to preserve complete and conformable Telychian to Ludfordian successions. Regional late Telychian subsidence and subsequent global transgressions saw the burial of even the most persistent structural highs. Collectively, these changes serve to mark the onset and evolution of the collision and post-collision phase of the LPWB's development (Figs 3-5). The diachronous Ludlow to (?)Early Pridoli arrival of northly sourced Caledonian molasse announced the demise of the LPWB as a marine depocentre and the evolution of the successor Anglo-Welsh foreland basin. The latter went on to accommodate the thick Pridoli to Early Devonian red bed succession of the ORS Supergroup (King, 1994; Barclay *et al.*, 2015). Sparce bentonitic clay beds testify distant volcanic activity ongoing throughout the tract assemblage. Thicker tuffaceous levels evidence the output from nearer, but unknown volcanic centres notably during the Wenlock (Cave and Loydell, 1998). Figures 13, 14, 21 and 22 show the principal structural and palaeogeographical features that influenced the development of Tract Assemblage C.

## 3.1 CI SYSTEMS TRACT (LATEST AERONIAN-LATE TELYCHIAN)

CI System Tract rocks crop out most extensively in mid Wales. Representative outcrops in North Wales occur near Llanystumdwy in eastern Llŷn, in the Conwy Valley, the Cyrn-y-Brain and Mynydd Cricor inliers and along flanks of the Berwyn Dome. Marginal Belt successions are seen in the Welshpool, Montgomery, Builth, Brecon, Llandovery and Haverfordwest districts. Outcrops in the Church Stretton district and in the Silurian inliers of the Welsh Borderland including the Malvern area provide a record of platformal deposition.

The systems tract captured the first significant impacts on the LPWB succession of Iapetus closure and plate collision. These were manifest as a progression of changes expressed in sediment provenance and volumes, migratory facies belts, fault reactivation, and of differential patterns of subsidence. The complex array of facies that make-up the CI Systems Tract describes the evolution of two dominant system types: a basin-wide mudstone drape system and a series of sandstone lobe systems. The relationships between these shows that differences between the North and South Wales sub-basins remained significant during the early development of the systems tract, but that these contrasts had largely disappeared by the late Telychian (*griestoniensis* Bozone) as previously separate belts of mud accumulation merged into a single, widespread depositional system. See Figures 9, 10 and 13.

*Base* – The impacts of plate collision and the resulting decoupling from eustatic control, though they ultimately ushed in a new assemblage of system tracts, overtook different sectors of the LPWB and Midland Platform at different times. Sedimentary systems and sub-systems of the preceding systems tract appear to have remained active well after the successor tract had established itself in other areas. The base of the CI Systems Tract is, accordingly, highly diachronous. In some areas its base is sharp and distinctive, but in other regions the sedimentological changes associated with its onset are subtle, arguably to point of subjectivity. Nevertheless, it is important that any group scale classification for the LPWP attempts to capture the impacts of one the most fundamental events that shaped its evolution. In places, this results in units that are coeval and/or similar in terms of facies composition and provenance being assigned to separate systems and system tracts, and different tract assemblages. The justifications for this are discussed further in Part 4.

Critically, and despite these issues, the CI Systems Tract boundary is widely linked to the bases of existing formations here recognised as components of a newly erected Trannon Group and for which mapped linework already exits. In the outer Marginal Belt successions recognised in the Llandovery, Garth and the Welshpool regions, the base of the green, locally maroon, mudstone dominated Cerig Formation marks the abrupt regional change in lithofacies that is emblematic of the system tract (Figs 17-19). The base of the possibly synonymous Millin Mudstone Formation marks this same event in the Haverfordwest succession. In the most distal setting of the Garth area, where there is evidence of a lateral passage with local divisions of the Castell Powys Group, the oldest parts of Cerig Formation are believed to date from the *sedgwickii-halli* biozonal interval (Schofield *et al*., 2004). In contrast, in its Llandovery type area, where accumulation of Cwm Rhuddan Group ramp facies and Castell Powys Group sand deposition persisted for longer, the base of the Cerig Formation is associated with the local first appearance of *guerichii* Biozone graptolites (Davies *et al*., 2012). In the Welshpool area, Loydell and Cave (1996) appear to have relied on previously published dates when suggesting a *turriculatus* Biozone age for the sharp base of their synonymous and now superseded 'Tarannon Formation'. Subsequently, Cave (2008) was content to view the latter as succeeding Aeronian rocks 'without any evidence of hiatus' (Fig. 19).

The base of the Purple Shales Formation (and its synonyms) marks the tract boundary in successions that accumulated across inner parts of the Marginal Belt and the outer parts of the Midland Platform, as seen in the vicinity of Long Mountain, along the flanks of the Shelve-Long Mynd Inlier and in the Church Stretton district (Cave and Hains, 2001; Cave, 2008; Greig *et al*., 1968). Where it conformably succeeds BIII Systems Tract rocks (Castell Powys Group), reported graptolites point the key facies change occurring within the modern *turriculatus* s.s. Biozone (see Table 1b) (cf. Cocks and Rickards, 1968; Loydell and Cave, 1993; Cave, 2008). The presence of *Stimulograptus (Monograptus) sedgwickii* in upper levels of the underlying BIII Systems Tract succession (Pentamerous Sandstone Formation) in the Hamperley Borehole appears anomalous (Cocks and Rickards, 1968). This may point non-sequence, although the taxon is known to range throughout the *guerichi* Biozone (Zalasiewicz *et al*., 2009). Locally, where it onlaps the preceding systems tract, the Purple Shales Formation rests on older rocks in a pattern that reveals the draping of a fault-influenced topography (Fig. 9).

Across inner parts of the Midland Platform, in the successions seen in Silurian inliers and some deep boreholes, the CI Systems Tract base is taken at the basal boundaries of proximal, sand and silt-prone facies recognised as the Yartleton Subgroup. The lowest levels of thick, largely concealed subgroup successions present in the Woolhope and Usk sub-basins, in the Fownhope Borehole, and at outcrop in the May Hill area, display conformable contacts with the underling BIII Systems Tract rocks and the onset of deposition likely pre-dated the *griestoniensis* Biozone (Fig. 13). In contrast, in the Malverns and Abberlys areas, where a significant non-sequence intervenes, the tract's transgressive basal beds shelly faunas that are traditionally correlated with that biozone (Cocks et al., 1992). Similar complexities are evident on fault blocks enclosed within the Church Stretton Fault Zone. At Pedwardine, CI Systems Tract facies believed to range from the mid-Telychian overstep BIII Systems Tract deposits to rest on Tremadoc rocks (Boynton and Holland, 1997; Ray *et al*., 2021). Nearby, there existed local edifices, for example at Nash Scar and Chenney Longville, where, if once deposited, such facies failed to be preserved. This is argued below also to be the case in the Skomer Sub-basin.

In the deeper slope apron facies of the Southern Welsh Sub-basin, the facies boundary that most closely matches that at the base of the Cerig Formation is linked to the Rhayader Mudstones Formation. For the historical reasons outlined in Part 3, the late Aeronian M. sedgwickii Shales Member has been included in the latter. However, it is in the Derwenlas Formation and in BIII Systems Tract that this anoxic unit is here considered better placed. This allows the base of a redefined Rhayader Mudstones Formation to be recognised as the CI Systems Tract boundary (see Part 3). This revised level still lies within the *sedgwickii-halli* biozonal interval. In contrast with their BIII counterparts, anoxic facies are typically thinner and more widely spaced in the slope apron succession that succeeds the M. sedgwickii Shales Member. The typically low levels of bioturbation seen in the pale grey and green, silt-laminated Rhayader Mudstone Formation facies also contrast with the intense burrowing seen in parts of the underlying division (Davies *et al*., 1997; Melchin *et al*., 2023).

However, recent practice has been to view the Rhayader Mudstones and Derwenlas formations as the subordinate divisions of a predominantly oxic, easterly sourced, slope apron succession labelled the 'Claerwen Group' (Davies *et al*., 1997). Selection of the top M. sedgwickii Shales Member as a tract assemblage boundary, though it conforms with the systems tract approach, requires the 'Claerwen Group' concept to be abandoned. Many may see the lithological changes linked to this level as insufficient to justify this and it also presents a mapping problem in areas where the former group has been mapped as a undivided unit. However, the link to the Cerig Formation is important and offers strong reason to support the coeval tract base selection in the coeval deep-water succession. This is despite the impacts of intra-Telychian mass-wasting, which, subsequently, widely served to destroy the physical link between the deeper and shallower Trannon Group divisions (Davies *et al*., 1997) (Text Box 8; Figs 17, 18). In contrast to the eustatic signal evident in Aeronian parts of the 'Claewen Group' (Davies *et al*., 2016), it was enhanced rates of Telychian subsidence, in common with the Cerig Formation, that characterised accumulation of the mainly oxic Rhayader Mudstone Formation (e.g. Woodcock *et al*., 1996).

Backing for this base selection also comes from North Wales. In the Llandudno area, the base of the CI Systems Tract also lies above graptolitic facies with *sedgwickii* Biozone graptolites and is taken at the base of a distinctive, predominantly green mudstone succession which spans most of the Telychian. Previously labelled the 'Pale Slates' (Warren *et al*., 1984), these strata are here recognised as a redefined Gyffin Formation (see Part 3). In western parts of both sub-basins, along the Cardigan Bay coast and at Llanystumdwy, anoxic facies yielding *sedgwickii* Biozone graptolites are thin and impersistent (unpublished BGS data; Baker, 1981; Warren *et al*., 1984). In the Llangollen Syncline succession, the absence of such graptolites persuaded Wedd *et al*., (1927) that a non-sequence intervened between Aeronian rocks and an overlying Telychian succession that is recognised on BGS maps as the Ty Draw Slates Formation.

Locally in the South Wales Sub-basin, along narrow corridors that include those associated with the Caban-Ystrad Meurig Subgroup and Llyn Brianne Formation (see Part 3), continued to receive BIII Systems Tract sand and gravel after the onset of CI Systems Tract mud deposition in surrounding areas (see above). In these areas, where its base is clearly diachronous, the impact of the changes wrought by the CI Systems Tract were offset until the early Telychian. From areas that experienced intra-Telychian mass-wasting, associated with the Tywi and Derwen anticlines and the western and southern margins of the North Powys Sub-platform, early deposits of the CI Systems Tract were either excluded or eroded. Here, and reminiscent of inner platformal settings (see above), the earliest preserved Telychian rocks are of *griestoniensis* or *crenulata* Biozone age (Davies *et al*., 1997). Across these same regions, facies of slope apron aspect assigned to the Dolgau Mudstone Formation overstep on to eroded levels locally as old as the BI Systems Tract. Slumped and debritic slope and foot-of-slope facies (Henfryn Formation) overlie the Tywi Anticline disconformity at the base of the CI Systems Tract (Davies *et al*., 1997).

In summary, in Marginal Belt and outer platform successions, facies changes that date locally from as early as the *sedgwickii* Biozone, but that are more widely associated with the bases of the *guerichi* and *turriculatus* biozones, serve as boundary levels for the CI Systems Tract. Throughout these regions, they chart the subsidence-induced demise of the sedimentary regime (Castell Powys Group) that formed part of the preceding tract assemblage (see above). Elsewhere, the earliest deposits are much younger, of *griestoniensis* and *crenulata* Biozone age, and there also exist sites, notably associated within the Church Stretton Fault Zone, from which Telychian deposition was excluded, or its products subsequently eroded. Non-sequence linked to the Aeronian-Telychian boundary interval serve to define the tract base in north-east Wales. In complete deeper water successions present in both the North and South Wales sub-basins, the system tract base is taken above *sedgwickii* Biozone anoxic deposits that serve as a practical, widely recognised marker at the top of the preceding BIII Systems Tract. Though this late Aeronian anoxic level has a eustatic signature, its westernmost expression may offer the earliest record of decoupling from such influences and the subsequent establishment of a tectonic systems tract. Work is needed to identify the base of the systems tract in areas where the former 'Claerwen Group' has been mapped as undivided.

*Nomenclature & evolution* – Though global deepening events were at work initially, it was enhanced rates of regional subsidence affecting both sub-basins, the Marginal Belt and outer Midland Platform regions that promoted the accumulation of a thick blanket of oxic green, maroon and purple muds (see Woodcock *et al*., 1996; Davies *et al*., 2016). The mud-prone blanket facies of platformal and Marginal Belt settings passed laterally westwards into green and maroon slope apron facies to form a linked set of mud-dominated Telychian subsystems. These were the key components of the oxic mudstone drape system here recognised as the **Trannon Group** (new name).

The predominantly green mudstones associated with this period of the basin's evolution were widely mapped by early surveyors as the 'Tarannon Pale Shales'. The term 'Tarannon' also gained favour as a name for rocks of this age. The work of Wood (1906) in the type area of the 'Tarannon' showed that the patterns of deposition were more complex and that the succession of its eponymous area was equivalent only to the younger levels of other 'Pale Shales' outcrops. Following the work of Jones (1925), the chronostratigraphical 'Upper Llandovery' was adopted and the term 'Tarannon', in both its litho- and chronostratigraphical senses, fell into disuse. Modern studies, in showing that different 'pale shale' successions formed under contrasting deep and shallow sedimentary regimes, underpin current formational nomenclatures. However, much was lost in this modernisation that the current study, by recognising a regional Trannon Group seeks to regain (Tarannon was the now disused anglicised version of the original Welsh name). Graptolite-yielding laminated hemipelagic mudstones, though thin and infrequent in Trannon Group successions, have enabled the recognition of many Telychian biozones (e.g. Loydell and Cave, 1996; Schofield *et al*, 2004). Use of the term 'Tarannon Shales Formation' for parts of the Welshpool Succession by Loydell and Cave (1993, 1996; also Cave, 2008) is both confusing and inappropriate. Despite the assertion of synonymy and seniority (see Cave and Hains, 2001), the Welshpool unit clearly differs both in terms of facies and stratigraphical context from Wood's (1906) Dolgau Mudstones (see Section 3).

Shallower water clastic blanket components of the Trannon Group that form the successions of the Marginal Belt and Midland Platform are assigned to separate sub-groups. The more distal mud-prone facies are included in a **Newbridge Subgroup** (new name). For the coarser and more proximal facies that accumulated across inner platformal settings, astride the sites of the Woolhope and Usk sub-basins and in the Malverns area, name **Yartleton Subgroup** adapts a long-standing May Hill Inlier term (Lawson, 1954). Widely, throughout this region, in common with parts of the North Wales Sub-basin, basal facies of the Trannon Group drape system succeed those assigned to the BIII Systems Tract without interruption.

**Text Box 8. Telychian Mass wasting:** Coincident with the tectonic accommodation of Telychian sandstone-lobe systems within the South Wales Sub-basin, and as a response to it, axial regions of the reactivated Derwen and Tywi anticlines and the western and southern margins of the North Powys Sub-platform evolved into sites of extensive intra-Telychian mass wasting. Earlier components of the CI System Tract were excluded and/or eroded and, in places, much of the preceding BIII and BII systems tract successions was also destroyed. Differentiation of the North and South Wales sub-basins clearly remained marked. The latter appears to have been encircled by this region of omission (Fig. 12), yet, as faunas confirm, its links to the open Iapetus Ocean was never completely severed. Intra-basinal high and foot-of-slope facies were a feature of the northern Tywi Anticline area. Mid Telychian (*turriculatus* Biozone) slope and foot-of-slope facies preserved in the anticline's flanking succession comprise material shed from the eroded region (Cwm Barn Formation). To the east, younger slumped and debritic strata (Henfryn Formation) drape the disconformity (Davies *et al*., 1997). Comparable deposits linked to the Derwen-Berwyn Axis may exist in poorly dated local successions in North Wales (see Part 3).

**Text Box 9. Late Telychian merging:** Overlying the mass wasting surfaces developed astride the Derwen and Berwyn regions, and the Tywi Anticline, are overstepping successions of *griestoniensis* Biozone and younger age (see Part 3). Compartmentalization by faulting had evidently declined as an active process during the late Telychian as sandstone lobe deposition ended. Late Telychian regional subsidence now oversaw the merging of the two sub-basins and the fusing of their resupplied slope aprons with shallower mud-prone blanket facies. This signalled the completion of the Trannon Group's evolution into a basin spanning mixed mudstone drape system. It was likely this same subsidence episode that aided accumulation of the Yartleton Subgroup and, with the expansion of shallower facies belts well beyond the Malvern Line, contributed to Telychian deposition achieving it greatest areal extent (Cherns *et al*., 2006).

In the South Wales Sub-basin, the requirement to exclude Telychian levels of the Caban-Ystrad Meurig Subgroup from the Trannon Group has been explained. The Nant Brianne, Devil's Bridge, Foel Fadian and Erwan Fach formations record the local invasion and blanketing of Trannon Group slope-apron facies by sandstone turbidites. These were supplied from opposing side of the South Wales Sub-basin during the early stages of Telychian re-configuration, some utilising conduits established during the preceding systems tract (see Part 3). However, accumulation of these sand-rich facies overlapped in time with the arrival and fault-controlled migration of the chemically and mineralogically distinctive southerly sourced, turbidite sandstone lobe system recognised as the **Central Wales Grits Group** (new name) (Ball *et al*., 1992; Morton *et al*., 1992). Though confined initially to the west of the South Wales Sub-basin during the *guerichi* and early *turriculatus* biozones (**Aberystwyth Grits Subgroup**), by mid *turriculatus* to *griestoniensis* biozone times this belt of southerly sourced facies, in the form of the **Cwmystwyth Grits Subgroup**, had expanded and migrated sufficiently to the east fully to replace the coeval easterly derived muddy slope apron system (Figs 14, 17). Combined with the impacts of associated mass-wasting, this saw the early development of the Trannon drape system within the southern basin brought to a temporary halt and its physical links to the Marginal Belt blanket system severed. Distal mudstone dominated parts of the Central Wales Grits Group are recognised as the **Gelli Shale Subgroup** (after Bassett, 1955).

In overview, the CI Systems Tract records a significant change in the tectonic setting of the LPWB as it responded to oblique plate collision further north. In western parts of the South

Wales Sub-basin, renewed rifting, largely a response to an evolving and migratory transtensional tectonic regime (see Woodcock and Strachan, 2012), saw many of its previously important fractures and structural lineaments reactivated during the early-mid Telychian. These acted to influence and accommodate the thick successions of sandy turbidites, sourced from Avalonian uplands, that feature in the South Wales Sub-basin, and to promote local mass-wasting (Fig. 13; Text Box 8). The Skomer Sub-basin experienced inversion. The role of eustasy in shaping platformal Telychian successions is debated (see Part 4). However, the diachronous onset of Trannon Group drape system facies appears to describe the eastwards migration throughout the LPWB and across Midland Platform of a subsidence front that was linked to regional collision-related tectonism without the need to invoke global forcing events (Fig. 13). Uplifted, erosion-prone blocks located within active fault belts were the only features to interrupt this front's progress. Rifting gave way to a late Telychian post-rift episode during which high rates of regional subsidence affected the entire basin and adjoining regions (Text Box 9). This period coincided with an interruption in the supply of sediment from uplifting intra-Avalonian source areas to the west and, the Yartleton Subgroup being an exception, saw largely mud-prone facies drape the whole region.

The dominance of oxic facies in the Trannon Group drape system is consistent with the changes in oceanic upwelling and organic productivity that accompanied the Telychian contraction of Iapetus; and associated red and purple marine mudstones (Plate 10), with sediment input from land areas experiencing strongly oxidising arid conditions (Hounslow *et al.*, 2021). Anoxic deposition was a subordinate feature of the systems tact and largely unrelated to contemporary eustasy (Davies *et al.*, 1997). Restricted conditions were established only periodically and most commonly across the rapidly subsiding floors of half graben that accommodated the sandstone lobe system facies of the Central Wales Grits Group.

At this point, the North Powys Sub-platform appears largely to have been extinguished as an influential palaeogeographical feature (see Appendix 4). However, whether the late Telychian subsidence regime that allowed the Trannon Group drape system to achieve basin-wide dominance also affected the basin's westernmost reaches is questionable. Strata younger that the *crispus* Biozone are absent from this region; and the local preservation of diagenetic white micas (Woodcock and Soper, 2006) offers compelling evidence that, despite the presence of an Acadian cleavage, the Telychian rocks of this region avoided deep burial prior to the Ludfordian onset of Caledonian molasse deposition. Partial inversion of this sector of the basin, including the North Pembrokeshire Sub-platform, the Harlech Horst and Llŷn Sub-platform, probably followed soon after the abandonment of the most westerly sandstone lobe systems in mid Telychian times. Thereafter, it likely existed as a region of reduced sedimentation and periodic emergence both during the later phases of Telychian tract expansion and throughout the Wenlock and early Ludlow (see below). The absence of CI Systems Tract deposits, and the major non-sequence that exists there between the local BIII and CII system tract successions, shows that the inversion of south Pembrokeshire Skomer Sub-basin persisted throughout much of the Telychian. The presence in upper levels of systems tracts's Haverfordwest succession of shelly faunas, reported by Cocks *et al*. (1992) to correlate with the *griestoniensis* and *crenulata* biozones, implies that this area escaped intra-Telychian denudation.

### *3.2* CII SYSTEMS TRACT (LATEST TELYCHIAN-EARLY LUDLOW)

Outcrops of CII Systems Tract strata in North Wales occupy a wide region east of the Conwy Valley Fault Belt and in the core of the Llangollen Syncline. The Wenlock succession of the Llanderfel Syncline links these northern occurrences to the extensive outcrops seen in eastern mid Wales, but where Ludlow rocks are restricted to eastern regions. Outcrops of the tract's Welsh Borderland succession with its prominent limestone divisions include those of the Wenlock and Ludlow type areas and seen in inliers seen further south. Throughout these occurrences, CII Systems Tract rocks typically, though not exclusively, overlie facies of the preceding systems tract (see below). Hillier *et al*. (2024) describe the overstep of the tract's Mynydd Epynt succession by late Ludlow marine and terrestrial facies, east of Carmarthen. More westerly occurrences are confined to south Pembrokeshire, where an uncomfortable succession of latest Telychian to early Ludlow strata crops out on the Marloes and Pembroke peninsulas.

The significant facies and faunal changes that overtook the LPWB and its adjacent platform in latest Telychian times, but that became fully apparent during the ensuing Wenlock, established a series of depositional systems that persisted locally into the Ludfordian. In regions of transition, the lateral contacts between deeper and shallower facies are highly gradational, but unlike earlier mixed drape systems, the differences between deeper and shallower water systems are sufficient to allow their inclusion in a set of separate overarching groups. In contrast with preceding Telychian facies, the CII Systems Tract testifies to the more regular and obvious influence of global events. However, tectonism remained significant as a factor that influenced the location of facies boundaries and sedimentary thicknesses and preservation. The outbuilding of anoxic slope apron systems across the sites of both former sub-basins was interrupted by a resumption in supply of collision generated sediment. Fluvial systems active to the south-west of the basin were the source for a series of progradational, in part deltaic, shallow marine successions. These accumulated alongside the calcareous blanket system that includes the well know limestone units of the platformal Welsh Borderland. See Figures 9, 10 and 14.

*Base* – In Wales as elsewhere, boundary successions between rocks of Llandovery and Wenlock age everywhere record the impacts of the global environmental, faunal, chemical and sea level changes that are identified collectively as the Ireviken Event (e.g. Jeppsson, 1997; Munnecke *et al*., 2003; Cramer and Saltzman, 2007; Calner, 2008; Hartke *et al*., 2021). This period of environmental flux had its origins in the latest Telychian, but it was during the ensuing *centrifugus* and *murchisoni* graptolite biozones that its maximum impacts were felt. In Wales, this acme interval marked the point at which the facies and systems emblematic of the CII Systems Tract were fully in place. At the time of writing, the definition of the Wenlock Series base, together with the suitability of the current GSSP, remain under review (see Melchin *et al*., 2020). The bases of the *centrifugus* and *murchisoni* graptolite biozones and last appearance *Pterospathodus amorphognathoides amorphognathoides* Biozone conodonts are candidates for selection as the key criterion.

Critically, throughout the LPWB and across the adjoining platform, facies and faunas in rocks of latest Telychian age reveal a transition between the CI and CII systems tracts. In deeper slope apron and outer Marginal Belt settings, units of graptolite-bearing anoxic mudstone appear interbedded with borrow-mottled strata typical of the underlying Trannon Group drape system. Platformal successions witness passages between purple and grey mudstones and upwards increases in carbonate content. The onset of this transitional phase of deposition occurred during the *lapworthi* graptolite Biozone (e.g. Loydell and Cave, 1996; Davies *et al*., 1997) and the lower part of the *Pterospathodus amorphognathoides amorphognathoides* conodont Biozone (e.g. Loydell, 2011). Though technically pre-Ireviken (e.g. Wang *et al*., 2024a), these transitional intervals reveal the impact of precursor chemical and faunal changes that were not unique to Wales (e.g. Melchin *et al*., 1998; Vandenbroucke *et al*., 2013).

Hence, it is contacts that mark the base and top of these transitional successions that emerge as candidate levels for the base of the CII Systems Tract and such strata have been widely mapped in both deep-water sub-basinal and distal Marginal Belt settings (Figs 17, 18). In the Marginal Belt successions of the Garth and Llandovery areas, they are recognised as a discrete Dolfawr Mudstone Formation (but see Part 3) that intervenes between the Trannon Group Cerig Formation and overlying, fully anoxic, Wenlock facies (Builth Mudstones Formation) (Davies *et al*., 1997). Comparable strata that crop out to the west of Welshpool were designated the Banwy Member by Loydell and Cave (1996; also Cave, 2008). The distinctive, locally shelly Butterley Mudstone Member occupies an equivalent level in the Long Mountain succession (e.g. Wang *et al*., 2024) but lacks graptolitic levels. It recalls the shoal-like 'Acidaspis Limestone' facies that cap the condensed Cerig Formation succession along the western flank of the Builth Inlier (Schofield *et al*., 2004). The opportunity to rationalise and/or rebrand these units is explored in Part 3.

In the oxic, shallow water, calcareous blanket successions of the Midland Platform, a facies gradation (the newly recognised Hughley Brook Member) spans the contact between the Purple Shales Formation and the Wenlock Buildwas Formation (e.g. Loydell, 2011; see Part 3). And, in the south-easterly Silurian inliers, a thin transitional succession is present beneath the Woolhope Limestone Formation (Ray *et al*., 2021). Transitional deep-water facies in the North Wales Sub-basin were recognised as 'passage beds' by Wedd et al. (1927) and Warren *et al*.

(1984) (Fig. 20). Comparable strata further south are present in lower levels of the widely mapped Nant-ysgollon Mudstones Formation (e.g. Davies *et al*., 1997; Wilson et al., 2016), but modern maps fail to chart their upper boundary with fully anoxic facies. The decision here to include all these transitional units in the CII Systems Tract is supported by accounts that previously recognised them as basal facies of otherwise Wenlock successions (e.g. Wood, 1906; Jones, 1945; Bassett, 1955; Palmer, 1970; Loydell and Cave, 1993, 1996; Davies *et al*., 1997). It follows that it is the bases of these units that are used to define the base of the tract and the lower boundaries of several of its component groups. It is freely acknowledged that future workers may find compelling the option to adopt the younger levels associated with the *centrifugus* and *murchisoni* biozones as more obviously representative of a new systems tract. Such a choice would find favour in parts of North Wales where the 'passage beds' have been mapped as part of underlying divisions (e.g. Wedd *et al*., 1927; Warren *et al*., 1984). Surveying to establish an equivalent level in the widely mapped Nant-ysgollon Mudstones Formation would then be required.

In contrast, sites that had avoided sediment accumulation during the preceding tract, that had been either emergent or experiencing mass-wasting, were overcome by latest Telychian-early Wenlock base level changes (e.g. Ray *et al*., 2021). Here divisions of the CII System Tract rest unconformably on rocks locally as old as Neoproterozoic in age as seen beneath parts of the Dolyhir Limestone Formation in the Old Radnor Inlier (see Part 3). The onlapping relationship of the Tirabad Formation (including its Ammanford and Carmarthen sheet synonyms) reveal the eastern flank of the Carmarthen High as a region that only gradually succumbed to Wenlock sediment accumulation. Condensed basal successions associated with the Builth Inlier (Davies *et al*., 1997) and the Wenlock GSSP (Mullins and Aldridge, 2004) testify to structural influences. In North Wales also, there are areas, notably in the Conwy Valley and in the vicinity of the Derwen Anticline, where, in response to omission, canyon cutting or faulting, the basal passage levels are absent. Here, sand-prone early Wenlock facies (Penstrowed Grits and Denbigh Grits subgroups) are the oldest preserved representatives of the CII Systems Tract (see Fig. 9).

The unconformable base of the Coralliferous Formation marks the onset of CII Systems Tract deposition in the Skomer Sub-basin. The shelly and conodont faunas recovered from the lower part of the formation are widely taken to indicate a late Telychian age (e.g. Walmsley and Bassett, 1976; Cocks et al., 1992; Aldridge, 2000). In a recent study, Veevers *et al*. (2024) place the base of the Coralliferous Formation in the *crenulata* Biozone based partly on an alignment of flooding surfaces with the sea level curve of Loydell (1998). However, they offer no biostratigraphical evidence to contradict an alignment with the latest Telychian *lapworthi-insectus* biozonal interval (e.g. Rubel *et al*., 2007; Loydell *et al*., 2009; Mannik *et al*., 2014), which allows the formation's transgressive base to be linked to the pre-Ireviken changes seen further north and east.

*Nomenclature & evolution* - The changes at the base of the CII Systems Tract ushered in a new assemblage of sedimentary systems and facies that went on to provide the building blocks for Wenlock to mid-Ludlow successions throughout the LPWB. Ongoing collision-related tectonics combined with global forcing to terminate the Trannon Group drape system and allow, in its place, strongly contrasting deep and shallow water systems to develop in different parts of the basin. Separately sourced deeper water slope apron systems of near identical aspect were established in both North and South Wales (see Part 3). The earlier demise of much of the North Powys Sub-platform allowed these separate systems to merge, likely in the vicinity of the Llangollen Syncline (see below), and justifying their inclusion in an all-embracing **Llangollen Group** (new name).

Across the Marginal Belt and Midland Platform, the pre-Ludfordian equivalents of the Llangollen Group, including the classic limestone-bearing successions of the Wenlock Edge and Ludlow areas, comprise the calcareous blanket systems of the **Welsh Borderland Group** (new name). Adoption of this term for parts of the Rumney Inlier succession renders the earlier term Cardiff Group redundant. In latest Telychian to Wenlock times, the most distal facies of this group extended as far west as the Tywi Lineament and, in the Welshpool region, to the west of the Severn Valley Fault Belt. Ludlow deepening resulted in an eastwards withdrawal to the Church Stretton Fault Zone. Formations principally associated with the Marginal Belt that describe the advance of shallower water, clastic delta and ramp systems from the south-west are here included a the newly recognised **Epynt Group**. A succession of latest Telychian to Wenlock shallow marine and intertidal facies testifies to the reactivation of the Skomer Sub-basin. suggest a supply link to the South Wales Sub-basin and hence to the Epynt Group succession, but structural isolation allied to palinspastic uncertainty (e.g. Dimberline *et al.*, 1990) favour the use of separate terminology. For these rocks, the Hillier and Morrisey's (2010) term **Marloes Group** is retained.

For these shallower water CII Systems Tract successions, existing formational nomenclature identifies the facies components of at least two shoaling-upwards events - one spanning the Wenlock, one of Gorstian age. Evidence for a third, early Ludfordian shoaling episode, is evident in the Ludfordian CII Systems Tract succession preserved in Clun Forest Sub-basin (see below). During these shoaling episodes clastic sediment supply remained predominantly from southerly quadrants. Hemipelagic and slump-prone mudstones of Wenlock to early Ludlow age (Builth Mudstones Formation) record accumulation in a distal ramp-upper slope Marginal Belt setting that had affinities to both deep and shallower water regions. Nevertheless, the gross distribution of these rocks and of the preceding Dolfawr Mudstones Formation (see Fig. 21) favours exclusion from both the Epynt and Llangollen groups, and inclusion in the Welsh Borderland Group (see Part 3). Gorstian red bed facies seen in south-west Wales that are predominantly, but not exclusively supplied from local sources (e.g. Trichrug, Red Cliff, Albion

Sands formations) are traditionally included in the ORS (Barclay *et al*., 2015) (Fig. 14). Their dating as Gorstian follows a reassessment of spore assemblages (Hillier et al., 2019).

The sedimentary changes associated with the base of the CII Systems Tract signalled a departure from the oxic regime that had influenced deposition during much of Telychian. A link to the environmental changes that preceded and accompanied the Ireviken Event appears clear. Discussion of the origin of this event is beyond the scope of this study. Munnecke *et al*. (2003), Vandenbroeke *et al*. (2015), Trotter *et al*. (2016), Hartke *et al*. (2021), Stolfus *et al*. (2023) and Wang *et al*. (2024b) offer in some cases contradictory insight into the complex linkages between the faunal, physical and chemical changes associated with the event. In Wales, as elsewhere (e.g. Cramer and Saltzman, 2007), these changes were accompanied by a rise in marine base level and the inundation of previously emergent settings. This appears not to have been a global event. Other datasets identify the *lapworthi* Biozone as time of lowered sea levels and climate warming, and associate the lower Wenlock with a period of global cooling. There is consensus that the Ireviken Event coincided with an increase in organic productivity and the widespread imposition in deeper settings of anoxic and reducing bottom water conditions.

The collision between Avalonia-Baltica and Laurentia concluded during the Wenlock. A marine setting remained in place, temporarily, along the British sector of the suture zone, but before then the LPWB's link to the open ocean was primarily to the south, via the submerged sectors of the Midland Platform and Baltica. This was evidently sufficient to allow the basin and its surrounding area to respond to global processes and allow faunal restocking. In settings such as the LPWB, the outflow of warm surface waters from the adjacent platformal seas (Scotese, 2014) likely also played an important role in maintaining deep-water anoxia at times of when shallower regions were experiencing significant environmental flux including periods, as in the Sheinwoodian, of suspected glaciation. In Wales, anoxic conditions were maintained, with only minor interruption, throughout both sub-basins and outer parts of the Marginal Belt until well into the Ludlow. During mid-Gorstian times, they had spread onto outer parts of the Midland Platform (Goggin Road Formation). The mid-Homerian witnessed the significant exception.

The Wenlock and Ludlow progradations confirm that subsequent global events, linked specifically the Mulde and Linde events, also played a part in shaping CII Systems Tract successions. The Homerian (late Wenlock) base level changes recorded in the Welsh Borderland by the Much Wenlock Limestone Formation warrants additional comment. The detailed work of Ray and his collaborators (see Ray *et al*., 2019 and references therein) informs such discussion. Successions in Wales show that the late Wenlock regression achieved its maximum impacts during the mid-Homerian *nassa* to lower *ludensis* (*praedeubeli-deubeili*) biozones. The oxygenated bottom waters introduced at this time allowed bioturbating and shelly benthos briefly to colonise the deeper settings associated with the Llangollen Group in both sub-basins. Correlative mid-Homerian shoal facies are also recognisable in the successions of both the Welsh Borderland and Epynt groups. The synchronous appearance of oxic facies linked to this shoaling episode resembles the pattern seen in the mudstone drape systems of the BI and CI systems tracts (see above). In contrast, strata of late Homerian age (upper *ludensis* Biozone) in Wales speak to a period of rising marine base levels and this gave Cave and Hains (2001, p. 89) cause to question regional correlations. However, modern isotopic and graptolitic studies that reveal the relationship to the Mulde isotopic excursion endorse accepted correlations (Fry *et al*., 2017) (see Part 3).

Coarse clastic deep-water subsystems present within the Llangollen Group show that tectonism linked to ongoing plate convergence also remained influential even after the abolition of the Iapetus Ocean (Figs 3, 4). It was via routes that traversed the westerly region of inversion established during the Telychian that separate sand-prone Wenlock subsystems received sediment. Intra-basinal faulting also resumed its role as a confining influence (e.g. Warren *et al*., 1984; Dimberline and Woodcock, 1987; Davies *et al*., 1997). A new, early to mid-Wenlock, southerly supplied, sandstone lobe subsystem (**Penstrowed Grits Subgroup)** advanced into the South Wales Sub-basin, its eastern extent determined locally by the Garth Fault (Fig. 17). In failing to include detritus of obvious Laurentian affinity (e.g. Morton *et al*., 1992), it seems that collision-generated Avalonian uplands continued in their role as a source of far-travelled detritus. The putative delta that supplied this Sheinwoodian sand was an earlier feature than that revealed by outcropping Epynt Group successions (see Part 3) and must have been positioned in the region of eroded stratigraphy well to the north (Fig. 14). At its northernmost limits, the Penstrowed Grits turbidite subsystem traversed a belt of renewed mass-wasting associated with the Derwen Anticline before it spilled into the Llangollen Syncline region of the North Wales Sub-basin (Fig. 14). The **Denbigh Grits** and **Elwy subgroups** comprise unrelated and more localised sandy deep-water accumulations in the North Wales Sub-basin and offer evidence that coarse sediment sourced from the west continued to be generated well into the Ludlow.

By the mid to late Wenlock, the area of upwarp in west Wales had likely expanded fuelling speculation that by the early Ludlow it was the Central Wales Lineament that served to limit the westerly extent of deeper conditions. Uplift in the west of the LPWB was complimented by the subsidence in the east that resulted in the abolition of barriers between the North and South Wales sub-basins and culminated in the development of the Clun Forest Sub-basin. In the Knighton, Mongomery and Welshpool regions, the distribution of the hybrid and multi-sourced shelly siltstone event beds of the **Bailey Hill Formation** (see Tyler and Woodcock, 1987), together with enveloping Epynt Group facies, chart the largely Gorstian evolution of this depocentre (see Part 3). The formation warrants designation as a discrete mixed subsystem and has in the past been viewed as the most easterly of the post-Aeronian ‘grit’ systems that feature in the South Wales Sub-basin succession (e.g. Cummins, 1969). However, its shell and silt-rich event beds are very different in aspect and its complex pattern of palaeocurrents implies input from multiple sources. Though some parts of the division clearly had physical and genetic links to the south-westerly sourced deltaic facies of the Epynt Group (see Part 3) (e.g. Tyler and Woodcock., 1987), other parts of the formation appear transitional with calcareous facies of the Welsh Borderland Group that lay to the east and turbiditic Llangollen Group rocks located further west (e.g. Cave and Hains, 2001). Pending future work which may allow these separate components to be differentiated, the mixed Bailey Hill Subsystem has arbitrarily been included in the Epynt Group. The Clun Forest Sub-basin's margins were sites mass-wasting and extensive slumping.

Much of the CII Systems Tract succession in the South Wales Sub-basin testifies to the supply of sediment from the cryptic landmass labelled Pretannia, and the successions of the Marloes and Rhymney areas provide evidence of accumulation in the vicinity its northern shoreline (Cherns *et al*., 2006) (Fig. 14). But, as collision-related events unfolded, the pattern of sediment supply changed. The presence of mica reported to be of Caledonian affinity in late Gorstian red beds in south Pembrokeshire (Red Cliff Formation) offers the first evidence of sediment transfer across the collision zone (Sherlock *et al*., 2002; Hillier and Williams, 2004). Hillier *et al*. (2019 and 2024) contend that, by the close of the Gorstian, much of the western sector of the LPWB had evolved into an extensive piedmont plain eroded by rivers emerging from the uplifted Caledonian Orogen to the north. However, the transition into the CIII Systems Tract was not straightforward. The Clun Forest Sub-basin succession includes facies of Ludfordian age that are contiguous with their Gorstian counterparts and that require inclusion in the CII Systems Tract's Epynt Group (Figs 9, 10 and 21) (see Text Box 16). At the time these rocks were accumulating, facies of the successor systems tract were already advancing into Wales from separate northerly sectors. The palaeocurrent data are complex (e.g. Cave and Hains, 2021), but for a period that spanned the Leinwardinian there existed a remnant sub-basin that continued to be supplied from the southerly source region and where CII Systems Tract deposition persisted for the longest (Fig. 22).

### 3.3 CIII SYSTEMS TRACT (LATE LUDLOW-(?)EARLY PRIDOLI)

The Dinas Brân Formation's outcrop (Plate 11) near Llangollen is arguably the system tract's sole representative in North Wales. In eastern mid-Wales, tract successions crop out on Long Mountain, in the Clun Forest and Knighton areas and on Mynydd Epynt - all former Marginal Belt settings. The Mynydd Epynt crop links with the belt of fractured outcrops associated with the course of the Church Stretton Fault Belt, west of Hay-on-Wye. It also extends south-westwards into the Llandeilo area, terminating near Golden Grove (Hillier et al. 2024). Welsh Borderland outcrops include those in the Ludlow area and provided by Silurian inliers further south, including those at Usk and Rumney.

CIII Systems Tract successions everywhere succeed those of the CII Systems Tract. They encompass the culmination of the change in sediment provenance first witnesses during the

Gorstian and of the tectonic reconfiguration that signalled the demise of the LPWB. Changes in marine base levels also played their part in the shaping CIII Systems Tract. There is a sequence stratigraphical case to view the CIII Systems Tract not as part of the LPWB fill, but as an early component of the successor Anglo-Welsh Basin. However, the significant temporal overlap of the CII and CIII systems, seen most notably within the Clun Forest Sub-basin, mitigates against such a radical departure from standard practice. Figures 9, 10, 21 and 22.

*Base* – Facies changes and contacts seen the deeper water CII Systems Tract succession of the Clun Forest Sub-basin (see above) testify to the late *incipiens* Biozone onset of a deepening episode. However, in shallower water successions, it was the Leintwardinian impacts of this event that define the base of the CIII Systems Tract (see Hillier *et al*., 2024). Aside from near Llangollen and the Golden Grove area of east Carmarthenshire, the local base of the Cae'r mynach Formation marks this contact. Across a wide swath of the Midland Platform, transgressive Leintwardinian facies succeed features that testify to omission and erosion including hardgrounds and local karstic pitting, and the formation's lowest levels commonly include beds of limestone conglomerate (e.g. Cherns, 1980) (see Part 3). There also sites, as for example at the Ludfordian Stratotype (Cherns, 1988), in the Malverns (Phipps and Reeve, 1967) and at Rumney (Waters and Lawrence, 1987), where Welsh Borderland Group facies continued to accumulate well after the first appearance of *leintwardinensis* Biozone graptolites. In these places, the base of the CIII Systems Tract succession is gradational. The pattern of overstep seen at the systems tract base in south-west Wales is described by Hillier *et al*., (2024). In the Sawdde Gorge area, siliciclastic conglomerates of the Cae'r mynach Formation (Cribyn Du Member) rest on Gorstian red beds of the Trichrug Formation. Further west, near Golden Grove, it is micaceous sandstones of the Tilestones Formation that occupy the basal position (Fig. 21).

Across the site of the Clun Forest Sub-basin, in marked contrast to the successions of the Welsh Borderland and east Carmarthenshire, the base of the Cae'r mynach Formation is highly diachronous. In places, the replacement of CII Systems Tract facies by their successors was delayed until the early Whitcliffian (Fig. 21). The age and relationships of the Llangollen region's Dinas Brân Formation are discussed in Part 3.

*Nomenclature & evolution* – CIII Systems Tract deposits were excluded from the westerly region of piedmont development and ORS deposition established during the Gorstian (see above). Preserved Ludfordian and early Pridoli facies show that marine conditions were confined principally to a contracting region of the Marginal Belt and Midland Platform. The diachronous assemblage of northerly sourced deltaic, pro-delta and off-shore blanket facies, here identified as the **Mortimer Group** (new name), comprise the youngest of the prograde systems that feature in the upper Hafren Supergroup. Adoption of this term and its definitions render obsolete the term Cardiff Group used by Waters and Lawrence (1987) for the Ludlow succession of the Rumney Inlier. As sediment supply from the south declined and the Church Stretton Fault Zone ceased as a significant divide, CIII Systems Tract deposition attained its greatest extent within a setting that Hillier *et al*. (2024) label the Cae'r mynach Seaway. The impacts of intra-platformal tectonism are reflected in the condensed Mortimer Group successions associated with the Gorsley and Golden Grove axes (Fig. 21). The relationship between Mortimer Group rocks and coeval CII System Tract facies of the Clun Forest Sub-basin are addressed in Part 3.

Following on from the recommendations of Barclay *et al*. (2015), sand-prone deltaic units (Tilestones Formation, Downton Castle Sandstones Formation), hitherto viewed as basal units of the Old Red Sandstone and of the former Downtonian Series (e.g. Allen, 1974; Bassett *et al*., 1982; Siveter *et al*., 1989), are here recognised as forming a contiguous part of the regional marine Silurian succession, and no longer to be exclusively Pridoli in age (see Part 3). As divisions of the Mortimer Group, these units include the youngest components of the Welsh Basin-Midland Platform Marine Mega-system. The seeding of Leintwardinian deltaic facies on the Golden Grove Axis, and the role of the associated Carmarthen High in generating the unconformity seen beneath coeval ORS rocks in west Wales, are assessed by Hillier *et al*. (2024). The latter authors question the lithostratigraphical affinities of the former Rushall and Clifford's Mesne 'beds' recognised in the Woolhope and May Hill areas, and of the 'Speckled Grit' of the Usk Inlier (see Fig. 21).

The Ludlow to Early Devonian spread and accommodation of ORS Caledonian molasse signalled the final demise of the LPWB in its original form. Preserved ORS successions lie predominantly to the south and east of the former basin, but illite crystallinity studies imply that, prior to the cleavage-forming Acadian deformation, the Lower Palaeozoic mudrocks of south-west, mid and North Wales were also once buried beneath a significant thickness of Lower ORS (Woodcock and Soper, 2006). This is consistent with models that link the accumulation of the this once more extensive cover of Caledonian molasse to the evolution of a rapidly subsiding, southwards expanding foreland basin. At its acme, this occupied much of the site of the former LPWB and the adjacent platform (e.g. King, 1994). On-going strike-slip displacements along the former Iapetus suture zone and the growing influence of early Variscan tectonics likely also played their part in creating 'pull apart' space to accommodate terrestrial red bed accumulation (Woodcock and Strachan, 2012; Hillier *et al*., 2024). Thus, the Mortimer Group acts as the interface between the predominantly marine Hafren Supergroup and terrestrial facies of the succeeding Old Red Sandstone Supergroup, with affinities initially to the former, but then recording the growing influence of provenance and tectonic regimes that characterised the latter.

# Part 3 – Detailed lithostratigraphy

## 1 Introduction to Part 3

Parts 1 and 2 of this report outline the system and system tract approach used to develop a new lithostratigraphical scheme for post-Tremadoc Ordovician to (?)early-Pridoli Silurian succession of the Lower Palaeozoic Welsh Basin (LBWB) and the adjoining Midland Platform. Newly conceived systems tract and tract assemblages are defined, and the spectrum of depositional and volcanic systems recognised in the basin and across the platform are described (Tables 3 and 4). This provides the basis for a new supergroup, group and subgroup-scale lithostratigraphy for the strata here recognised as forming the Welsh Basin-Midland Platform Mega-system (Fig 8).

Part 3 of this report provides more detailed lithostratigraphical definitions for the new supergroups, groups and subgroups and, in listing their principal formation level components, offers further commentary on their events and processes that shaped them. These are dealt with in order of systems tracts – oldest to youngest.

### 1.1 PRESELI SUPERGROUP (NEW NAME)

The main areas of Preseli Supergroup outcrop, encompassing rocks of Arenig to Caradoc age, occur in South Wales, in south Ceredigion, north Pembrokeshire and Carmarthenshire, and in North Wales, on Llŷn and in Snowdonia, including Cadair Idris and the flanks of the Harlech Dome. They also core of the Berwyn Dome. Further outcrops occur as inliers associated with the Marginal Belt in mid-Wales and the Welsh Borderland (Fig. 1). Regional correlation of these disparate outcrops has previously been hampered partly by incomplete biostratigraphy, but also because similar lithologies have developed across different fault blocks with different sedimentary and structural histories (Beckly, 1987). The Preseli Supergroup equates with Tract Assemblage A and the recognition of two discrete system tracts provides the pathway for an improved lithostratigraphical synthesis of these strata.

The supergroup name is derived from the Preseli Hills in north Pembrokeshire, which forms part the of the extensive south-west Wales outcrop of these strata and includes its most complete succession (Fortey and Owens, 1987, 1990). The Preseli Supergroup is equivalent in terms of its boundaries to the former Ogwen Group of north-west Wales (Rushton and Howells, 1998). Track Assemblage A successions in this area are incomplete. The Ogwen Group was defined in regional terms and has been abandoned. The Preseli Group's areas of outcrop include many of the original type sections for the regional chronostratigraphical scheme that remains widely in use for Ordovician rocks of the UK (Table 1a) (Brenchley *et al*., 2006b).

### 1.2 HAFREN SUPERGROUP (NEW NAME)

The Hafren Supergroup, in addition to post-Caradoc Ordovician rocks, includes the entire marine succession of the Silurian's historical type area. It takes its name from the catchment of the Afon Hafren, the Welsh name for the River Severn, which encloses representative outcrops of its principal lithostratigraphical divisions. Following its earlier manifestation, the intra-basinal Derwen-Berwyn Axis remained periodically important in delineating two separate areas of deep-water deposition in North and South Wales (Figs 3, 13). Local successions within these sub-basinal regions locally exceed 4 km in thickness but nowhere is a complete Ashgill to late Ludlow basinal sequence preserved. Distal Marginal Belt facies locally approach 3.5 km in thickness, but thin eastwards towards and across the Midland Platform and southwards across the structurally positive regions of south-west Wales, above a basal unconformity. In these areas, the successions preserved in sub-basins, and in the sub crop, contrast with attenuated counterparts associated with structural and palaeotopographical highs. Contrasting deeper and shallower system components are reflected in the revised hierarchy of groups, subgroups and formations (Fig 7 to 9; appendices 2 and 3). The supergroup's outcrop includes many of the current type sections for the series and stages of the Silurian.

The Hafren Supergroup comprise two separate system tract assemblages (B and C) that record the pre-collision and collision and post-collision phases of the LPWB's evolution, respectively. The gradational nature of these assemblages mitigates against separate supergroup status and favours instead the informal use of the terms **lower Hafren Supergroup** and **upper Hafren Supergroup**.

# 2 Tract Assemblage A (Preseli Supergroup)

### 2.1 AI SYSTEMS TRACT (ARENIG-EARLY LLANVIRN)

#### 2.1.1 Foel Cwmcerwyn Group (new name)

The Foel Cwmcerwyn Group is a new term for the lowermost division of the Preseli Supergroup in south-west Wales. The term is derived from the highest promontory of the Preseli Mountains and seen as emblematic of a region that contains some of the most complete and extensively studied early Ordovician sequences in Wales (Beckly, 1987, 1988; Fortey and Owens, 1987, 1990; Traynor, 1988; Rushton, 2000). In this area, the lower part of the group comprises a diachronous succession of generally shallow water, deltaic, intertidal and shoreface sandstones represented by a range of formations including the basal **Ogof Hên Formation**. It is the Ramsey Island type section for this early Moridunian division that is adopted as a nominal type locality for the base of the Foel Cwmcerwyn Group and *de facto* the Preseli Supergroup.

Despite fault-influenced complexities, Fortey and Owens (1987) have shown that the Foel Cwmcerwyn Group succession is divisible into a series of formations and members with much lateral equivalence. The complex interdigitation of shallower with deeper water facies (see Brenchley *et al*., 2006b), including units that host distinctive cyclopygid trilobites, justifies their inclusion in a mixed depositional system. Moreover, many of the extant BGS maps of the Foel Cwmcerwyn Group outcrop pre-date and therefore fail to depict this detailed classification. Considerable surveying effort will be required to allow their adoption. The imprecision of earlier terms such as 'Brunnel Beds' and the 'Tetragraptus Shales' persuaded Burt *et al*. (2012) to erect the name Triffleton Group for these poorly surveyed early Arenig (Moridunian – early Whitlandian) successions. Pending remapping, it is advised that this name be retained, but downgraded to **Triffleton Subgroup**. Fortey and Owens (1987) were content to extend the Ramsey Island term Ogof Hên Formation into the Carmarthenshire type area of the Moridunian Stage and to imply a depositional link between the formation's type area and the developing Whitland-Llandeilo Sub-basin. They subdivide the easterly Ogof Hên Formation and succeeding **Carmarthen Formation** into a succession of unmapped members that chart differences in fauna, sand-mud ratios and sedimentary structures. In the former, they recognise the **Allt Cystanog** and **Bolahaul members** and in lower part of the latter, which includes facies of deeper and more distal aspect, the **Pibwr** and **Cwmffrwd members**. The black mudstones and olenid trilobite fauna of the Carmarthen Formation's capping **Cwm yr Abbey Member** testify to accumulation under anoxic bottom conditions in the east of the sub-basin (Fortey and Rushton, 1992). Whitlandian Triffleton Subgroup divisions, including the sand-prone **Blaen cediw** and, to the east, the more muddy **Afon Ffinnant formations**, record a deepening and deposition by mass-flow processes. Contrary to BGS (1992a), Fortey and Owens (1987) council against use of the term 'Ogof Hên Formation' for transgressive early Whitlandian sand-prone facies in the St. David's district. They recognise these strata, which include the 'Porth Gain Beds' and 'Brunel Beds' of previous authors, as the **Abercastle Formation**.

The erection of an **Eastern Cleddau Subgroup** (new name) enables the upper levels of the 'Tetragraptus Shales' depicted on some extant BGS maps to be included in a revised stratigraphy that reflects the late Whitlandian–early Llanvirn facies variations recognised by Fortey and Owens (1987) and mapped by BGS in the Preseli region (Burt *et al*., 2012). The subgroup's name is taken from the eponymous river that flows southwards across its principal area of outcrop. Burt *et al*. (2012) recognise the **Penmaen Dewi Shales Formation** as the principal division in the north of this area. South of the Bronnant Fault, a set of younger, laterally equivalent shallower water divisions succeed this mudstone unit and testify to the impacts of late Arenig regression. Variations in trilobite faunas, levels of burrowing and in sandstone and tuff content facilitate the recognition in adjacent fault blocks of the **Foel Tyrch** and **Ysgoborwen formations**.

The successions of the Whitland-Llandeilo Sub-basin differ from those to the north. They include the separate succession of early Eastern Cleddau Subgroup rocks developed in the Whitlandian Stage type area. Here, an upward transition from shallow to deeper facies is reflected in the subdivision of the local **Colomendy Formation** into the **Rhyd Henllan, Castell-draenog** and **Whitland Abbey members** (Fortey and Owens, 1987; Traynor, 1988). The extent to which these will prove viable as mappable entities remains to be tested. The fauna of the basal Rhyd Henllan Member suggest a correlation with parts of the former 'Brunel Beds' that Burt *et al*. (2012) assign to the Triffleton Subgroup. The Colomendy Formation and the succeeding coarser grained and turbiditic early Fennian facies of the **Cwmfelin Boeth Formation** undergo an as yet uncharted eastwards transition into a mud-prone succession to which some apply the term **Capel Dewi Shales Formation** (see Brenchley *et al*., 2006b). The deeper, Fennian mudstone facies that subsequently spread throughout the sub-basin, and that succeed the Penmaen Dewi Shales Formation in the area south of the Penfordd Fault, contain a distinctive assemblage of blind benthic and large eyed pelagic trilobites (see Text Box 2). Fortey and Owens (1987) recognise these rocks as the **Pontyfenni Formation**. The burrow-mottled and tuff-bearing mudstones of the succeeding **Llanfallteg Formation** show that the impacts of late Arenig shoaling extended into the early Llanvirn, although Hearing et al. (2016) insist that water depths remained significant. Synsedimentary sliding likely accounts for the absence of much of the Triffleton Subgroup succession on Ramsey Island, where the 'Road Uchaf Formation' of Kokelaar *et al*. (1985) is viewed a synonymous with Penmaen Dewi Shales Formation (BGS, 1992a).

Facies transitions in strata that succeed the Eastern Cleddau Subgroup, principally of Abereiddian age, are reflected in the southwards passage from the anoxic **Aber Mawr Formation** into the partly oxic **Abergwilli Formation**. The latter is now used as a modern term for the 'Bifidus Beds' (Schofield *et al*., 2009a) that some BGS sheets continue show (e.g. IGS, 1970, 1975). Locally, both the Aber Mawr Shales and Abergwilli formations extend upwards into the lower levels of the *murchisoni* Biozone. It is these younger levels of the Abergwilli Formation that pass eastwards into coarser facies of the Whitland-Llandeilo Sub-basin that are recognised as the **Ffairfach Grit Formation** (Fig. 16; Text Box 4). The latter records the erosion of a nearby, but now concealed volcanic edifice sited to the east. In contrast to the shallow water origin advocated by Williams *et al*. (1981), Schofield *et al*. (2009a) attribute deposition to mass flow processes in a deeper setting. Rapid accumulation on a westward spreading volcaniclastic fan delta may provide a compromise solution. The anomalously fossiliferous westernmost facies of the Ffairfach Grit Formation (see Strahan *et al*., 1907, p.22; Williams, 1953, p.184) warrant identification as a newly named **Carbery Mount Member** (but see Montgomery Group). Uplift to the south of the Roch-Egremount fracture system, and contiguous faults in the St. Clears region (Owens, 2000), accounts for the absence of much of the pre-Abereiddian Foel Cwmcerwyn Group succession in the Narberth and Haverfordwest areas. Here, astride the Haverfordwest

Tilt-block, the Abergwilli Formation serves as a more appropriate label for strata that Fortey *et al*. (2000) refer to the Aber Mawr Formation.

On Ramsey Island, the reported late Fennian age of an interval containing thick tuff horizons implies an equivalence to the Sealyham Volcanic Formation of the mainland succession (see below) and calls into question its inclusion by BGS (1992a) in the overlying Aber Mawr Formation succession. Mudstones with abundant debrite units characterise the succeeding **Porth Llauog Formation** (Kokelaar *et al*., 1985; Owens, 2000) and record the instability associated with this site of Llanvirn intrusion and eruption.

The output of contemporary volcanic centres plays its part in the local subdivision of the Foel Cwmcerwyn Group (see Burt *et al*., 2012). The **Roch Volcanic Formation** appears to record the products of Whitlandian eruptions during the later stages of Triffleton Subgroup deposition. The younger, late Fennian, **Sealyham Volcanic Formation** forms a local capping to the Eastern Cleddau Subgroup that intervenes between the Penmaen Dewi Shales and Aber Mawr formations and passes southwards into the Foel Tyrch Formation. North of the Bronnant Fault, the mid-Llanvirn Volcanic rocks that cap the group's North Pembrokeshire Sub-platform succession comprise the Fishguard Volcanic Group. Kokelaar *et al*. (1985) term the contemporary, volcanic units that rest unconformably on the early Abereiddian Ramsey Island succession, the **Carn Llundain Formation**.

A Llanvrin succession of interbedded sandstones and mudstones crops out in south Pembrokeshire, on the Marloes Peninsula and in the cores of the Freshwater West and Freshwater Easy anticlines. Extant BGS paper maps (IGS, 1978; BGS, 1983) recognise these as 'flags of Llandeilo age', or as 'Llandeilo Flags', whereas some digital maps label them Aber Mawr Shales Formation. Palinspastic uncertainties suggest that the inclusion of these south Pembrokeshire successions in LPWB scheme is questionable, as is the lithostratigraphical separation of Abereiddian levels from otherwise comparable Llandeilian strata (see below). Here, the term **Musselwick Bay Formation** erected by Bettley *et al*. (2001) for the Abereiddian parts of the Marloes succession is utilised pending further investigations.

### 2.1.2 Shelve Hill Group (new name)

The group takes its name from the eponymous prominence of the Shelve Inlier. It overlaps, but differs in stratigraphical range from the defunct Shelve Group of Whittard (1979). The base of the AI Systems Tract within the inlier is marked by the transgressive base of the early Arenig (Moridunian) **Stiperstones Quartzite Formation** and the type section for the latter is taken as the nominal type locality for the base of the new group. The alternation in the overlying mixed succession of more muddy and more sandy facies underpins its subdivision into the Arenig **Mytton Flags Formation** and Abereiddian **Hope Shale** and **Weston Flags formations** (Cave and Hains, 2001). The Hope Shale Formation hosts units that testify to the impacts of local Llanvirn vulcanism. Cave and Hains (2001) recognise a series of tuff and tuffaceous units intercalated with lower levels of the formation as the **Hyssington Volcanic Member**. The varied succession, approaching a kilometre in thickness, of younger, vent-proximal volcanic facies, enclosed within the upper parts of the Hope Shale Formation, identify the site of an important, if only briefly active eruptive site located within the northern part of the Shelve-Builth Sub-basin. This warrants upgrading from the member status assigned by Whittard (1979) and Cave and Hains (2001) and is here designated the **Stapeley Volcanic Formation**.

The Llanvirn succession of the Builth Inlier, believed to have accumulated in the southern reaches of the Builth-Shelve Sub-basin, is dominated by the lavas, tuffs and volcanoclastic sediments that comprise the Builth Volcanic Group. The sub-volcanic **Camnant Mudstones Formation** spans the *artus-murchisoni* biozonal boundary and, in addition to unnamed tuff levels, includes the **Bettws Tuff** and **Gelli Tuff members** (BGS, 2004; Schofield *et al*., 2004).

### 2.1.3 Cadair Idris Group (new name)

This group encompasses the Arenig to early Llanvirn mixed system of north-west Wales, including the Llŷn Peninsula, and takes its name from the eponymous peak to the south of Snowdonia (Figs 11 and 15). The differential preservation of Arenig strata and rapid lateral variations in facies illustrate well the tectonically active nature of the region and its compartmentalisation by active faults. Current practice sees the Arenig rocks that the crop out south Snowdonia, along the flanks of the Harlech Dome, in the Cadir Idris area, and including the historical type Arenig region, assigned to an all-embracing **Allt Lŵyd Formation**. It is the basal stratotype of the latter (Allen and Jackson, 1985, p. 34) that also defines the base of the Cadair Idris Group. Owens *et al*. (2000) recognise the Allt Lŵyd Formation as synonymous with Carnedd Iago Formation of the Arenig area (Zalasiewicz, 1984). Transgressive Moridunian sandbodies locally preserved at the base of the formation are recognised collectively as the **Garth Grit Member**. Sand-prone strata in northern Snowdonia are now also included in the Allt Lŵyd Formation. Despite the recommendations of Rushton and Howells (1998), there appears merit in formally labelling these Bangor district facies the **Graianog Sandstone Member** (Fig. 15) (but see below).

Traynor (1990), Pratt *et al*. (1995) and Howells and Smith (1997) describe the array of Allt Lŵyd Formation facies. Zalasiewicz (1984) erected a succession of members in the historical type Arenig area, which, in addition to the Garth Grit, included the **Llyfnant, Henllan Ash** and **Olchfa members**. These units may be more widely applicable in the successions that flank the Harlech Dome (e.g. Brenchley *et al*., 2006b). However, rapid lateral variations and evidence of internal overstep and non-sequence testify to the impacts of contemporary faulting during Allt Lŵyd Formation deposition and to levels of complexity which Figure 15 fails to capture. In contrast to the Arenig succession in western Llŷn (see below), Whitlandian facies are largely unproven and omission at this level may be widespread. Zalasiewicz (1984) established the presence of such a break in the Aran area, where the succeeding succession of Fennian conglomerates has been labelled the 'Aran Boulder Bed' (e.g. Ridgeway, 1975; Allen and Jackson, 1985). This rank is inappropriate for the many metres of fanglomerate that pass laterally into shallow marine volcaniclastic sandstones. However, in seeking to upgrade this division, the term **Aran Boulder Bed Member** introduced by Rushton and Howells (1998) appears incongruous. Future workers may wish to reconsider the rank and naming of the Allt Llŵyd Formation divisions. An upgrading of the basal Garth Grit and Graianog Sandstone members to formations for example would bring them in line with the rank given to equivalent transgressive Moridunian sandbodies in South Wales. This would address the likelihood that the Graianog Sandstone of the Bangor district formed in a setting that was isolated from coeval rocks that flank the Harlech Dome (see Text Box 3). Such revision would allow the recognition of an upgraded and inclusive Allt Llŵyd Subgroup. BGS (1997) reveal sites associated with the Mid-Ordovician Unconformity and later vulcanism that record the local excision Arenig stratigraphy (Fig. 15).

The complex Arenig succession seen in the west of the Llŷn Peninsula formed across a rifted topography developed adjacent to the Menai Strait Fault System (Gibbons and McCarroll, 1993; Young *et al*., 2002). Unnamed conglomerates and sandstones occur at the base of the mud-prone **Wig Bâch Formation**, which provides a record of continuous Arenig accumulation beginning in early Moridunian times. Confined to the Aberdaron area is a mudstone interval rich in phosphatic nodules recognised as the **Wig Member** and bioturbated sandstones of Fennian age labelled the **Trwyn Cam Member** (Gibbons and McCarroll, 1993). Upper parts of the formation in this area, represented by the resedimented facies of the **Porth Meudwy Formation**, testify to the presence of steep local gradients. The relationships of these Aberdaron area units to facies in nearby successions is unclear. However, the near complete Arenig successions of the Wig Bâch Formation contrast with attenuated accumulations of shallower water facies associated with adjacent upfaulted areas from which Moridunian and Whitlandian deposition was largely excluded. Outcropping to the west, between the Llyn Shear Zone and the Cefnamwlch-Rhiw Fault, is the Fennian **Bryncroes Formation**. A more easterly, but comparable Fennian succession is seen on the St. Tudwal's Peninsula. There, in place of the St. Tudwal's Sandstone of earlier accounts (e.g. Owens *et al*., 2000), Young *et al*. (2002) recognise the **St. Tudwal's Formation** and a succeeding, finer grained **Llanengan Formation**. Lithological variations in the former are described by its subdivision into the **Pared Mawr, Trwyn-yr-Wylfa, Penrhyn Du** and **Machroes members**. These units attest to deposition in a range of tidal to deeper, storm-influenced settings developed astride an active St. Tudwal's fault block. The passage between these western Llŷn Arenig successions and the easterly Allt Lŵyd Formation is not exposed.

In assessing the Arenig-Llanvirn succession in North Wales, Rushton and Howells (1998) recognised the unsatisfactory nature of the term Nant Ffrancon Subgroup for strata that span the hiatus interval adopted here as a systems tract divide. The need to define this or an equivalent diving line in the former subgroup's type succession has been alluded to (Text Box 3). Widely, however, it is possible to erect new names for the pre- and post-hiatus stratigraphy. Over a kilometre of extensively bioturbated, mud-prone, pre-hiatus rocks, here newly designated the **Criccieth Formation** (but see Text Box 3), accumulated within the Snowdon Trough (Fig. 12). Deposition began first in northern Snowdonia during the early Arenig (Fig. 15). The subsequent spread of such facies throughout Snowdonia and Llŷn, in place of the Allt Lŵyd and other Arenig formations, was in response to early Llanvirn (Abereiddian) deepening. In its type section, on the eastern flanks of Mynydd Ednyfed Fawr (BGS, 2015), the new formation conformably succeeds the Allt Lŵyd Formation. The base of the **Hen-dy-capel Ironstone Member** marks its base in the St. Tudwal's area and a basal ironstone is also present further west, where lower levels of the Criccieth Formation have passed into the silty **Trygarn Formation** (Young *et al*., 2002). The latter includes the **Mynydd Rhiw Tuff Member**. In the Rhiw Bach area of eastern Snowdonia, up-doming linked to magma intrusion prior to the areas eponymous vulcanism, may account for anomalous contacts between the local Criccieth Formation succession and the early Arenig Garth Grit Member. The Arenig to Caradoc mudstone succession of the Bangor to Caernarfon region is currently shown as undivided (see Text Box 3). The once commercially important **Llandegai Ironstone Member** warrants formal recognition, but controversy surrounds its age. Trythall *et al*. (1987; see also Trythall in Trythall and Young, 1993) recognise it as a late Llandeilian to early Caradoc shallow water deposit that may overlie a significant non-sequence. However, BGS and others lean towards an early Llanvirn age (e.g. Howells *et al*., 1985; Young, 1991; Rushton and Howells, 1998) that justifies its inclusion in an unmapped Criccieth Formation succession (see Text Box 3).

The thick succession of Abereiddian Cadair Idris Group facies present on the southern flanks of Cadair Idris are recognised as the **Cregennen Formation** (see below). Tuffs, debrites and resedimented conglomerates interbedded with graptolitic mudstones testify to accumulation in a down slope setting adjacent to sites of active vulcanism.

### 2.1.4 Volcanic groups associated with the AI Systems Tract

The volcanism that occurred at a number of sites during the evolution of the AI Systems Tract produced a range of high-level intrusive and extrusive units. Individual formation level units intercalated with the sedimentary successions have been listed above. Group level units testify to sites of large scale and prolonged vulcanism. Associated with the Foel Cwcerwyn Group in the west Pembrokeshire is the **Fishguard Volcanic Group** (Bevins and Roach, 1979; Lowman and Bloxam, 1981; Burt *et al*., 2012), which comprises the **Porth Maen Melyn**, **Strumble Head Volcanic** and **Goodwick Volcanic formations**. The isolated outcrop of the Fishguard Volcanic Group in Abereiddi area is recognised as a local **Llanrhian Volcanic Formation**. In the latter, Owens (2000) recognises a **Cyffredin Shale Member** with lower *murchisoni* Biozone graptolites as intervening between an underlying **Lower Rhyolitic Tuff** and overlying **Abereiddi Tuff members**. It may correlate with a mudstone unit in Fishguard harbour (Plate 6).

The **Builth Volcanic Group** identifies an important Llanvern eruptive site located within the Shelve-Builth Sub-basin (Schofield *et al*., 2004). It includes the **Llandrindod Tuff, Gilwern Volcanic, Carneddau Volcanic** and **Llanelwedd Volcanic formations**. The younger **Cwm-amliw Tuff Formation** is taken to mark the final phase of Llanvirn vulcanism at the Builth centre. Sections that show this tuff as younger than the Newmead Sandstone and imply that it belongs to the AII Systems Tract are in error. The presence in the sandstone of clasts derived from tuff (Schofield *et al*., 2004) shows the latter was available for erosion at the local onset of AII Systems Tract deposition (see below). This supports the inclusion of both the tuff and underlying, locally preserved unnamed mudstone unit in the Builth Volcanic Group. The relationship of the Cwm-amliw Tuff Formation to volcanic units seen further south, in Carmarthenshire and Pembrokeshire, has been a matter of past speculation, but recent revisions confirm it pre-dates both the Asaphus Ash and Coed Duon Volcanic formations of the Montgomery Group (see below; Owens, 2000).

The Cadair Idris Group encloses the **Lower Aran Volcanic Group** (adapted name; see below). The Robell Fracture Zone appears to have acted as the conduit for the magma intrusion that fuelled multiple eruptive centres, Kokelaar (1985) raising the possibility that this same crustal fracture belt had links to the Fishguard Volcanic Group caldera (see Part 2) (Fig 11). Rushton and Howells (1998) provide a detailed account of group's component formations and members. Volcanic formations inter-finger with the sedimentary succession of the Cadair Idris Group so that it is not always clear to which group the separate divisions belongs. Thus, the Aran Volcanic Group as presently defined (Allen and Jackson, 1985) includes the predominantly argillaceous Cregennen Formation (Pratt *et al*., 1995). Reassignment of these sedimentary strata to the Cadair Idris Group mixed system may resolve this problem. Though listed as divisions of the Cregennen Formation (BGS, 1995; Rushton and Howells, 1998), the case to exclude the Bryn Brith and Cefn Hir members from the Lower Aran Volcanic Group is less secure. Arguably, they are better included in an expanded Llyn y Gafr Volcanic Formation (see Fig. 15).

## 2.2 AII SYSTEMS TRACT (LATE LLANVIRN-CARDOC)

### 2.2.1 Hengae Group

The Hengae Group comprises a system of predominantly turbiditic and hemipelagic mudstones, but with units in which turbiditic sandstones and debrites are significant, that accumulated in parts of the LPWB during the late Llanvirn and Caradoc. These deeper water AII System Tract facies appear to record the earliest development of a series of separately sourced slope apron systems and associated coarse-grained subsystems. However, pragmatism requires the inclusion within the Hengae Group of both shallower water and slope and foot-of-slope facies locally present at, or near its base (see below). The name Hengae Group was originally proposed by Pugh (1923) for Caradoc strata of the Corris area that succeed tuffs and lavas that are now recognised as the uppermost division of the Aran Volcanic Group (Cox and Wells, 1921; Pratt *et al*., 1995; Rushton and Howells, 1998). However, Rushton and Howells (1998) argued that the Hengae Group could be extended downwards to include a sedimentary succession of *gracilis* to *foliaceus* Biozone age, the **Ty'r Gawen Mudstone Formation**, that succeeds the Mid-Ordovician hiatus and passes laterally into these volcanic strata. This recommendation is adopted here. In a significant change of usage, strata previously assigned to the Nod Glas Formation are recognised as a separate group (see below). Pratt *et al*. (1995) argue that down-slope mass flow processes were influential during the accumulation of Ty'r Gawen Mudstone Formation which includes unnamed tuffs, tuffaceous sandstone, slump disturbed units and an olistostrome. Its basal, pyritic and phosphate nodule-rich **Fron Newydd Member** contains an extensively worked, resedimented, oolitic ironstone.

The turbidites and disturbed beds of the succeeding, silt and mud-prone **Ceiswyn Formation** were sourced from the north and north-east, from the region of Eryri Group deposition (see below). Reworked Soudleyan shelly faunas are present as various intervals. Thick and abundant anoxic hemipelagites characterise the **Craig Hen-gae Member**. Pratt *et al*. (1995) and BGS (2012) considered this unit is synonymous with rocks encountered near Dinas Mawddwy that Pugh (1928, 1929) had labelled 'Upper Ceiswyn Beds'. However, the presence of a shelly fauna suggests the onset of a northward a transition into the Eryri Group facies of the Bala region and invites the introduction of the term **Bwlch Siglen Member** (Pugh, 1928). The significant dating issues that arise from the fauna recovered from these rocks and their implications for lateral correlation are discussed below (see Text Box 10).

On the opposing southern flank of the Fishguard-Robell Fracture Belt, the Hengae Group succession seen on the Cardigan Bay coast north of Fishguard rests unconformably on the Fishguard Volcanic Group. Here Caradoc slope and slope-apron systems are linked to the site of the former caldera. In the lower part of the **Penyraber Mudstone Formation**, ferruginous ooids and oncoids are present at the base of the sandy and conglomeratic **Castle Point Member** (Plate 6). A reworked shelly fauna, reported to include taxa seen in the Castell Limestone Formation (Drefach Subgroup) (Rushton, 2000), points to an early Caradoc age (see also Williams *et al*., 2003; Burt *et al*., 2012) (see below). Limestone rafts attributed to the same formation occur within the overlying melange-like **Saddle Point Member** (Burt *et al*., 2012) and illustrate the destructive reach of associated mass-wasting. Davies *et al*. (2003) compare the latter with the Rhyd Melange of Snowdonia. Graptolitic mudstone rafts show that instability in the Fishguard region, as in North Wales, also persisted into the *foliaceus* (formerly *multidens*) Biozone (Burt *et al*., 2012) and periodically interrupted accumulation of weakly oxic, Penyraber Mudstone Formation slope-apron facies. Deposition under anoxic bottom conditions during the *clingani* Biozone is recorded by the **Cwm-y-Eglwys Mudstone Formation** and the partly coeval **Dinas Island Formation**. The latter arguably represents the earliest example of confined sandstone-lobe deposition within the LPWB. The contrast between this sand-prone sub-system and the coeval Nod Glas Group of North Wales is marked (Text Box 10). Davies *et al*. (2003) recognise a series informal mudstone-rich packets within the Dinas Island Formation. The **Carreg Bica Mudstone Member** hosts the base of the *morrisi* Subzone, and the **Cwm Degwel Mudstone Member**, the base of the *linearis* Biozone. The abrupt boundary between these Hengae Group facies and the coeval strata seen to the south, here included in the Mongomery Group (Drefach Subgroup), records the impact of intra-Caradoc fault displacements along the northern edge of the North Pembrokeshire Sub-platform (but see Davies *et al*., 2003).

The late Llanvirn to Caradoc strata that crop out in the north and along the eastern flank of the Tywi Anticline are also assigned to the Hengae Group. The succession of the Llanwrtyd Inlier records deposition along the eastern margins of the evolving deep-water region and preserves an interface between Hengae and Montgomery group facies. These Tywi Anticline outcrops differ from their western counterparts in offering no evidence for the Mid-Ordovician break. Mid to late Caradoc pyritic mudstones with levels rich in turbidite sandstones and bentonites comprise the **St. Cynthlo's Church Formation** (Davies *et al*., 1997). The older, partly graptolitic **Llanwrtyd Volcanic Formation** testifies to deposition on the slopes of a volcanic centre that was active in the Llanwrtyd area during late Llanvirn to early Caradoc times (Schofield *et al*., 2004). Mass flow processes emplaced locally bioturbated tuffaceous sediments and oolitic ironstones. Primary erupted materials include the late Llanvirn **Kilsby Tuff**, the early Caradoc **Nant Cerdin Tuff members** and unnamed basalts. Foundering of this centre during the *foliaceus* Biozone, and associated instability along the eastern margin of the deep-water belt is recorded by the overlying interval of slumped St. Cynllo's Church Formation facies, mapped as the **Pistyllgwyn Member**. The succeeding black graptolitic mudstones and the Caradoc succession that crops out to the east of the Garth Fault in the Llanwrtyd area are here reassigned to the Montgomery Group (see below).

### 2.2.2 Montgomery Group (new name)

The Montgomery Group is a new term for the late Llanvirn-Caradoc diverse array of clastic blanket system facies that characterise the AII Systems Tract successions of the North Pembrokeshire Sub-platform, the southern part of the North Powys Sub-platform, the Marginal Belt and the Shropshire sub-basins. It includes the successions of the Whitland-Llandeilo Sub-basin and that crop out in Shelve and Builth Ordovician inliers and in the vicinity of Llanwrtyd Wells. The group takes its name from the former Welsh county in which many of the studied sections have been described. Above its diachronous base (see Part 2), the Montgomery Group comprises a spectrum of sandstones, siltstones and mudstones, with subordinate volcanic rocks and limestone. In contrast to its deeper water counterparts, Montgomery Group sedimentary facies yield a diverse mix of trilobites, brachiopods and graptolites. Many of the group's outcrops are geographically isolated from those of the coeval deeper water Hengae Group system. In North Pembrokeshire, the Aber Richard Fault acts as an abrupt dividing line, but the Llanwrtyd Inlier succession appears to preserve transitional relationships (see above). A lateral passage into facies of the Eryri Group likely exists within southern Berwyn Dome succession, but major faults again offer a pragmatic dividing line (see below).

The Mongomery Group of the Shelve Inlier can be viewed as its type succession, where its base is taken at the base of the late Abereiddian, dark and graptolitic **Bretton Shale Formation**. The **Meadowtown** and **Rorrington Shale formations**, of late Llanvirn and early Caradoc age, are succeeded by the Costonian **Spy Wood Sandstone**, the Harnagian **Aldress Shale** and the Soudleyan **Hagley Shale** and **Whittery Shale formations**. Together these units chart the halting progress of the late Llanvirn-Caradoc transgression across the Shelve region (Cave and Hains, 2001). Strata younger than the Soudleyan are absent from the Shelve succession.

Montgomery Group deposition in its type area was initially confined to the region of the Shelve-Builth Sub-basin, but the Costonian saw it extend east of the Church Stretton Fault Zone. There, the AII Systems Tract successions preserved in the half-graben sub-basins of the Caradoc area have been reviewed by Bowder-Hicks *et al*. (2002). Upper shoreface sandstones and conglomerates of the **Hoar Edge Grits Formation**, a correlative of the Shelve area Spy Wood Sandstone Formation, rest unconformably on Cambrian and Neoproterozoic rocks and record the upper *gracilis* Biozone onset of sedimentation. The younger (Harnagian-Soudleyan) **Harnage Shales** and **Chatwall formations** encompass a complex array of facies deposited during the subsequent deepening. Locally, at the base of the former, the **Hope Bowdler Pebble Bed** records the inundation of remnant topography. Earlier studies recognised the potential for further subdivision of the Harnage Shales. Bowder-Hicks *et al*. (2002) labels facies of more proximal aspect the **Smeathen Wood** and **Glenburrell members**. The Chatwall Formation similarly includes the **Chatwall Flags** and **Chatwall Sandstone members**. Together the succeeding, storm-generated and limestone-bearing facies of the **Cheney Longville** and **Acton Scott formations** span much of the Woolstonian to Onnian and correlate wholly, or in part with the Nod Glas Group (see below). At its base, the **Alternata Limestone Member** comprises a condensed unit of sandy, coquinoid deposits with phosphate nodules and phosphatised fossils that transgresses a local omission surface (Hurst, 1979; Bassett *et al*., 1992). Significant facies differences between the Caradoc area sub-basins are recorded within the Cheney Longville Formation by the distribution of the **Glynboro** and **Crosspipes members**, and in the overlying Acton Scott Formation, of the **Ragton, Henley** and **Wistanstow members**. Preserved within the confines of the Ludlow Sub-basin, the **Onny Formation** records a subsequent episode of distal mud deposition (e.g. Brenchley and Newall, 1982). This the youngest part of the AII Systems Tract to escape the impacts of intra-Ashgillian erosion that account for the widespread absence of latest Caradoc rocks elsewhere in the region.

The west of the Shelve Inlier, the Montgomery Group succession of the Welshpool region has been assessed by Cave (2008). There, the base of the tract is not exposed. The ‘Black Grit’ present at the base of the Harnagian-Soudleyan **Stone House Shale Formation** has links to the more easterly, shallow water, Spy Wood Sandstone Formation (Cave and Hains, 2001), remaining parts recording the deposition of more distal, graptolite-preserving muds. The formation extends to the west of the Severn Valley Fault Belt where it forms part of a North Powys Sub-platform succession that includes the younger **Pwll-y-glo** and **Gaer Fawr formations**. These form part of a thickening upwards succession of storm-generated hummocky cross-stratified sandstones that records a late Soudleyan to Longvillian progradation speculated to be in eustatic origin (e.g. Young *et al*., 2005). Active faulting in the region is reflected in the distribution of the **Forden Mudstone Formation** and, in the more northerly Breidden Hills succession, of the volcanogenic conglomerates of the **Bulthy Formation** and the overlying bioturbated and storm influenced **Hill Farm Formation**. Cave (2008) implies that there may be scope to rationalise the Montgomery Group nomenclature of the Shelve and Welshpool regions. Mongomery and Eryri Group facies likely interdigitate in the southern Berwyn Dome region, however, the Tanat and Cynllaeth faults link to provide a convenient, if arbitrary boundary. The crop of the Allt-tair-ffynnon Formation shown on the provisional BGS map of this area (BGS, 2000a) is likely divisible into the units mapped in the Welshpool district (BGS, 2008a) and should be abandoned. Strata in this region currently assigned to the Pen-y-garnedd Limestone Formation form part of the Gaer Fawr Formation (Cave, 2008).

The unconformity at the base of the **Newmead Sandstone Formation** marks the Montgomery Group base in the southern part of the Builth Inlier. Further north, the coeval contact between the Cwm-amliw Tuff Formation and the late Abereiddian, trilobite-rich lower levels of the **Llanfawr Mudstones Formation** is seemingly conformable (see Part 2). It needs to be noted that the depiction of the latter formation on digital BGS maps for the northern part of the Builth Inlier is grossly incorrect.

Evidence of contemporaneous vulcanicity associated with the northern Marginal Belt regions of Mongomery Group deposition include both subaqueous and subaerial erupted material. The Velfreyan **Trelowgoed Volcanic Formation** caps the Montgomery Group succession of the Builth Inlier (Davies *et al*., 1997). Soudleyan (*foliaceus* Biozone) volcanic units recognised in predominantly mudstone successions include the vent-proximal **Middletown Quarry Member** seen in the Breidden Hills, at the top of the Stone House Shale Formation (Dixon, 1988, 1990; Cave, 2008). In the Shelve area, the **Hagley** and **Whittery Volcanic formations** (Cave and Hains, 2000) locally underlie their eponymous Soudleyan shale divisions.

The need to reject the stratigraphical nomenclature used by Williams (1953), Williams *et al*. (1981) and Schofield *et al*. (2009) for the Mongomery Group succession of the Whitland-Llandeilo Sub-basin, and to reinstate and rebrand the divisions of Strahan *et al*. (1907) as the **Llandeilo Flags Subgroup** is explained in Text Box 4 (see Fig. 16). Nevertheless, it remains clear from the work of these past authors that there is scope to recognise subordinate divisions. Ferretti and Bergstöm (2021) assess the conodont faunas recovered these rocks. In the east of the sub-basin, the succession that overlies the AII Systems Tract boundary includes much of what Strahan *et al*. (1907) referred to as the ‘Sandy Basement Beds’, but it is the presence of a widespread volcanogenic unit that offers the most practical means for subdivision. Based on Williams (1953), the name **Garn Formation** is proposed for the heterolithic fossiliferous succession that underlies this volcanic level. Schofield *et al*. (2009) felt unable to map the scheme proposed Willams (1953), but the lateral facies variations he described imply scope to erect local members. Assemblages of shelly benthos that show that the Garn Formation spans the Abereiddian-Llandeilian boundary also provide evidence of multiple shoaling upwards cycles (Owens, 2000) (Fig. 16). Limestone lenses yield conodonts of the *Pygodus serra* Biozone (Fig. 16). The overlying volcanogenic interval preserves the output of a small, briefly active Llandeilian eruptive centre. BGS (2008b) recognised tuffs and rhyolite lavas in the Coed Duon area as the **Coed Duon Volcanic Formation**. This term could usefully be extended to include the successions of tuffs and shell-bearing tuffaceous sediments seen further west, and to include, as a local capping, the **Rhyolitic Conglomerate Member** (based on Williams, 1953). Local unconformities present at the base and top of this volcanic succession testify to volcanic relief. Eruption at the Coed Duon site may have coincided with that of the basalt lavas proved in a borehole in the Llanwrtyd Inlier area (Fortey *et al*., 2000). Conodont-bearing limestones in the Rhyolitic Conglomerate Member yield assemblages of the *Pygodus anserinus* Biozone (Fig. 16).

For the post-volcanic portions of the Llandeilo Flags Subgroup, the term **Golden Grove Formation** is an adaptation of nomenclature proposed by Sutton *et al*. (2000). The divisions labelled ‘Lower’, ‘Middle’ and ‘Upper Llandeilo Flags’ by Williams (1953) were essentially biostratigraphical and Schofield *et al*. (2009a) questioned their traceability. The erection of the overarching subgroup (see above) renders these terms both confusing and redundant. Nevertheless, sandy facies locally present at the base of this succession, together with the lithological and faunal differences described by Williams (1953; see also Wilcox and Lockley, 1981, Owens, 2000), confirm potential for local subdivision. In the Llandeilo and Ffairfach areas, the Golden Grove Formation extends from the *Pygodus anserinus* conodont Biozone into the *Amorphognathus tvaerensis* Biozone. The biostratigraphically important trilobite *Lloydolithus lloydii* first appears several metres above its base (Fig. 16).

The Golden Grove Formation appears to expand westwards at the expense of the earlier sandy and tuffaceous levels seen at Ffairfach. At Golden Grove, the absence of *L. lloydii* from limestone-bearing strata that contain *Pygodus anserinus* Biozone conodonts (Rhodes, 1953; Ferretti and Bergstöm, 2021) shows that facies of the eponymous formation have likely replaced the Coed Duon Volcanic Formation (see Fig. 16). Strahan *et al*. (1907, p.24) believed that strata in the Ffairfach railway cutting assigned to the Garn Formation also disappeared to the south and west. In this context, the systems tract and group credentials of the Carbery Mount Member (see Foel Cwmcerwyn Group), which appears to share lithological and faunal features in common with the Garn Formation, warrants scrutiny. The presence, in the Golden Grove region, of a disconformity (e.g. Bergström *et al*., 1987), and of an overstep relationship comparable to that seen astride the Haverfordwest Tilt-block, needs to be considered (see Part 4). The transition between the Llandeilo Flags Subgroup and north-easterly Montgomery Group facies is unexposed, but graptolites of the Llandeilian *teretiusculus* and Caradoc *gracilis* biozones, and the ranges of key benthic taxa, enable accurate correlations (Fortey *et al*., 2000; Owens, 2000).

The southwards thickening succession of flaggy limestones seen in the Haverfordwest district, including in the Clarbeston area, was also labelled 'Llandeilo Flags' by Strahan *et al*. (1914), but has since been shown to be incomplete. Its accumulation above an asymmetrically subsiding Haverfordwest Tilt-block was delayed until the Caradoc and persisted for longer than in the Llandeilo region. It is identified as the **Narbeth Formation** (status downgraded). Lithological and faunal variations permit recognition of the **Gilfach, Bryn Glas, Bryn Sion** and capping **Bryn Banc Limestone members** (Fortey *et al*., 2000; Bettley *et al*., 2001). The lateral relationships between these rocks and those of the Llandeilo region are not exposed, but outcrops in the intervening St. Clears area support their inclusion in the Llandeilo Flags Subgroup, if not synonymy with Golden Grove Formation.

BGS maps also include the succession of intercalated sandstones and mudstones seen on the Marloes Peninsula in south Pembrokeshire that is acknowledged to span the Abereiddian-Llandeilian boundary (Bettley *et al*., 2001), in the 'Llandeilo Flags'. The nature of any link between these south Pembrokeshire units and those deposited in the Whitland-Llandeilo Sub-basin remains uncertain, but facies of this type were evidently blanketing wide areas during this time interval. Pending further study the term **Musselwick Flags Formation** (adapted from Bettley *et al*., 2001) is proposed as a south Pembrokeshire division of the Llandeilo Flags Subgroup.

The appearance and distribution of distal, black, graptolitic Montgomery Group mudstone facies recognised as the **Drefach Subgroup** (Wilby *et al.*, 2007, Burt *et al*., 2012) has been alluded to in Part 2. In north Pembrokeshire and parts of west Carmarthenshire, these rocks, together with trilobite-bearing limestone units, make up the entire Mongtomery Group succession. But it is only Caradoc parts of the subgroup that extend into the Llandeilo area and that are seen in the Llanwrtyd Inlier (see below). The subgroup's locally mapped divisions include Abereiddian facies rich in *D. murchisoni* labelled the **Felin-wen Formation** by Wilby *et al*. (2007). These comprise only the upper levels of the '*murchisoni* Beds' of Strahan *et al*. (1909). The graptolite taxon recognised by previous workers as *D. muchisoni* var. *geminus* has since been designated a separate species and assigned to the *artus* Biozone (see Williams, 1953). The strata that contain this form are now assigned to the either the Aber Mawr or Abergwilli formations of the AI Systems Tract (Schofield *et al*., 2009a). Younger, late Llanvirn to Caradoc units seen in the Haverfordwest and Carmarthen areas include the basal Llandeilian **Asaphus Ash**, the trilobite-bearing **Hendre Shales formations** and the younger **Mydrim Limestone Formation**. Yielding abundant graptolites of the *foliaceus* and *clingani* biozones, the **Mydrim Shales Formation** caps these Pembrokeshire and Carmarthenshire subgroup successions. The inclusion of Strahan *et al*.'s (1909) 'Lan Flags' in the upper part of a redefined Asaphus Ash Formation by Wilby *et al*. (2007) was evidently as a mapping convenience. The recognition that these Llandeilian rocks, as at Golden Grove (see above), likely pass into the sandy and tuffaceous levels of the Llandeilo Flags Subgroup, may warrant a reassessment of this decision (Owens, 2000). The new dating for the Ffairfach succession confirms that deposition of the 'Asaphus Ash' predated the eruption at Coed Duon and that neither relates to emplacement of the Abereiddian Cwm-amliw Tuff of the Builth Inlier succession. The succession seen in the Aberreiddi area differs from that further east. There, the late Llanvirn **Caerhys Shale** and the largely Caradoc, trilobite-rich **Castell Limestone formations** underlie strata labelled the Dicranograptus Shales (Plates 2 and 7). The case to include that latter, as elsewhere in south-west Wales, in an expanded Mydrim Shale Formation is compelling.

The Caradoc succession of the Llanwrtyd Inlier preserves relationships, not seen elsewhere, that testify to the basinward advance of distal Montgomery Group facies across earlier slope deposits. To the west of the Garth Fault, slumped strata of late Llanvirn to early Caradoc age are assigned to the St. Cynthlo's Church Formation (Hengae Group). Schofield *et al*. (2004; also BGS, 2005a) recognise overlying late Caradoc (*clingani* Biozone) graptolitic mudstones as the 'Sugar Loaf Member' of the St. Cynllo's Church Formation. These rocks display lithological features and relationships with BI Systems Tract facies that compare more closely with the Mydrim Shales Formation (Drefach Subgroup). It is as an extension of that division that they should be recognised, and the term Sugar Loaf Member abandoned. It follows that the local Caradoc succession that crops out east of the Garth Fault, currently labelled 'St. Cynthlo's Church Formation undivided' (BGS, 2005a), require similar rebranding.

### 2.2.3 Eryri Group (new name)

The mixed volcano-clastic system here recognised as the Eryri Group is used in place of earlier terminology for the succession of proximal to distal sediments that accumulated during the build-up and emergence of volcanic islands within the northern sector of the LPWB during the Caradoc (Fig. 15). The term comes from the Welsh name for Snowdonia, where its principal outcrops are located, but the group also comprises much of the Caradoc succession seen in Berwyn Dome. This new division has lateral contacts with both the Hengae and Montgomery groups and encloses several volcanic systems. Where its top has escaped the impacts of later erosion, it is everywhere overlain by the facies of the Nod Glas Group. The Eryri Group includes a range of shallow marine, intertidal, deltaic and fluvial deposits, mostly sandstones and siltstones with a large volcaniclastic component. Debritic facies testify to deposition on unstable volcanic and fault-generated slopes and graptolitic mud-prone turbiditic facies to accumulation in deeper regions away from active volcanic centres. In addition, individual tuffs that cannot be allocated to named volcanic systems are recognised as local marker horizons. The Eryri Group embraces the former Nantmor Group as used by Howells *et al*. (1987) for the succession of sedimentary rocks below the Snowdon Volcanic Group that are now included in the Cwm Eigiau Formation (see below). However, the name Nantmor Group was also applied to most of the sedimentary succession between the Snowdon Volcanic Group and the 'Mid-Ordovician Unconformity' (e.g. Howells *et al*., 1991) and to avoid confusion has been rejected.

The silty mudstone-dominated succession that succeeds the Mid-Ordovician Unconformity, in southern and western Snowdonia, and that were included by Rushton and Howells (1998) in the upper part of their Nant Ffrancon Subgroup, are here recognised as the newly named **Porthmadog Formation**. Sections near Penrhyndeudraeth described by Smith *et al*., (1995, fig. 3) serve as the type locality for the base of the new formation and nominally for the Eryri Group as a whole. For the interval of undisturbed strata that overlies the unconformity in this area the term **Penrhyndeudraeth Member** (new name) is proposed. However, it is the succeeding complex suite of disturbed deposits, including slumps, mélanges and breccias and that include clasts derived from the underlying stratigraphy as well as levels of re-deposited ferruginous ooids, phosphates and cherts that widely descends to occupy a basal position. The down slope movement and mixing of material generated by the collapse of steep local gradients is indicated and Smith (1988) suggests that interstratal slip also played a part in their emplacement. The **Rhyd Melange Member** is emblematic of these disturbed strata. Comparable facies present to the east of the Ffynnon Eida Fault, in addition to pods of the Garth Grit Member, appear to include huge rafts derived from the Rhiw Bach Volcanic Formation.

Fine-grained, silt-laminated turbidites and hemipelagites were important in building Porthmadog Formation successions in which fossil graptolites were only locally able to escape the destructive of effects slate-forming cleavage. It is these rocks that form much of the slate resource of the Blaenau Ffestiniog area. Slumping seen affecting upper levels of the Porthmadog Formation succession has been linked to seismicity and the onset of widespread mid-Caradoc vulcanism (Howells and Smith, 1997). Enclosed within the mud-prone succession are several ironstone units most of which have informal names (Trythall *et al*., 1987). They are typically assigned a shallow water origin, but they also include resedimented pods within the disturbed succession that overlies the Mid-Ordovician break (see Howells and Smith, 1997). The Porthmadog Formation also includes volcanic units that lie without the main Caradoc volcanic groups. These include the **Moelwyn Volcanic** and **Penamnen Tuff formations** of southern Snowdonia, the former divisible into **lower** and **upper members**; and the **Moelfre Tuff Member** of the Llandudno region.

Recognition of the Porthmadog Formation in northern Snowdonia and in the Bangor areas is problematical and linked to issues identifying the base of the AII Systems Tract in this region (see Part 2). Though recent studies fail to endorse the existence of such a division, H. Williams (1927), D. Williams (1930) and Shackleton (1959) provide evidence for its presence and, together with Campbell *et al*. (1988), offer plausible linework for its basal boundary (see Text Box 3). These accounts, if viewed as accurate, imply that significant thickness differences developed between northern and southern Snowdonia during the early Caradoc. The <100 m of principally early Caradoc strata present beneath the Braich Ty Du Volcanic Formation in Nant Ffrancon and Nant Peris areas, contrasts with the over 2 km of Velfreyan to early Soudleyan sediments present in the Porthmadog Formation's type area (Rushton and Howells, 1998). Though the northern region had occupied the axial part of the Snowdon Trough during the preceding systems tract (Text Box 3), this area was the first to succumb to volcanic up-doming and hosts the earliest outpourings from Llewlyn Volcanic Group centres. The emplacement of volcanic rocks was delayed further south where a subsidence-prone region of the Snowdon Trough remained active for longer.

The nomenclature used for complex association of younger volcanic and sedimentary facies that characterise the main Caradoc eruptive sites of north Wales has been assessed by Rushton and Howells (1998). An important, widely recognised proximal sedimentary unit is the late Soudleyan **Cwm Eigiau Formation** of Snowdonia (Fig. 15). Within the latter, local sandstone intervals are recognised as the **Prenteg Sandstone** and **Moel Hebog Sandstone members**. The divisions erected for the equivalent strata on the Corwen Sheet (BGS, 1993b), including the Carn y Parc and Eidda formations, were rejected by Rushton and Howells (1998), but there appears merit in retaining the **Blaen Eidda Member** as an additional sandstone unit. In western Snowdonia and parts of the Llŷn Peninsula, where earlier levels of the Eryri Group were either excluded or subsequently destroyed, it was sandy facies of the Cwm Eigiau Formation that were first preserved above the regional hiatus at the base of the AII systems tract (Young *et al.*, 2002; Rushton and Howells, 1998). Separately mapped in these areas, are the arenaceous and volcanoclastic **Dwyfach** and **Yoke House formations** that display complex lateral relationships with the Llanbedrog Volcanic Group. In the former, Young *et al*. (2002) recognise Longvillian calcareous mudstones as the **Plastirion Member** and a local sandstone as the **Bodwrog Member**, although neither of these divisions appear on the BGS Pwllheli Sheet.

Throughout its areas of outcrop, the boundaries between the predominantly sedimentary Eryri Group and coeval volcanic systems are both complex and gradational. Such concerns also come to the fore when seeking to identify its transitions into both the Hengae and Montgomery groups. Rushton and Howells (1998) included the early Soudleyan volcanic and volcaniclastic rocks of the Corwen and Bala regions in their definition of the Hengae Group. The reasons for this are not clear. Bassett *et al*. (1966), Lockley (1977) and BGS (1993b) describe a succession that is of coarser aspect, locally strongly bioturbated, that contains levels with prolific shelly faunas and provides evidence of periodic emergence. In testifying to shallow water deposition, these strata differ in all aspects from the turbiditic Ceiswyn Formation in which Rushton and Howells (1998) sought to place them. Their affinities to facies of the Eryri Group are clear. Coarser grade volcaniclastic sediments began to accumulate earlier in the Bala area than the adjacent parts of Snowdonia (Fig. 15); together with their associated tuffs, they were supplied from a separate source and require separate nomenclature. Bassett *et al*. (1966) review the lithological criteria available for the subdivision of these rocks, but relied on key tuff horizons. Mapping problems arise where these marker tuffs fail and the reliance on these as defining levels masks the presence of lithological contacts that future workers may feel have greater merit as regional formational boundaries (see below and Lockley, 1977 fig. 3.3). The early Soudleyan succession of siltstones and sandstones recognised as the **Glyn Gower Siltstones Formation** overlies the **Cefn Gwyn Tuff Member** and is capped by **Frondderw Tuff Member**. For the succeeding interval of burrowed, late Soudleyan rocks the abbreviated Corwen District term **Allt Ddu Formation** is preferred for a succession that is only mudstone dominated in the south. The **Pont-y-ceunant Ash Member** is seen locally at the base of the succeeding, Longvillian-Woolstonian **Gelli-grin Calcareous Ashes Formation**. The latter, a succession of calcareous tuffs and volcaniclastic shelly sandstones, siltstones, mudstones and debrites, includes the extensively studied **Cymerig Limestone Member** (e.g. Bassett *et al*., 1966; Lockley, 1980a, b; Rushton, 2000).

The lateral relationship between the mudstone-dominated, early Caradoc Porthmadog Formation (Eryri Group) and coeval levels of the Ceiswyn Formation (Hengae Group) warrants further comment. This relates to the status of strata recognised as the Nant Hir Mudstones in the Bala and Corwen districts (Bassett *et al*., 1966; BGS, 1993b). Previous authors consistently recognised the need to distinguish the Snowdonia rocks from contiguous, more obviously turbiditic facies of the Corris region. However, the selection by Rushton and Howells (1998) of the Ffynnon Eida Fault as a dividing line was an arbitrary one. No supporting lithological, or sedimentological evidence was provided. Sedimentological studies of the cleaved silty mudstones that characterise the Porthmadog Formation's type succession are in short supply. Such facies undoubtedly provide a record of deeper water accumulation, but by enveloping the products of local volcanic sites, including tuffs and tuffaceous silt and sandstone horizons, and displaying evidence of periodic bioturbation and of deposition close to sites of brachiopod and trilobite colonisation, both these rocks and the coeval Bala area strata display features consistent with the mixed system signature of the Eryri Group (Bassett *et al*., 1966; Smith *et al*., 1995).

Gradational south to north facies changes recognised by Lockley (1977, 1980a, b; also James, 1985) show that the transition between Eryri-Hengae Group facies takes place south of the Bala Fault. This southerly location allows the range of the Porthmadog Formation to be extended to embrace much of Nant Hir Mudstones crop located to the north. It also permits a realignment of the basal, highly fossiliferous **Derfel Limestone Member**, Rushton and Howell's (1998) inclusion of which in the turbiditic Ceiswyn Formation appearing anomalous (but see Lockley, 1977 p.16). Ground truthing to verify the nature and location of this transition is required and a sedimentological study of the mud-prone Eryri Group facies that host one of the region's important Ordovician slate resources is overdue.

**Text Box 10. Boundary region between the Bala and Dinas Mawddwy sheets:** BGS linework did not fully to capture the relationships between the Eryri, Hengae and Nod Glas groups on the southern limb of the Derwen Anticline. Determining the ages and relationships of rocks that Lockley (1977, 1980a, b) recognised as his Llaethnant Siltstone Formation and Dyfi Mudstone Member, and Pugh (1928, 1929) labelled 'Upper Ceiswyn Beds', are key to resolving these problems. Lockley, approaching this region from the north, was content to extend Bassett *et al*.'s (1966) Bala area nomenclature. Pugh, working from the south, sought to apply his Corris area stratigraphy (Pugh, 1923). He recognised northward facies changes affecting the upper levels of the Ceiswyn Formation south of Dinas Mawddwy. It was from the c.90 m-thick succession of rusty weathering mudstones that underlie the Nod Glas Group in this area that he first encountered assemblages of shelly fossils that include the pre-Longvillian trilobite *Salterolithus caractaci* (see Pratt *et al*., 1995). These rocks become more calcareous and fossiliferous northwards, where they include sandstone beds, but continue to yield the same distinctive fauna. Pugh (1929) assumed that calcareous ashes seen in the Llanymawddwy area that also underlie 'Nod Glas' facies offered evidence that his 'Upper Ceiswyn Beds' passed laterally to the Bala area Gelli Grin Calcareous Ashes Formation. Yet, the fauna in these rocks, in which Pugh recognised *Trinucleus gibbifrons* as the dominant trilobite, contrasts with that to the south.

Pugh and Lockley note the appearance north of Dinas Mawddwy of beds and nodules of shelly and phosphatic limestone in the lower part of the Nod Glas Group. Their presence formed the basis for Lockley's Dyfi Mudstone Member, but in which he included the upper levels of Pugh's 'Upper Ceiswyn Beds'. Lockley offered what he viewed as compelling faunal and lithological evidence that his member passed northwards into the Gelli Grin Calcareous Ashes Formation, recognising a prominent nodular limestone bed as a continuation of the Cymerig Limestone. BGS (2012) reinstated Pugh's original concept but followed Pratt *et al*. (1995) by including the 'Upper Ceiswyn Beds' in the Craig Hen-gau Member. Herein the term Bwlch Siglen Member is preferred. Only the topmost levels of Lockley's member, including the prominent limestone bed seen at Aber-Cywarch (Pugh, 1928), formed part of a 'Nod Glas' interval too thin to show on the published map.

Pugh (1928) was aware that the presence of *Salterolithus caractaci* in his 'Upper Ceiswyn Beds' was problematical. This taxon is confined to older levels of the type Caradoc succession (see Pratt *et al*., 1995). Its presence in strata underlying a Nod Glas Group succession believed to be much younger was seemingly anomalous. Pugh wondered if the taxon might have persisted longer in the deeper waters setting of the Corris-Dinas Mawddwy region. Lockley (1980a, b) argued that his Dyfi Mudstone Member provided evidence that Nod Glas Group deposition began earlier in this area. In assessing the Bala succession, he was able to recognise in the distribution of coarser and finer clastic sediments, and their faunas, multiple prograde events (see also James, 1985). He was aware that the local reliance on marker tuffs created lithostratigraphical problems where these failed southwards but was confident that his Llaethnant Siltstone Formation broadly encompassed a lateral transitional between the Glyn Gower Siltstone Formation and the deeper water Ceiswyn Formation. However, the turbiditic succession further south, with its hemipelagic-rich capping, offers little to corroborate subsequent shoaling events. Facies and biostratigraphical considerations better support an alignment of the Craig Hen-gau Member with mud-prone parts of the Soudleyan Allt Ddu Formation.

Rushton and Howells (1998) were aware of the implications of such a correlation. Though they did not endorse Lockley's terminology, they acknowledged that: 1) deposition of the Nod Glas Group may have commenced much earlier in the Corris area than in other regions of North Wales, despite an absence of graptolitic proof; and, hence, 2) there may exist a lateral transition between at least the lower parts of the Nod Glas Group mudstone succession seen in its type area and the Gelli Grin Calcareous Ashes Formation, including those strata in which Pugh (1929) recorded *Trinucleus gibbifrons*. In the parlance of this report, that there must exist a lateral interface between the Nod Glas and Eryri groups. On the other hand, if the Craig Hen-gau Member records a decline, during the Soudleyan, in the supply of northerly-sourced turbidites to the embryonic South Wales Sub-basin, surely the black, euxinic Nod Glas Group mudstones and associated phosphatic limestones mark the culmination of this process. Mechanisms then need to be invoked that permit the efficient segregation of early Nod Glas Group facies from the nearby region of Longvillian-Woolstonian vulcanism and coarse clastic deposition. The idea that the Nod Glas Group records a distinct, widely felt post-volcanic episode of coarse sediment deprivation and thermal subsidence must then be seen as simplistic. However, there is agreement that Nod Glas Group mudstones rest directly on Woolstonian levels of the Gelli Grin Calacareous Ashes Formation to the south of Gelli Grin.

Perhaps because they viewed such a conclusion as unpalatable, Brenchley *et al*. (2006b) favour an alternative alignment. In an endorsement of Pugh's correlations, they advocate a lateral relationship between the phosphatic limestones Lockley had included in his Dyfi Mudstone Member and the condensed phosphatic horizon seen in the Berwyn Dome and Welshpool areas. The question arises: is there omission at the interface between the *Salterolithus caractaci*-bearing 'Upper Ceiswyn Beds' and the overlying Nod Glas Group? This possibility was entertained by Williams *et al*. (1972) and James (1985). A period of non-deposition and/or mass-wasting affecting the developing northern flank of the South Wales Sub-basin would explain the failure to recover pre-c*audatus* Subzone graptolites from lower levels of the Nod Glas Group. A synsedimentary slide that excised Longvillian to Woolstonian strata, and was then draped by Nod Glas mudstones, could similarly account for the aberrant age relationships. Such a solution would require the dislocation to extend beneath the whole of the Nod Glas Group on the southern limb of the Derwen Anticline. Its physical impacts would then be similar to the tectonic decollement model advanced by Pratt *et al*. (1995). Strike faulting is a complicating factor in the Dinas Mawddwy area (BGS, 2012). Such models imply that rocks equivalent to the much of volcanic succession in Snowdonia are missing. In other parts of the LPWB, where the mid-late Caradoc succession is complete, the input of coarse sediment remained significant well after the onset of Nod Glas Group conditions in North Wales (see Hengae Group).

The transitions along the southern limb of the Derwen Anticline between the younger Eryri Group divisions of the Bala succession and the mud-prone successions of the Hengae and Nod Glas groups is a source of particular confusion (Text Box 10). Lockley (1977, 1980a, b) and James (1985) illustrate the complex lateral interface that must exist in the boundary region between the Bala and Dinas Mawddwy sheets, but further work is required before a fixed view of the lithostratigraphy of this region can be achieved. Distal Eryri Group facies with shell-bearing storm event beds present in the Llanymawddwy area, appear to capture the transition principally between the Glyn Gower Siltstone Formation and coeval levels of the Hengae Group (Ceiswyn Formation) (Lockley, 1977, 1980a). But the exact equivalence of these strata to the divisions of the Eryri Group is uncertain in an area where the formation-defining tuff horizons have failed. Rushton and Howells (1998) reject Lockley's nomenclature for these rocks.

The transition between the Bala area Eryri Group succession and that seen in Snowdonia occurs on the northern limb of the Derwen Anticline, in the region of Ysbyty Ifan (BGS, 1993b). Overstep at the base of the BI Systems Tract succession and erosion linked to the putative Garn Prys and Foel Ddu canyons combine to destroy the passage between the Gelli-grin Calcareous Ashes Formation and coeval levels of the Cwm Eigiau Formation (Fig. 15). At a lower level, pods of tuff assigned to the Capel Curig Volcanic Formation (Llewelyn Volcanic Group) are present in both successions. Rushton and Howells (1998) considered these correlatives of the Frondderw Tuff Member, whereas the Corwen Sheet shows them at a higher level (BGS, 1993b). Despite such intimacy, the fossil evidence confirms that coarser grade Eryri Group facies began to accumulate in the Bala region well before the accumulation of comparable Cwm Eigiau Formation sediments in Snowdonia became widespread (Fig. 15). Such relationships provide early evidence that the anticlinal region had begun divide southerly from northerly AII Systems tract successions. However, by late Soudleyan times separately sourced shallow water Eryri Group facies occupied much of north-west Wales. That the spread of volcaniclastic facies went on to achieve its widest extent during the Longvillian to Woolstonian appears at odds with dating that implies the supply of turbidites from the Derwen Anticline region to the Hengae Group declined during the early Soudleyan (see Text Box 10).

The Eryri Group succession of the Berwyn Dome succession, now believed to be entirely Caradoc in age (Fortey *et al*., 2000), is confined to the north of the Tanat-Cynllaeth system of faulting. The sedimentology of this succession and evidence for shallow water accumulation and periodic emergence is summarised by Brenchley *et al*. (2006b; and references therein). Widespread tuffs and tuffaceous horizons have been used to subdivide the succession into a series of formations. Near the base of the exposed succession, BGS (1986) advocate the presence of an unconformity below the calcareous tuffs of the **Craig-y-glyn Formation**, rendering the parentage of the underlying mudstones uncertain. Both the tuffs and the succeeding impure limestones warrant member status. For the limestone unit, the historical label 'Llandeilo Limestone' is inappropriate. The **Pen-y-graig Tuff Member** and **Mynydd Mawr**

**Limestone Member** are offered as candidate terms. The contact between the calcareous mudstones that form the upper levels of the Craig-y-glyn Formation and the silty, tuff-bearing **Llangynog Formation** is faulted. Of the numerous named tuffs in the succeeding succession, the **Cwm Clwyd Tuff, Swrch Gorge Tuff** and **Pandy Tuff**, here all considered **members**, serve as the defining basal divisions of the **Pen plaenau Siltstone**, **Terw Siltstone** and **Bryn Siltstone formations** respectively, although BGS (2000a) appears to dissent from this view. The locally preserved **Pen-y-graig Tuff Member** caps the Bryn Siltstone Formation. The appropriate use of these formational divisions will negate the need for Brenchley's (1978) 'Cwm Rhiwarth Siltstones Formation'. The published BGS maps imply that the both the Terw Siltstone and Bryn Siltstone formations pass laterally westwards into a mud-prone succession for which the use on BGS maps of the term 'Allt-tair-Ffynon Formation' is also inappropriate (e.g. BGS, 1986, 2000a). The latter has its type area in the south of the Berwyn Dome, in a succession now recognised as forming part of the Montgomery Group and where its usefulness as a lithostratigraphical label is also questioned (see above). Improved correlations of the marker tuffs of the Berwyn region with those of the Bala and Corwen districts will likely permit the nomenclature of the two successions to be further rationalised. The facies changes noted above resemble those seen in the Allt Ddu Formation and the latter may emerge as useful regional term for the late Soudleyan silty mudstone succession that crops out on the opposing limbs of the Llandderfel syncline. The rank of the Terw Siltstone and Bryn Siltstone formations may then warrant revisiting.

Cave (1965; see also Saigal, 1985) explained the importance of excluding the once economically important phosphate-rich facies that occur along the western and southern flanks of the Berwyn Dome from the **Pen-y-Garnedd Limestone Formation** (see below). Since it is only these phosphatic strata that extend into the Welshpool area of Montgomery Group deposition, such exclusion allows the remaining calcareous succession to be seen as the Berwyn Dome's youngest Eryri Group division. The dolomitised limestones, and tuffaceous mudstones and siltstones emerge as the direct correlative of the Longvillian to Woolstonian Gelli Grin Calcareous Ashes Formation and, Cave (2008) contends, upper levels of the Montgomery Group Gaer Fawr Formation.

### 2.2.4 Nod Glas Group (amended status and usage)

Pugh (1923) was the first to use the label 'Nod Glas' for the distinctive latest Caradoc succession of anoxic mudstones that underlies the pronounced facies changes seen at the base of the BI Systems Tract in the Corris area. It was subsequently widely employed for comparable rocks, but that locally include a basal phosphatic limestone, present in a region encompassing the southern flanks of the Derwen Anticline and the central and southern sectors of the North Powys Sub-platform (e.g. BGS, 1986; Cave, 1965, 2008). Rushton and Howells (1998), by extending the scope of the 'Nod Glas Formation' to include coeval strata preserved locally close to the crest of the Derwen Anticline (Tyn-y-glyn Mudstone), more extensively in the

**Text Box 11. Nod Glas Group dating:** Rushton (2000) and Brenchley *et al*. (2006b) summarise problems linked to the dating of Nod Glas Group facies, notably the age of the basal Pen-y-garnedd Phosphorite Formation. In the Gwern-y-Brain area near Welshpool, specimens of the conodont *Plectodina bullhillensis* from the lowermost parts of the formation are said not to exhibit evidence of reworking (Savage and Bassett, 1985). This taxon is typically associated with Woolstonian and older rocks. Upper levels of the phosphorite unit contain *Amorphognathus ordovicicus* and, together with the overlying fossiliferous mudstones (Gwern-y-Brain Formation), are taken to be Onnian in age. Many correlation charts sidestep the implication of these findings and show the Welshpool succession as confined to the Onnian (e.g. Fortey *et al*., 2000; Molyneux *et al*., 2023). Objectively, they may reveal that condensed phosphatic deposition ranged from late in the Woolstonian to early Onnian.

The phosphorite facies can readily then be seen as the condensed correlatives of the older (*caudatus* Subzone) levels of the Nant-y-Nod Formation successions present to the north and south of the Derwen Anticline, as inferred by Brenchley *et al*. (2006b, fig. 3.42). However, the past assignment of graptolites to the *foliacus* Biozone implies that, in some areas, Nod Glas Group mud deposition occurred during the Burrellian; yet this was a time of widespread vulcanism and volcaniclastic Eryri Group deposition. In recognising this conundrum, Rushton and Howells (1998) question the reliability of the *foliacus* Biozone graptolite identifications in the strongly cleaved North Wales succession. Work to confirm the biostratigraphical range of Nod Glas Group graptolites and of the conodont *P. bullhillensis* is needed to confirm the fully post-volcanic credentials of the group. The presence at Gwern-y-Brain of *A. ordovicicus,* a taxon more widely reported from post-Caradoc rocks, requires confirmation.

Conwy Valley (Cadnant Shales; Black Slates of Dolwyddelan), and on the Llŷn Peninsula (Penarwel Mudstones), discuss some of the misconceptions associated with its usage.

A detailed stratigraphical and sedimentological synopsis of these strata is provided by Brenchley *et al.* (2006b) (see Part 2). They reflect accumulation across a region of intra-basinal uplift – or reduced subsidence – and are here recognised as a distinct depositional system and included in the upgraded Nod Glas Group. Its nominal type section is as recognised by Lockley (1980a, b) and Rushton and Howells (1998). The group succeeds volcanic groups and volcanoclastic Eryri Group facies throughout Llŷn and Snowdonia, deeper water Hengae Group facies on the south side the Derwen Anticline, and shallower Mongomery Group facies on the south-eastern side of the Berwyn Dome and in the Welshpool region. The group comprises three principal facies that form the basis for a revised formational nomenclature: 1) phosphatic limestones of limited geographical extent that are here upgraded to the **Pen-y-garnedd Phosphorite Formation**; 2) its dominant and widespread black, pyritic and graptolitic anoxic mudstone facies for which the new term **Nant-y-Nod Formation** is introduced; and 3) mudstones comparable to the former, but that contain a shelly fauna that comprise the newly labelled **Gwern-y-Brain Formation**.

Cave (1965) recognised that the need to distinguish the basal phosphatic deposits of the ‘Nod Glas’ interval from the earlier Pen-y-garnedd Limestone Formation and that these rocks serve to locate the sites of greatest late Caradoc condensation and omission. These rocks, rich in plectambonitid brachiopods, succeed Eryri Group facies in the Berwyn Dome region, but extend south-eastwards to overlie strata included the Montgomery Group near Welshpool. Despite seldom exceeding 5 m in thickness, their regional significance justifies assigning them formation status. Brenchley *et al*. (2006b) recognise some of the rocks in the Dinas Mawddwy area that

Lockley (1977) included in his unadopted Dyfi Mudstone Member, as comparable (see text boxes 10 and 11).

The Nant-y-Nod Formation takes its name from, and shares the same type section as the Nod Glas Group and in this area, the stratigraphical range of the group and the formation are identical. A basal phosphatic limestone is not developed in an area where the thick mudstone succession likely marks the region of deepest Nod Glas Group deposition. However, Pratt *et al.*'s (1995) suggestion of a gradational relationship with the underlying Hengae Group facies (Craig Hen-gae Member) is problematical is a succession where reported graptolites arguably range no lower than the *caudatus* Subzone (see text boxes 10 and 11). Anoxic mudstones that yield *caudatus* Subzone graptolites overlie Snowdon Volcanic Group rocks of Woolstonian age in north-western Snowdonia and the Conwy area. An anomalous 400 m-thick succession seen near Dolgarrog records the infilling of volcanic relief. The succession on Llŷn rests on the Llanbedrog Volcanic Group.

Intervening between these southern and northern developments, in successions that have escaped later erosion and where the Pen-y-garnedd Phosphorite Formation is present, the group's characteristic black mudstones are confined to the latest Caradoc *morrisi* Subzone (Onnian Substage). Here, use of the Nant-y-Nod Formation is recommended in place of the plethora of earlier terms (see Wills and Smith, 1922; Brenchley, 1978; Cave, 1965; BGS, 1986; Rushton, 2000). It is these mudstones that directly succeed Woolstonian Eryri Group rocks (Gelli Grin Calcareous Ashes Formation) on the southern limb of the Derwen Anticline (Text Box 10), where the absence of an underlying phosphorite division points to disconformity.

This wider usage of the Nant-y-Nod Formation implies that the region starved of coarse-grade sediment extended well beyond the sites of maximum upwarp and omission to take in the whole of the North Powys and Llŷn sub-platforms, both flanks of the Derwen Anticline and likely, though conjecturally, the Harlech Dome region (Fig. 12). The silt content of the mudstones is reported to vary (Brenchley *et al*., 2006b) and more northerly developments of the formation likely record accumulation in shallower setting than the type succession; nevertheless, the black anoxic signature and evidence of reduced coarse clastic supply imply that even above the crest of the Derwen-Berwyn Axis, deposition likely took place below the depth of storm influence and benthic colonisation (see below). Throughout much of its area of outcrop, the Nant-y-Nod Formation underlies a significant omission surface at the base of the overlying BI Systems Tract. Only in its type area is the Nod Group (Nant-y-Nod Formation) believed to underly an intact Corris Group succession, though confirmatory dating remains elusive. Future workers may see merit in distinguishing the separate developments of the Nant-y-Nod Formation as local members.

Downfaulting on the west-side of the Severn Valley Fault Belt evidently allowed the isolated Nod Glas Group succession seen to the north of Welshpool to avoid Ashgill denudation. Overlying the thin, local development of the Pen-y-garnedd Phosphorite Formation, the local black mudstone succession differs from Nant-y-Nod Formation facies only in hosting an abundant Onnian shelly fauna (Cave, 1965, 2008; Brenchley *et al*., 2006b). These strata, despite their previous inclusion in the defunct Pen-y-garnedd Shale (e.g. Rushton, 2000), appear not to resemble those seen at Pen-y-garnedd and are newly designated the Gwern-y-Brain Formation. Cave and Price (1978) link the presence of the distinctive fauna to accumulation on the contemporary intra-basinal high. Given its location, it may equally signal the onset of a south-eastwards transition into the coeval Montgomery Group divisions seen in the Shropshire, the evidence for which has elsewhere been destroyed. The fauna demonstrates that the prevailing anoxic bottom conditions were no obstacle to colonisation.

#### 2.2.5 Volcanic Groups associated with the AII Systems Tract

The AII Systems Tract overlapped with the second and final phase of Ordovician vulcanism in Wales that gave rise to the well-studied Caradoc eruptive centres of Snowdonia. The accounts of these volcanic systems provided by Howells and his collaborators (see Howells *et al*., 1991 and references therein) informed the BGS stratigraphical framework report of Rushton and Howells (1998). Complementing these studies is the work by Young *et al*. (2002) on the volcanic successions of the Llŷn Peninsula. Most of the nomenclature recommendations arising from these volcanic investigations are not revisited in this account. The principal group terms have been listed in Part 2, where the requirement to recognise an **Upper Aran Volcanic Group** (adapted name) is also explained.

# 3 Tract Assemblage B (lower Hafren Supergroup)

## 3.1 BI SYSTEMS TRACT (PRE-HIRNANTIAN ASHGILL)

### 3.1.1 Corris Group

The Corris Group is a new name for the thick succession of mudstones, subordinate sandstones and localised limestones that accumulated widely throughout the LPWB following the late Caradoc shutdown of vulcanism. The term is taken from the area of extensive slate working to the south-east of Cadair Idris and the Bala Fault, where a complete succession outcrops on the south-eastern limb of the Corris Anticline (Pratt *et al*., 1995). Here, it embraces the former Abercwmeiddaw and part of the Abercorris groups of Pugh (1923). Where it is conformable with units of the preceding system tract, the marked regional facies change that mark the base of the Corris Group has been taken to mark the base of the Ashgill Series in Wales. The work of Zalasiewicz *et al*. (1995) on the Whitland road cutting has called this into question and an intra-Pusgillian age now seems probable.

The group embraces a spectrum of slope apron, slope, outer ramp and clastic blanket facies. However, facies and faunal transitions are highly gradational, and, given the destruction of most proximal successions, it is unrealistic to erect different groups. Existing formational nomenclature appears to offer a means to distinguish these different system components but is principally also an artifact of different generations of mapping and/or of mapping pragmatism determined by outcrop patterns. This notwithstanding, it is feasible, if only for descriptive purposes, to recognise a series of subgroups that seek to capture the subtle facies contrasts embodied within the Corris Group.

### 3.1.2 Tresaith Subgroup

This subgroup embraces the deeper, turbiditic facies that characterise the Corris Group of the Southern Sub-basin. The name utilises the previously abandoned term of Anketell (1963) and Craig (1987) for the Cardigan Bay succession centred on the coastal village of Tresaith. Throughout this region, Caradoc mudstones are abruptly, but conformably overlain by paler, burrow-mottled Ashgill mudstones. These record the subsequent accumulation of a thick succession of oxic slope apron facies as subsidence linked to lithospheric cooling became more widespread. The **Nantmel Mudstones Formation** (Plate 3A), widely mapped throughout mid Wales, had links to the sub-basin's southern and eastern flanks. For the separately sourced succession of the sub-basin's northern flank, in the Corris area, the slate workers' names 'Broad Vein', 'Red Vein' (see below) and **'**Narrow Vein' were utilised by Pugh (1923, 1928). Pratt *et al*. (1995) found, as elsewhere (see Davies *et al*., 1997, 2006), that the mapping of the 'Red Vein' was unsustainable (see below) and recommended that the equivalent strata be subsumed within an expanded **Broad Vein Formation**. The overlying widely worked **Narrow Vein Formation** was retained; the quality of this slate being linked to the homogenisation wrought by bioturbation (JRD personal observation). Conditions across parts of these oxic mudstone slope apron systems were able to sustain a bottom-dwelling trilobite fauna that formed the deeper and distal component of a faunal gradient shared with shallower settings (Price and Magor, 1984; Pratt *et al*., 1995). In contrast to these mudstone-rich units, the **Nant-y-moch Formation** of the Plynlimon region appears to record the ponding of sandy turbidites in a central setting.

In the upper parts of each of these successions, units of sparsely graptolitic, laminated hemipelagic mudstone **(lh)** yield a sparse graptolite fauna suggestive of the *anceps* Biozone and that record the episodic, but widespread return of anoxic bottom conditions to the Southern Sub-basin (Pratt *et al*., 1995; Zalasiewicz *et al*., 2009; Davies *et al*., 2006b). It is strata containing such units that slate workers in the Corris region recognised as the 'Red Vein' and that recent studies link to the global climatic changes wrought by the Boda Event (*sensu* Cherns and Wheeley, 2007; Fortey and Cocks, 2005; Challands *et al*., 2009).

Along the Tywi Lineament, also interbedded with upper levels of the Nantmel Formation, are units of coarse-grained turbiditic and debritic sandstone and conglomerate containing igneous clasts, and a resedimented mid-Ashgill fauna of bryozoa, corals, trilobites and shell detritus. These units, mapped as the geographically isolated **Doldowlod**, **Bryn Nicol** and **Taliaris formations**, are interpreted as lenticular bodies confined within fault-bounded troughs (see

Schofield *et al*., 2004, fig. 6). Both faulting and the supply of sediment have linked to the late Rawtheyan impacts of the Shelveian Orogeny and the uplift and deep erosion of regions to the east (but see Part 2). The slumping affecting Nantmel Mudstone Formation successions of the Builth and Llandovery districts testifies to related instability in proximal slope apron settings. A late Cautleyan or early Rawtheyan unit of shelly debrites and disturbed strata is recognised as the **Llwyncus Member** (Schofield *et al*., 2004). Shell-bearing sandstone event bed facies interbedded with the Nantmel Mudstones Formation include the Cautleyan **Cefn Nantmel Member** of the formation's type succession and the Cardigan region's **Eglwyswrw Member** (new name). These units testify to an early Ashgill period when shelly sands sourced from shallower settings were widely being supplied to contemporary slope-apron surfaces (see Tridwr Formation below).

### 3.1.3 Llandillio Subgroup

In North Wales, Tresaith Subgroup facies pass gradationally northwards and eastwards into the contiguous shallower water components of the Corris Group drape system. A plethora of local names exist for facies here recognised as the Llandrillio Subgroup after a Berwyn Dome location. In marked contrast with the Tresaith Subgroup, a non-sequence typically intervenes between Llandillio Subgroup successions and the underlying units of BI Systems Tract. Strata of Pusgillian to early Cautleyan age are reported to be widely absent and in some areas the preservation of Ashgill rocks was delayed until the mid Rawtheyan. Limestone units (see below) occur locally at the base of successions of bioturbated sandy mudstones with shallower water benthic assemblages that succeed facies of the Nod Glas Group (Price and Magor, 1984), or where the latter is absent, rest disconformably on earlier Caradoc strata.

Separate outcrops of these rocks are depicted on the BGS Bala Sheet as the Moelfryn Mudstones and Nant Achlas Siltstones formations and, in the Corwen district, as the Maerdy Mudstone Formation. These terms are here all viewed as synonyms of northern Berwyn Dome **Dolhir Formation**, although this requires field-based confirmation. Hillier (1981) sought to distinguish comparable facies of the Cyrn-y-brain and Mynydd Cricor inliers as the Cyrn-y-brain Formation, but BGS (1992b) rejected these terms in favour of Dolhir Formation. Hillier (1981) followed earlier authors in erecting a basal Ty'n-y-Twmpath Member, but it is unclear how lithologically distinctive this unit is. Inclusion of his Glyn Formation in the overlying BII Systems Tract renders his Glyn Valley Group also redundant. Cave (2008) extended the range of the Dolhir Formation into the Welshpool district in place of the former Trawscoed Mudstone.

Faunal and sequential differences suggest it is prudent to assign separate nomenclature to the geographically isolated succession in the Conwy Valley region strata that had strong links the northern margin of the LPWB. The term in current use, the Conwy Mudstones Formation, includes facies here ascribed to both the BI and BII systems tracts and is not fit for purpose (see below). For trilobite-bearing Ashgill rocks in this area that underlie the Conwy Castle Grit, the term **Bodeidda Mudstones Formation** as mapped by Elles (1909, plate 8) is reintroduced.

These strata are reportedly exclusively Rawtheyan in age, a significant non-sequence intervening between them and an underlying, incomplete Nod Glas Group succession (Fortey *et al*., 2000; Molyneux et al., 2023). Evidently, there is scope for subdivision. A distinctive trilobite fauna in its upper part enabled Elles (1909) locally to distinguish her 'Deganwy Mudstones' and the latter, though not currently shown on modern BGS maps, includes an upper interval containing *anceps* Biozone graptolites that recall the 'Red Vein' of the Corris Group type area (see above). Rocks at the very top of the 'Deganwy Mudstones' that Elles reported to contain abundant *Phacops mucronatus* (=*Mucronapsis mucronata*) possibly record the strongly oxic conditions that, in the Corris region, promoted the intense levels of bioturbation seen in the Narrow Vein Formation. Brenchley and Cullen (1984) contend that the distinctive trilobite assemblage is indicative of an Hirnantian age, but Wang *et al*. (2019; also Rong *et al*., 2020) imply that such assemblages need not. Again, work is needed to confirm and define the status of all these separate intervals and faunas in the Conwy region.

The shell-bearing Ashgill strata seen in outliers on the Llŷn Peninsula succeed a non-sequence between the AII and BI systems tracts comparable to that at Conwy. As there, these rocks record deposition close to the LPWB's northern margin. Their current isolation may justify retention of the local name **Crugan Mudstone Formation**. The onset of Rawtheyan deposition here, in common with other areas in North Wales, marked the establishment of a shallow marine setting that extended throughout much of the region and, in light of this, future workers may see the retention of some local nomenclature to be unnecessary.

The transition, present on the southern limb of the Derwen Anticline, between Llandillio Subgroup divisions and those of the turbiditic Tresaith Subgroup is currently taken at the boundary between the Bala and Dinas Mawddwy sheets; an artificial selection that requires revisiting. As with many internal Corris Group transitions, the laterally passage is seamless and the mapping of any boundary will be arbitrary, but the onset of Ashgill overstep in the Dinas Mawddwy area (see above) appears an appropriate starting point. Further north and east, in areas where Nod Glas Group is very thin or missing, across parts of the Derwen Anticline and much of the Berwyn Dome, limestone units at the base of the Llandillio Subgroup's Dolhir Formation evidently locate sites that were initially isolated from clastic deposition. The **Dolhir Limestone Member** records the mid Cautleyan onset of Ashgill deposition in the Berwyn Dome area. The **Rhiwlas Limestone** and **Hafod Ifan Limestone members** show that the accumulation of preserved deposits across the Derwen Anticline was delayed until Rawtheyan times. A late Rawtheyan shoaling event finds expression in Llandillio Subgroup succession of the Berwyn Dome where calcareous facies locally deposited in the vicinity of the Glyn Ceiriog, the **Glyn Limestone Member**, contrary to Hillier (1981), are here viewed as a capping to the Dolhir Formation. Sites associated with the Berwyn Dome, where early Cautleyan rocks are preserved, may serve to locate re-entrants or breaches in the Derwen-Berwyn Axis (see Brenchley *et al*. 2006b, p. 70). In such settings, despite the protestations of Molyneux *et al*.

(2023), Pusgillian deposition might also have occurred, or perhaps these were locations where once more widespread early Ashgill facies were preferentially preserved (Fig. 13). Narrow regions of down warp adjacent to the Bala and Severn Valley Fault belts may have been significant in these contexts.

### 3.1.4 Whithybush Subgroup

The spectrum of shallower Corris Group facies associated with southern margin of the South Wales Sub-basin, the southern counterparts to the Llandillio Subgroup, are here included in the newly recognised Withybush Subgroup. The name comes from the suburb of Haverfordwest located on an extensive outcrop of the local Ashgill succession. Separate exposures of cool water (Cherns and Wheeley, 2007) limestone seen locally at the base of this succession have been viewed by BGS (see Schofield *et al*., 2009a) as representatives of a single unit, the **Sholeshook Limestone Formation**. This has previously been thought to succeed a significant non-sequence, however, the work of Zalasiewicz *et al*. (1995) in the Whitland area, by demonstrating that Pusgillian levels conformably succeed black shales of the preceding AII System Tract (Mongomery Group; Drefach Subgroup) has shown that at least locally this is not the case (see Part 2). Lateral facies and faunal variations are reflected in the past use of local nomenclatures. Distinctive, coral-rich facies appear to warrant designation as a **Robeston Wathen Limestone Member** and, if not separate formations, their faunal differences suggest that the **Birdshill Limestone** and **Crûg Limestone members** deserve comparable status (see Owens, 2000). Price (1980) asserts that that more northly regions of Sholeshook Limestone deposition were significantly deeper than those to the south is supported by BGS (2008b) mapping that that shows a passage into Tresaith Subgroup slope apron facies (Nantmel Mudstones Formation).

The thick clastic blanket succession of bioturbated, silty and sandy mudstones interbedded with thin, storm-generated shelly sandstones that overlies the more southerly developments of the Sholeshook Limestone comprises the **Slade and Redhill Formation** (Geological surveyors on the Haverfordwest Sheet initially recognised the ‘Slade Beds’ and ‘Redhill Beds’ as separate units, but delineation proved contentious, and the conjoined name was used on the published map in 1920 and has been employed ever since). Across sites of fault-initiated mass-wating (see Part 2), it is Rawtheyan levels of this division that rests on eroded levels of the AII Systems Tract (Drefach Subgroup). In the Garth and Llandovery areas, the sandy event-bed facies of the **Tridwr Formation** interleave with slope apron mudstones in a way that recalls the turbiditic Eglwyswrw and Cefn Nantmel members (see above). However, the formation expands eastwards to form the whole of a Corris Group succession that ranges from Pusgillian to Rawtheyan in age. Here, its facies and system tract relationships suggest synonymity with the Slade and Redhill Formation and certainly support its inclusion in the Withybush Subgroup. The division illustrates well the continuum of mass flow processes that operated across the surface of the Corris Group drape system (see Fig. 7) and the arbitrary nature of its subgroup boundaries.

Late Rawtheyan strata are absent from southerly Withybush Subgroup successions, but in the Garth and Llandovery areas, thoroughly bioturbated muddy sandstones, in the form of the **Cribarth Formation**, preserve the impacts late Rawtheyan progradation across coeval Tresaith Subgroup rocks. The likely synonymous Pentre Formation, located between splays of the Garth Fault (Davies *et al*., 1997), represents the most northerly occurrence of shallow water Withybush Subgroup facies. As with coeval divisions to the north, the relationship of the Cribarth Formation with overlying Hirnantian strata (BII Systems Tract) is strongly affected by the deep erosion that accompanied the early Hirnantian global fall in sea level. However, in a setting close to the seaward limit of incision, the weakly bioturbated mudstones of the Garth area **Penrhiwmoch Member** evidence an abrupt decline in burrowing activity at the close of Rawtheyan. The current inclusion of these facies in the Cribarth Formation and Withybush Subgroup is open to question.

## 3.2 BII SYSTEMS TRACT (EARLY-MID HIRNANTIAN)

### 3.2.1 Yr Allt Group (amended status and usage)

The early-mid Hirnantian rocks that succeed the deep-water facies of the Tresaith Subgroup (Corris Group) comprise a thick succession of coarse silt-laminated turbiditic mudstones with packets of turbiditic sandstone (sa) and units of slumped and disturbed strata (db). Throughout much of mid Wales, these are shown on modern geological maps as the Yr Allt Formation. These areas of outcrop should now be classified as **Yr Allt Group undivided**. Viewed as modified slope apron successions, these rocks record the deep erosion of landward settings and consequential increase in sediment supply to the LPWB that resulted from a combination of Shelveian uplift and lowered global sea levels (see Part 2). Significantly reduced levels of bioturbation have been seen to reflect the high rates of deposition and units of slumped and destratified strata record the frequent slope failures that accompanied the rapid basinward progradation of this sedimentary wedge. Changes in salinity likely played a part and a global scale extinction was also underway.

In some Yr Allt Group successions, the regressive and transgressive Hirnantian facies can be recognised as distinct formations. In the Plynlimon region, facies that record the earlier regressive interval and the early parts of subsequent transgression are mapped separately as the **Drosgol Formation** and **Bryn-glâs Formation** respectively (BGS, 1984). Lenticular and more persistent units of coarse-grained turbiditic sandstone and conglomerate, including the **Pencerrigtewion Member** (of the Drosgol Formation), are thought mark the position of submarine channels and of sand and gravel lobes that reached the centre of the basin during the acme of the glacial low stand (Cave and Hains, 1986; James, 2014). In this context, the work of Davies *et al*. (2009), by implying that the **Dol-y-fan Conglomerate Member** represents the fill of a correlative feeder channel, shows that mapping on the Rhayader Sheet in the vicinity of Llanyre (BGS, 1993a) is in error. The incorrect inclusion of some transgressive BII Systems Tract facies in units that should properly be confined to the succeeding systems tract in outcrops east of the Tywi Anticline requires correction (see Text Box 12). At the base of the Bryn-glâs Formation succession in the Plynlimon area, Wilson *et al*. (2016) recognise a thin-bedded, trace fossil-bearing unit as the **Lluest-y-Graig Member**.

Work ongoing in the Llangrannog area shows the local Yr Allt Group succession includes facies that differ from those seen elsewhere. They offer evidence of sustained reworking by bottom currents and host a distinctive suite of trace fossils (Nicholls, 2019). Coastal sections also permit the separate recognition of regressive and transgressive successions, and of subordinate divisions, and suggest that the erection of formation and member-scale units will be possible. Names currently under consideration include the **Garclwyd** and overlying **Nodwydd formations**, for separate parts of the regressive succession, and **St. Crannog Formation** (see front cover) for the transgressive levels. As elsewhere, the effects of synsedimentary disturbance is widespread in these Hirnantian rocks (Plate 1) and how easy it will prove to map these putative divisions inland remains uncertain.

As with the preceding systems tract, evidence that the Yr Allt Group succession of the Corris region was supplied with sediment from the northern flank of the South Wales Sub-basin (Pratt *et al*., 1995) may justify retention of the local term Garnedd-wen Formation. Pratt *et al*. (1995) advocate the presence of a significant non-sequence to explain the attenuation of the 'Garnedd-wen' succession seen in the Corris area. This requires investigation. However, according to Davies *et al*. (2009), regressive and transgressive components of this Hirnantian unit are recognisable as the 'lower' and 'upper' divisions of Pugh (1928). The presence of extensive sandstone units, some labelled the Pencerrigtewion Member (BGS, 1995), suggest that limited remapping may allow **Lower** and **Upper Garnedd-wen formations** to be distinguished. Pugh (1928) recovered *Mucronapsis* trilobite fragments from the lower unit in which aberrant cross-stratified muddy sandstones seen to the south of Dinas Mawddwy warrant recognition as the **Aberangell Member** (see Pugh, 1929; Pratt *et al*., 1995; James, 2014). The latter suggests that, as in the Llangranog area, bottom current reworking of the local slope apron sediments was locally active. The northwards passage from this Yr Allt Group succession into the Cwm Hirnant Group along the southern limb of the Derwen Anticline remains poorly understood.

Yr Allt Group facies interdigitate with the coeval Scrach Group along the south-eastern margin of the South Wales Sub-basin. In the south, this transition occurs with a narrow belt linked to the Garth and Crychan fault belts. A strongly diachronous contact seen in the northern part of the Tywi Anticline, in the Abbeycwmhir area, sees Scrach Group facies extend westwards as far the Cwmysgawen-Glanalders Fault Belt. Intra-Telychian mass-wasting accounts for the absence of transgressive Hirnantian facies (Davies *et al*., 1997) in this region. The Yr Allt Group facies that crop out in this region are the local equivalent of the Drosgol Formation. Yr Allt Group facies are absent or unexposed further north.

For the large areas of undivided Yr Allt Group outcrop of southern mid Wales, including its Tywi Anticline type succession, limited remapping will likely allow its separate regressive and transgressive components also to be identified. It remains to be seen if the existing Plynlimon region terminology will prove applicable, or whether new terms will need to be introduced.

### 3.2.2 Scrach Group (amended status and usage)

The Scrach Group recalls the earlier term ‘Scrach Formation’ of Cocks *et al*. (1984) for the early to mid-Hirnantian rocks of the Llandovery region (see also Woodcock and Smallwood, 1987). Davies *et al*., (2009), following their recognition of a major sequence boundary and an associated angular unconformity, argued for its abandonment. The sequence boundary remains an important dividing line between regressive and transgressive Hirnantian facies and formations, but the approach adopted here, in matching the practice adopted for deep-water facies (see above), finds the former term useful as a label for the coeval assemblage of both regressive and transgressive shallower water facies.

In its type succession at Llandovery, and at Garth, the regressive parts of the group include the coarsening upwards passage from the interbedded, weakly bioturbated mudstones, siltstones and sandstones of the **Ciliau Formation** into the wave-knitted sandstone facies of the **Cwmcringlyn Formation**. Characteristic elements of the ‘Hirnantia Fauna’ have been recovered from these strata (Davies *et al*., 1997; Schofield *et al*., 2004). That mapping of the Scrach Group succession in the Abbeycwmhir region of the northern Tywi Anticline is faulty in failing to show separately facies equivalent to the Ciliau Formation, requires confirmation.

The boundary which separates these regressive divisions of the Scrach Group from the succeeding mid-Hirnantian transgressive facies, as it is traced eastwards, develops into an unconformity of increasing magnitude and angularity (Davies *et al*., 2009, 2011). This is overlain by transgressive sandbodies recognised at different localities in the Llandovery and Garth areas as the **Cwm Clyd Sandstone** and **Gasallt-fawr Sandstone formations**. The overlying succession of smooth, shell-free mudstones and lenticular sandstones with a distinctive suite of bedding plane trace fossils that comprise the **Garth House Formation** provides a record of post-glacial maximum deepening across the unventilated and/or desalinated margin of the South Wales Sub-basin (Davies *et al*., 2009). Locally, as to the east of the Crychan Fault Belt, where they overstep the early Hirnantian succession to rest on earlier Ashgill rocks, these transgressive facies are the sole representatives of the BII Systems Tract.

This also appears to be the case in the Haverfordwest area where the transgressive **Portfield Formation** of Cocks and Price (1975) includes a basal **Scotchwell Shale Member** and succeeding **Cethings Sandstone** and **Cuckoo Shales members**. Aside from a solitary brachiopod, these strata are barren of shelly macrofossils. Cocks and Price (1975) show the

Scotchwell Shale Member as Rawtheyan, however, the fossil recovered from the this unit (?*Onniella*) permits an Hirnantian age. The irregular distribution of conglomerate facies locally present at the member's base is consistent with the infilling of topography incised during the glacio-eustatic lowstand. The Cethings Sandstone Member must then be viewed as younger element of this transgressive stratigraphy that was not identified by Davies *et al*. (2009). Similarities with the Llandovery area succession studied by the latter may persuade future workers to rationalise their nomenclature.

The Welshpool region BII Systems Tract succession was likely palaeogeographically contiguous with that of the Scrach Group type area. The channel-infilling **Meifod Limestone Formation** with its reworked Rawtheyan fauna and karstic top record intervals of incision and emergence that accompanied the early Hirnantian regression (Brenchley *et al*., 2006a), though this interpretation appears to have been rejected by Cave (2008). The overlying, but laterally more extensive **Graig-wen Sandstone Formation** was emplaced during the mid-Hirnantian post-glacial maximum transgression. In common with the coeval sandbodies seen in the Garth and Llandovery areas, this unit is also overlain by a thin succession of barren mudstones. The latter are currently included and mapped as part of the typically more fossiliferous Laundry Mudstones Formation (see below; Cave, 2008), but from which, Davies *et al*. (2009) imply, it should now be excluded. The **Fron-haul Formation** is offered as a new name for this distinctive, but currently unmapped unit. In the vicinity of the Berwyn Dome, the BGS Oswestry Sheet shows BI Systems Tract rocks (Dolhir Formation) as widely overlain by the local representative of the BIII Systems Tract. This has been taken to imply that an irregular topography installed by Hirnantian incision was effective in limiting the areas of BII Systems Tract deposition and preservation. However, work is needed to ensure that the Hirnantian succession of the Brogan Anticline, exposed near Llanfyllin (Brenchley and Cullen, 1984) and to the south-west of Meifod (Brenchley *et al*., 2006a), is not more widely developed. Both regressive Scrach Group facies and the nature of the lateral passage in the coeval deeper water Hirnantian system of the South Wales Sub-basin (Yr Allt Group) are concealed beneath younger systems tracts and nowhere exposed in this region.

### 3.2.3 Cwm Hirnant Group (new name)

Rocks of this group include those of the historical type section for the Hirnantian Series and from where its distinctive cold water shelly fauna was first described (e.g. Elles, 1922). Despite its long history of investigation (see Nicholls, 2019) significant problems remain in terms of mapping, dating and interpretation. That there is a northwards lateral passage from slope apron facies of the Yr Allt Group (Garnedd-wen Beds of Pugh, 1928, 1929) of the Corris and Dinas Mawddwy areas into the shallower early-mid Hirnantian ramp facies of the Bala district is unquestionable. The latter are currently included in an all embracing Foel-y-dinas Formation (Bassett *et al*., 1966; BGS, 1986), but is not clear from the accounts of Pugh (1929), Elles (1922) and Bassett *et al*. (1966) whether the unqualified use of this term properly captures the nature of the transition, the local succession of facies and the evidence of local overstep. Use of the term Cwm Hirnant Group undivided, though it also has the benefit of resurrecting historical terminology, offers a means to sidestep these issues, the unravelling of which will requires new mapping and modern dating. Such research may endorse the conceptual merit of a **Lower Foel-y-dinas Formation** for the trilobite-bearing early Hirnantian regressive facies that are equivalent to the Lower Garnedd-wen Formation (Yr Allt Group) (see Pugh, 1928, 1929); though confirmation that these strata post-date the Narrow Vein Formation (Corris Group) is first required. Evidently younger, by inference mid-Hirnantian facies that equate with Pugh's (1923) 'Upper Garnedd-wed Beds' were recognised as the 'Hirnant Beds' by Elles (1922). Much debate ensued about the upper limit of these strata in subsequent discussions between Jones, Pugh and Elles (see Jones, 1924). For these rocks the term **Upper Foel-y-dinas Formation** may come to be seen as appropriate. The resedimented and pisolitic **Hirnant Limestone** and the **Calettwr Quartzite** host historically important faunas and are deserving of **member** status. Further study is needed to confirm whether the former marks the acme of the early Hirnantian glacioeustatic regression and the latter the onset of the ensuing transgression.

There are aspects of the Cwm Hirnant Group that resemble those of an intra-basinal high system. In the Bala area (Nant Hafhesp), overstep has resulted in the loss of a significant portion of the Hirnantian succession on the north side of the Bala Fault. The surviving Cwm Hirnant Group succession in this region is very thin, evidently transgressive (James, 2014) and likely representative of only the mid-Hirnantian. The impacts of Telychian mass-wasting notwithstanding, such attenuation and the group's absence from a broad area associated with the axis of the Derwen Anticline (BGS, 1993b) testify to contemporary uplift (see Part 2).

### 3.2.4 Ceiriog and Conwy groups (new names)

The early-mid Hirnantian succession preserved in the northern sub-basin differs from that seen in the southern sub-basin. The barren interval widely recorded overlying transgressive mid-Hirnantian sandstones further south is not observed. In their place, body-fossil-bearing facies appear to show that ventilated conditions were maintained in the northern sub-basin throughout the Hirnantian interval. In doing so, they illustrate how effective of the Harlech-Derwen-Berwyn system of structural highs were in temporarily isolating the South Wales Sub-basin from fully open marine influences.

The shallow water Hirnantian facies that outcrop along the northern flank of the Berwyn Dome and in the Cyrn-y-brain and Mynydd Cricor inliers have been most recently assessed by Hiller (1980, 1981) following earlier work by Lake and Groom (1893), Groom and Lake (1908) and Wedd *et al*. (1927). The term **Ceiriog Group** is introduced for the succession these rocks described by Hillier (1980, 1981), in its nominal type area south of Glyn Ceiriog. For the coarse-grained, wave-ripple cross-laminated sandstones that occupy much of the lower part of this type succession the label **Glyn Grit Formation** (adapted from Brenchley *et al*. 2006b) is preferred, for reasons of clarity, in place of Hillier's (1981) Glyn Formation. Its deposition records the shallow, sublittoral environments that developed in parts of north-east Wales during the glacio-eustatic lowstand, although Wang *et al*. (2019) question the Hirnantian credentials of the fauna recovered from these rocks. The previously included Glyn Limestone Member (see above) contains a Rawtheyan fauna and is excluded from the Ceiriog Group notwithstanding Hillier's report of a gradational upper contact. Groom and Lake's (1908) report of an unconformity within the sandstone unit, that may represent an internal contact between regressive and transgressive units, requires confirmation. Further to the west, the stratigraphical relationships of the transgressive Corwen Grit differ significantly from the sandstones seen at Glyn Ceiriog, though both have long been viewed as lateral equivalents (e.g. Brenchley *et al*., 2006b). BGS's (1993) recognition of the grit as a member of the Dolhir Formation is considered incorrect. The newly designated **Corwen Grit Formation** likely correlates with only the upper part of the Glyn Grit Formation. Dating of the grey, sparsely fossiliferous mudstones that succeed these sand-prone units (Lake and Groom, 1893; Hillier, 1980) is insecure (see BIII Systems Tract; Fron Frys Formation). At their base, they likely include transgressive mid-Hirnantian facies that warrant inclusion of the Ceiriog Group and, according to BGS (1992b), it is likely these levels that overstep the Glyn Grit Formation westwards to rest on BI Systems Tract rocks.

Reportedly deeper water early-mid Hirnantian facies present in the Conwy Valley are currently included in the Conwy Mudstone Formation. Inclusion in the latter of strata here assigned to both the BI and BII systems tracts is unsatisfactory and necessitates reclassification (see above). Here, it is proposed to exclude pre-Hirnantian Ashgill rocks (BI Systems Tract) from this unit and to recategorize the remaining BII Systems Tract rocks as the **Conwy Group**. The sharp base of the northerly sourced **Conwy Castle Grit Formation** evidently records the abrupt local onset of regressive turbidite fan deposition; though the presence of benthic fossil assemblages in the underlying Bodeidda Mudstone Formation (see above), of a transported 'Hirnantia Fauna' in the grit itself, and of shelly fossils in the overlying strata suggest that the depositional setting was not that deep. Elles (1909) recognised a transition from the grit unit into a succession of graptolite-yielding mudstones and thin sandstones that formed part of her predominantly Silurian 'Gyffin Shales'. This was evidently incorrect. Warren *et al*. (1984) demonstrated the presence, between the Conwy Castle Grit and the BIII Systems Tract Bryn Dowsi Mudstones Formation, of an unnamed succession of silty mudstones from which they obtained a sparse shelly and fragmentary graptolite fauna. This upper division of the Conwy Group, representative of the transgressive mid-Hirnantian event, is here recognised as the **Colcon Mudstones Formation** (new name) after the set of boreholes in which it has most clearly been identified.

## 3.3 BIII SYSTEMS TRACT (LATE HIRNANTIAN-MID TELYCHIAN)

### 3.3.1 Pont Erwyd Group (readopted name)

The deep-water succession of the South Wales Sub-basin has been the subject of a sustained BGS mapping campaign over the last 30 years. This has allowed a detailed sedimentary

**Text Box 12. Tycwtta Mudstone Formation:** The term Tycwtta Mudstones formation was first used on the Rhayader Sheet for a succession preserved to the east of the Tywi Anticline, but west of the Garth Fault, that included both oxic and anoxic slope apron facies (Davies *et al.*, 1997). In its type area, the formation is incomplete due to intra-Telychian mass-wasting.

Subsequent mapping east of the Garth Fault, on the Builth, Brecon and Llandovery sheets, demonstrated a lateral passage between the Tycwtta Mudstones Formation and the Chwefri Formation. In these areas, the formation forms part of a Marginal Belt succession that escaped the impacts of later mass-wasting. It is questionable whether these Tycwtta Mudstones Formation successions continue to form part of the deeper water Pont Erwydd Group or represent a distal expression of the Cwm Rhuddan Group ramp system. The alignment of Davies *et al*. (1997) is preferred. Such successions capture the intergradation between coeval outer ramp and upper slope apron facies.

In addition, the findings of Davies *et al*. (2009), show that, locally, transgressive mid-Hirnantian rocks have been included incorrectly in either the Tycwtta Mudstones, or Chwefri formations. Such rocks form part of the BII Systems Tract succession and should properly be assigned to either the Yr Allt or Scrach groups. It emerges that the base of the type Tycwtta Mudstones section in the River Wye is likely faulted. Ground investigations are needed to the enforce the necessary realignment of mid-Hirnantian facies.

architecture to be constructed (Fig. 17) and a standardised lithostratigraphical nomenclature for formation and member level divisions to be established (e.g. Davies *et al*., 1997; 2006a; 2006b; Schofield *et al*. 2004). The group name adopted here reprises the nomenclature of O T Jones' (1909) seminal paper on the geology of its type area. The succession largely records the construction of a mudstone-dominated slope-apron system that thinned away from the basin's eastern and southern Marginal Belt towards its centre and extended onto the southern flanks of the Derwen Anticline and peripheral regions of the Berwyn Dome. Pont Erwyd Group successions to the west of the Tywi Anticline record deposition in median to distal parts of the deep-water slope apron system and envelope sandstone and conglomerate subsystems deposited intermittently within narrow corridors and as terminal lobes (see below). The lithostratigraphical subdivision of the muddy system reflects its accumulation during a regime in which anoxic and oxic bottom conditions alternated in step with contemporary eustatic events (Davies *et al*., 2016). The widely recognised **Mottled Mudstone Member**, aside from its basal '*persculptus* Band,' comprises the oxic basal unit of the otherwise predominantly anoxic, richly graptolitic, late Hirnantian to early Aeronian **Cwmere Formation** (see Melchin *et al*., 2018, 2023) (Plates 3B and 8).

There is a case to view the **Cwm yr Aethen Mudstones Formation** of the Bala area, which comprises facies identical to, and contiguous with those of the Cwmere Formation (see BGS, 1985 and 2012), as a synonym. However, the likelihood that, in common with preceding BI and BII systems tract divisions in this area, is includes sediment supplied from the Derwen-Berwyn Axis to north, argues for its retention. This is also viewed as a more appropriate term for the graptolitic succession preserved locally beneath overstepping CI Systems Tract rocks (see below) along the Berwyn Dome's western and southern flanks, for which use of the north Berwyn Dome term 'Fron Frys Formation' by BGS (1985) is inappropriate.

Regressive, bioturbated facies are more prevalent in the Aeronian **Derwenlas Formation**. Different levels have been taken to define the base of this unit (see Melchin *et al*., 2023). Cave and Hains (1986) linked the base to the entry of *triangulatus* Biozone graptolites seemingly in an effort to align the formation with the former ‘Middle Llandovery Series’. However, Davies *et al*. (1997; see also Melchin *et al*., 2023) recognise a level within the succeeding *magnus* Biozone that marks the base of a crag-forming packet of strata as the most appropriate for regional mapping (Plate 8). Widely recognised anoxic intervals within the Derwenlas Formation, some several metres thick, mark the impact of discrete deepening episodes notably during the *convolutus* Biozone. For historical reasons linked to the earlier concept of an ‘Upper Llandovery Series’ (e.g. Jones, 1949), standard practice has been to include the transgressive, late Aeronian **M. sedgwickii Shales Member** (Dark Grey Mudstone Member of Cave and Hains, 1986) in the largely Telychian Rhayader Mudstones Formation (Davies *et al*., 1997). The decision, discussed in Part 2, to recognise the M. sedgwickii Shales Member as an uppermost unit of the Derwenlas Formation and to include the succeeding, predominantly oxic green mudstone facies of the Rhayader Mudstones Formation in the Trannon Group (CI Systems Track), requires the former ‘Claerwen Group’ to be abandoned. Pending their remapping, areas where the former group is shown as an undivided unit, notably in the Dinas Mawddwy and Llangranog districts, should be relabelled Derwenlas and Rhayader Mudstones formations undivided.

The Llanymawddwy Formation of the Bala Sheet (BGS, 1986) is almost certainly hybrid in character and spans the BIII-CI systems tracts boundary. In its lower part, it likely to includes levels of slope-apron facies equivalent to both the Derwenlas and Rhayader Mudstones formations and, in its upper parts, distal facies of Telychian sandstone lobe systems (Central Wales Grits Group). Urgent remapping is required to identify the tract boundary and these separate depositional components for which local terminology may be need.

Davies et al. (1997) introduced the term **Tycwtta Mudstones Formation** for a succession of Hirnantian to early Aeronian slump-disturbed oxic and anoxic slope apron facies seen to the east of the Tywi Anticline. Though coeval, the presence of oxic intervals and of slumping were seen to contrast with the coeval Cwmere Formation facies and indicate deposition in an upper slope apron setting. Subsequent work has called the accuracy with which the Tycwtta Mudstones Formation has been defined and mapped into question (see Text Box 12). A unit of mass-flow conglomerates recognised as the **Allt-y-clych Conglomerate Member** may be linked to the Caban-Ystrad Meurig Sub-system.

Coarse clastic units within the Pont Erwyd Group include the laterally confined **Caban-Ystrad Meurig Subgroup**. In their mapping of the eponymous **Caban Conglomerate** (Plate 9) and **Ystrad Meurig Grits formations**, Davies and Waters (1995; also Davies *et al*., 1997) recognised a series of distinctive turbidite facies that, because of their complex interdigitation, resisted formal lithostratigraphical identification. Future workers may feel that this is possible. Certainly, the extensive basal sandstone unit of the formation merits distinction as a **Cerig Gwynion Grits Member** (adapted name). Early Telychian parts of the subsystem, as noted in Part 2, are coeval and contiguous with divisions of CI Systems Tract (Trannon Group), but from which they are excluded. To the south, in the Lampeter district, the Nant Brianne Formation of Schofield *et al*. (2006b) is no longer fit for purpose in its present form. Only the predominantly Aeronian conglomeratic and slumped lower levels of this former division, distinguishable from overlying levels that interdigitate with CI Systems Tract mudstone facies, form part of the BIII Systems Tract. These strata together with underlying sandstone units are considered components of a newly erected **Llyn Brianne Formation**. Limited remapping to accommodate this change will be required. For the lower sandstones, the labelling of Schofield *et al*. (2009b) is adapted to allow the recognition of the **Ystradffin** and **Dinas members**. Together these units mark the site of a further long-lived coarse clastic corridor that punctuated the Pont Erwyd Group slope-apron surface (Davies et al., 2006b; Schofield *et al*., 2006b). The Llangranog area **Allt Goch Formation** is a candidate for the associated distal lobe facies. The **Rhyddlan** and **Glaslyn formations** and unnamed conglomerate bodies mark the location of other sites of late Hirnantian to Aeronian turbidite sand and gravel deposition in the South Wales Sub-basin (e.g. Davies *et al*., 2006a; 2006b; Schofield *et al*., 2004, 2009b; Wilson *et al*., 2016).

### 3.3.2 Cwm Rhuddan Group (new name)

In the BIII Systems Tract shallow water ramp-like facies that characterise the Marginal Belt successions of the Llandovery and Garth areas, the alternation of mud-prone and sand-prone facies appear to record the impact of the same eustatic events that shaped the coeval deeper water Pont Erwyd Group (Davies *et al*., 2013, 2016) (Fig. 18). The Cwm Rhuddan Group takes its name from the former Llandovery area type location for the Rhuddanian Stage identified by Cocks *et al*. (1970). Levels of bioturbation vary, but where at its most intense, resulted in the homogenisation of previously interbedded sands and muds leaving little trace of primary bedding. Brachiopods are common in many units and are reported to represent different depth communities; graptolites are sparse and fragmentary, yet have proved essential for regional and international correlation. Davies *et al*. (2013) reject the delta model proposed by Cocks et al. (1984) for these rocks, yet the thick, localised sand-prone successions attest to sediment being supplied via a narrow conduit that traversed the more proximal, arguably emergent regions of the Marginal Belt. The clinoform model advanced by Davies et al. (2013) allows for a form of fan delta, but one on which bioturbation played a dominant role in sediment modification.

At the base of the group, the BIII Systems Tract boundary charts the pulsed progress of the post-glacial global marine transgression. In the Llandovery and Garth areas it is taken at the base of a the fossiliferous bioturbated sandy mudstones of the **Bronydd Formation** and of correlative outer ramp facies represented by the **Chwefri Formation**, which includes the basal, burrow-mottled **Ystradwalter Member** (Davies *et al*., 2009, 2013). The suggestion on the Builth Wells and Brecon sheets that the lowermost levels of Chwefri Formation pass laterally into transgressive mid-Hirnantian rocks (Garth House Formation) is mistaken (see Text Box 12). Limited remapping to rectify this is needed. The Rhuddanian **Crychan Formation** and its correlatives (Cocks *et al*., 1984; Schofield *et al*., 2004; Barclay *et al*., 2005; Davies *et al*., 2009, 2012; Schofield *et al*., 2009a) represents a progradational sandstone-dominated mid-ramp facies, which interdigitates with both the Bronydd and Chwefri formations. Sandstone deposition contracted markedly during the late Rhuddanian and early Aeronian, as reflected in the widespread distribution of the muddier **Trefawr Formation** and, at intervals during the late Aeronian, by the otherwise comparable **Rhydings Formation**. A lateral and upward passage into separate levels of the **Cefngarreg Sandstone Formation** (Plate 4B) records the subsequent pulsed re-advances of mid to late Aeronian sand-prone ramp facies. The much thinner and localised **Ty Gwylim Sandstone Member** of the Garth area Trefawr Formation succession, though a likely synonym, implies either that the bulk of the Cefngarreg Sandstone progrades of the Llandovery area failed to advance into this more northerly location, or that cryptic Telychian mass-wasting had an impact on their preservation.

The richly fossiliferous, muddy sandstones of the Llandovery area **Wormwood Formation**, overlie and oversteps earlier divisions. The formation's basal, *sedgwickii* Biozone graptolite-bearing **Ydw Member** equates with the Pont Ewyd Group's M. sedgwickii Shales Member and records the impact of same, short-lived, late Aeronian marine transgression. The eustatic nature of this event is debated, but its regional influence in Wales and more widely was marked (cf. Page *et al*., 2007; Davies *et al*., 2016). These units offer confirmation that ramp-like facies continued to accumulate in the Llandovery area into at least latest Aeronian times recalling the Caban-Ystrad Meurig Subgroup of the westerly deep-water succession. These youngest levels pass laterally into shoal facies of the Castell Powys Group (Fig. 18) (see below). Schofield *et al*. (2009a) recognised that strata included in the Cefngarreg sandstone Formation in the Brecon distict (see Barclay *et al*., 2005) should be redesignated Wormwood Formation. To the south-west of Llandovery, between Mandinam and the Sawdde Gorge, a thin, but distinctive succession of irregularly bedded limestones, sandstones and mudstones oversteps Rhuddanian and Ashgill rocks to rest uncomfortably on the CII Systems Tract's Llandeilo Flags Subgroup (see Williams, 1953). Late Aeronian brachiopods justify inclusion in the Wormwood Formation (Schofield et al., 2009a; Davies et al., 2012), but, with a type section in a tributary of the Afon Sawdde, these strata warrant recognition as the newly named **Rhyd-y-saint Member**. The author entertains the suspicion that these rocks and their fauna, together with much of the overlying Cerig Formation, are resedimented. Were this to be confirmed, alternative formation, group and tract alignments would need to be considered.

BIII System Tract succession seen in south-west Wales described by Cocks and Price (1975) includes the off-shore facies of the **Haverford Mudstone Formation** and the succeeding, storm-influenced **Gasworks Sandstone** Formation. Davies *et al*. (2009) suggest that the fossiliferous **St. Martin's Cemetery Bed** present at the base of this succession is the local equivalent of the Ystradwalter and Mottled Mudstone members and records the same late Hirnantian basin re-ventilation event. This interpretation is significant in implying that, along the margins of the South Wales Sub-basin, a modified 'Hirnantia Fauna' survived locally into the early Rhuddanian, as has been recognised elsewhere. To date, the detailed facies transitions recognised by Davies *et al*. (2012) in the Llandovery area have not been documented and assignment of these Haverfordwest area rocks to the Cwm Rhuddan Group ramp/delta system requires confirmation.

### 3.3.3 Castell Powys Group (new name)

The late Hirnantian to mid-Telychian successions that are widely developed across Marginal Belt and platformal settings, but that display stratigraphical relationships and facies that differ from the Cwm Rhuddan Group, constitute the transgressive sand-prone blanket system here recognised as the newly named Castell Powys Group. The successions of this group flank and extend to the west of the Severn Valley Fault Zone and crop out along the flanks of the Long Mountain Outlier and Shelve Inlier (Fig. 19). They are also identified in the Llandovery and Garth areas, where they interface with facies of the both the Cwm Rhuddan Group and the CI Systems Tract, as well as in the Church Stretton region and the south-eastern inliers. The group's type succession extends from the vicinity of Castell Powys (Powis Castle), south of Welshpool, westwards into the Meifod area (e.g. see King, 1928; Temple, 1987; Cave, 2008). Aside from in this westernmost expression, the group everywhere succeeds a basal unconformity, and its accumulation records the progressive expansion of Llandovery deposition as rising post-glacial sea-levels flooded the Marginal Belt and much of the adjacent platform (see Part 2). The Llandovery transgression was a pulsed affair, local non-sequences providing evidence of periods of base level fall, emergence and extensive erosion. One such episode accounts for disconformities widely present beneath facies introduced by the *sedgwickii* Biozone transgression, which was effective in extending the range of late Aeronian Castell Powys Group facies deposition as far as the Malvern Line.

The early to mid-Llandovery Castell Powys Group succession in its Welshpool type area is geographically isolated from more easterly parts of the group and include levels that are much older. The diachronous system of transgressive facies with basal conglomerates and sandstones oversteps older units in a pattern consistent with deposition adjacent to an active fault block (Cave, 2008). In the vicinity of the Severn Valey Fault Zone, the basal, highly diachronous **Powis Castle Conglomerate Formation** underlies the storm sheet sandstone-bearing **Laundry Mudstone Formation**. Further west, near Meifod, the latter forms part of the conformable succession that ranges from late Hirnantian, through the Rhuddanian and into the Aeronian. Needing to be excluded from the formation here are barren strata (Fron-haul Formation) that succeed the mid-Hirnantian Graigwen Sandstone Formation. These form part of the preceding BII System Tract (see above). The Laundry Mudstone Formation's transition into coeval deep-water facies of the Pont Erwyd Group (Cwm yr Aethen Mudstones Formation; see above) in the complexly faulted and folded ground south of the Berwyn Dome, notably along the limbs of the Brogan Anticline, requires an investigation that may necessitate the reassignment of some levels (see above). Ziegler *et al.*'s (1968) recognition of an Aeronian deepening episode linked to the local appearance of graptolitic facies strengthens this likelihood, but mass-wasting appears also have had a significant impact on this succession (Fig. 19).

In an easterly direction, the former Cefn Formation is recognised as a synonym of the Laundry Mudstones (see Cave, 2008, p. 18) and, as well as extending the latter's geographical range, also serves to extend its age into the early Telychian. This is an important divergence from past practise since it implies that there likely exists a physical link in the sub-crop between the group's Welshpool succession and those further east. These more easterly successions are known locally to range into and throughout the *guerichi* Biozone but also include levels that pre-date the local first appearance of *convolutus* Biozone graptolites (e.g. Cocks and Rickards, 1968; Cave, 2008). These rocks, previously given a range of local names that testify, in part, to facies variation (see Ziegler *et al*., 1968), are now recognised on BGS maps as the **Pentamerus Sandstone Formation** (Cave and Hains, 2001; Cave, 2008). Transgressive basal conglomerates and sandstones include the locally named **Bog Quartzite** and **Kenley Grit members**. Alternating brachiopod assemblages offer evidence that the progress of the Castell Powys Group deepening event was interrupted by episodes of regressive shoaling (Ziegler *et al*., 1968; Cocks and Rickards, 1968). The recognition that there exists a lateral passage between easterly Castell Powys Group successions and westerly CI Systems Tract facies has implications that are discussed more fully in Parts 2 and 4.

Shelly sandstones present along the western flanks of the Builth Inlier, at Trecoed, have previously been viewed as a basal member of the attenuated local Cerig Formation succession (Schofield *et al*., 2004). In containing *Pentamerus*-bearing levels (Plate 3), overlying a significant unconformity, and evidently recording the impact of deepening linked to the *sedgwickii* Biozone transgression, these rocks comprise a local development of facies comparable to the Pentamerus Sandstone Formation. They are here redesignated the **Trecoed Sandstone Formation** and placed in the Castell Powys Group. Further east, the conglomeratic and shelly **Folly Sandstone Formation** (see Ray *et al*., 2021; Ziegler, 1966) unconformably overlies the Neoproterozoic rocks of the Nash Scar Inlier and represents a similar localised development of late Aeronian Castell Powys Group facies.

The Castell Powys Group successions of the Garth and Llandovery areas contrast with those further north in displaying relationships with the Cwm Rhuddan Group (Fig. 18). In both these areas, Castell Powys Group facies succeed late Aeronian non-sequences. The pebble and granule-rich mudstones of the **Comin Coch Formation,** with its transgressive, *Pentamerus*-bearing basal **Tyncoed Sandstone Member** (Plate 4A), together with the succeeding sandstones of the **Ty-mawr Formation**, evidently record the impact of late Aeronian sea level changes in the Garth area (Schofield *et al*., 2004). These sand-prone, clastic blanket facies pass laterally westwards into CI System Tract Cerig Formation (see below). In the Llandovery area, transgressive sandstone facies also rich in disarticulated pentamerid valves rest unconformably on BII System Tract rocks, astride the Pen-y-waun High. Davies *et al*. (2013)

recognise separate units of the **Derwyddon Formation** dating from the late *convolutus* and *sedgwickii* Bozone as upper ramp facies. However, their stratigraphical relationships invite their alternative inclusion in the Castell Powys Group transgressive blanket system.

**Text Box 13. Woolhope and Usk sub-basins and their palaeogeographical significance:** Butler *et al*. (1997), in documenting the seismic and borehole data that led to the discovery of Rhuddanian and Aeronian strata preserved in the Woolhope and Usk sub-basins, contend that the region to the north, bounded by the Pontesford and Neath lineaments, resisted Rhuddanian to early Aeronian inundation. The Rhuddanian red bed succession (Fownhope Formation, BGS, 2000b) accommodated by the sub-basins was seen to offer a record of isolated terrestrial deposition.

Yet the dating of these facies by acritarchs, including at Huntley Quarry (Barron and Molyneux, 1989), shows that Rhuddanian deposition was linked to a marine setting. Butler *et al*.'s (1987) suggestion of southwards connection to the Rheic Ocean accords with some Late Ordovician reconstructions (e.g. Rushton *et al*., 2000). However, coarse-grained deposits show that an extensive source region, located to the south and west, supplied sediment to South Wales Sub-basin throughout the Silurian (Davies *et al*., 1997). Recent palaeographical maps endorse this view (e.g. Woodcock and Strachan, 2012). The evidence presented by Butler *et al*. (1987) shows that the Neath Disturbance was active, but also allows for the delineation of broad, pre-late Aeronian marine embayment (Fig. 12). By extending across the Marginal Belt and adjoining parts of the Midland Platform, this feature would have served to connect the Woolhope-Usk region to the deeper depocentre that lay to the west. The belt of islands and shoals aligned along the site of earlier, now inverted sub-basins (see Part 2) was evidently ineffective as obstacle to the westerly transfer of sediment (see Fig. 12).

Subsequent regressive episodes may have led to partial degradation of the deposits that accumulated within and particularly around the margins of this embayment, but the remnants of a concealed succession of BIII Systems Tract rocks dating from the early Llandovery may be widely to be present throughout this region (see Text Box 7). The lithostratigraphical affinities of this cryptic succession is open to question. At this point, it is prudent to limit use of the terms May Hill Sandstone Subgroup to successions south the Neath Disturbance. Use of the label **Castell Powys Group undivided** is offered as temporary label for concealed rocks further north that would only appear on generalised and structural BGS sections.

Butler *et al*. (1997) cite graded event beds in the Huntley Hill Formation as evidence of mass flow in deep-water. However, emplacement by storms and/or hyperpycnal flows is in keeping with a shallower setting.

The May Hill Inlier displays a succession of proximal Rhuddanian to ?mid-Telychian conglomeratic and sandy facies recognised herein as a redefined **May Hill Sandstone Subgroup** (see Part 2). Deep boreholes and seismic profiles reveal the presence of a thick, concealed succession of these rocks within the rifted confines of the Woolhope and Usk sub-basins (see Text Box 13) (see discussion in Part 4). Basal fluvial conglomerates underlie the reddened Rhuddanian sand-prone facies in the **Fownhope Formation**, the palaeogeographical significance of which is discussed in Text Box 13. The **Huntley Quarry Volcanic Member** (after Ziegler *et al*., 1968), a succession of interbedded Rhuddanian lavas and red tuffaceous sediments, records the output of an eruptive centre located close to the southern limits of Fownhope Formation deposition (Figs 10B and 12). The erosive contact between these rocks and the basal volcaniclastic sandstones of the overlying **Huntley Hill Formation** appears to give rise to the prominent 'near top Rhuddanian' seismic line documented by Butler et al. (1997). The succession of grey sandstones and conglomerates ranges down into the Aeronian and is reported to underlie a gradational contact with late Telychian CI Systems Tract facies (Lawson, 1955; Ziegler *et al*., 1968). Work is needed to confirm that Castell Powys Group deposition in this area persisted into the mid-Telychian. Also included in the May Hill Sandstone

Sub-group, but excluded from the Huntley Hill Formation, are coarse-grained transgressive facies seen in the Malverns and Abberleys areas. These are recognised as the **Cowleigh Park Formation** and offer evidence of inundation during the late Aeronian (e.g. Ziegler *et al*., 1968; Cherns *et al*., 2006). Early and mid-Telychian rocks appear to be absent from these easterly locations.

### 3.3.4 Northern flank of the South Wales Sub-basin

Clear evidence that shallower BIII System Tract facies were deposited along the northern flank of the South Wales Sub-basin is lacking. The observation by Bassett *et al*. (1966) of a shelly mudstone with fragmentary graptolites, evidently located at or close to the base of the local Silurian succession in Cwm Hirnant, recalls the St. Martin's Cemetery Bed of the Haverfordwest area (see above). A reassessment to confirm the age and affinities of this unit is needed. However, any previously more extensive development of such strata including evidence of a previous link to the more northerly Capel Garmon Group (see below), was obliterated by Telychian mass-wasting affecting the Derwen-Berwyn Axis.

### 3.3.5 Skomer Volcanic Group

The BIII System Tract succession that accumulated in the south Pembrokeshire Skomer Sub-basin comprises the **Skomer Volcanic Group**. Currently included in this group is a transgressive succession of late Aeronian shallow marine sediments, with subordinate lavas and tuffs, that accumulated to the east of main Skomer Island eruptive centre (e.g. Ziegler *et al.*, 1969; Hillier, 2000). There is clearly a case to view this mixed volcano-clastic unit, here newly named the **Cable Bay Formation**, as part of a separate sedimentary system. However, geographical separation and palinspastic uncertainty mitigates against the inclusion of this south-westerly succession in the Castell Powys Group. The wholly or partly coeval **Rosemarket Formation** (formerly Beds) that crops out in the south of the Haverfordwest district, with its basal conglomerate and common *Pentamerus* valves, also recalls the more easterly transgressive systems rather than the much closer occurrences of the Cwm Rhuddlan Group ramp facies. It was likely emplaced by the same transgressive event as the Cable Bay Formation, of which it might be considered a synonym. However, its location astride the Benton Horst, along the northern margin of the Skomer Sub-basin, favours its recognition as separate, isolated component of the Skomer Volcanic Group.

### 3.3.6 Capel Garmon Group (new name)

BII Systems Tract facies of the North Wales Sub-basin, assigned to the newly recognised Capel Garmon Group, crop out along the Conwy valley and on the northern flanks of both the Derwen Anticline, its *defacto* type area, and the Berwyn Dome; and in all these areas are in urgent need of reinvestigation. The late-Hirnantian to Aeronian mudstone slope-apron succession of the Conwy area documented by Warren *et al*. (1984) was subsequently named the **Bryn Dowsi Formation** (BGS, 1989). Graptolitic anoxic facies and burrow-mottled oxic facies that alternate in a pattern comparable to that seen in mid-Wales (Pont Erwyd Group) suggests it may be capable of future refinement. Baker's (1981) work on the closely comparable more westerly succession seen in the Silurian outlier at Llanystumdwy on the Llŷn Peninsula persuaded her that the richly graptolitic **Llanystumdwy Formation**, which includes two trilobite-bearing event beds, had close affinities to that of the English Lake District. Aeronian levels of the succeeding oxic mudstone succession, to which the modified term **Lower Dwfor Formation** can be applied to be distinguish it from the Telychian levels that form part of the CI Systems Tract.

The BGS maps for the BIII Systems Tract successions that crop out along the northern flanks of the Derwen Horst and Berwyn Dome are provisional. On the north side of the Derwen Horst, the poorly studied **Bron y graig Formation** (BGS, 1993b) comprises a succession of mudstones with sandstone packets that is reported to rest unconformably on earlier rocks and to locally occupy an incision feature here labelled the Foel Ddu Canyon. Cave *et al*. (1992) infer a deep-water origin and report an Aeronian graptolite fauna, but the sedimentology, mapping and dating of this unit needs urgently to be revisited.

In the North Wales Sub-basin, facies of the BIII Systems Tract crop out along the northern flank of the Berwyn Dome and flank the more northerly Ordovician inliers at Cyrn-y-brain and Mynydd Cricor (Hillier, 1981). The name in current use for these rocks is **Fron Frys Formation**, but they likely span the BII-BIII systems tract boundary and future work should seek to differentiate and reallocate these separate parts. Hillier's (1980, 1981) report of a Rhuddanian brachiopod fauna from locally burrow-mottled mudstones near the base of the formation preceded the redefinition of the stage (see Holland and Bassett, 1989). Though it appears to have been endorsed by Cocks *et al*., (1998), it remains unclear how accurate this age assignment remains. Fortey *et al*'s (2000) assignment of the basal Fron Frys Formation to the *persculptus* Biozone is invalid. It refers strata that outcrop further south here reassigned to the Cwm yr Aethen Mudstones Formation (see above). Upper parts of the Fron Frys Formation include dark grey levels that yield Rhuddanian to mid-Aeronian graptolites (Lake and Groom, 1893; Wills and Smith, 1922), but strata of late Aeronian (*sedgwickii* Biozone) age are believed to be absent.

# 4 Tract Assemblage C (upper Hafren Supergroup)

## 4.1 CI SYSTEM TRACT (TELYCHIAN)

### 4.1.1 Trannon Group (amended spelling, status and usage)

The evolution and *raison d'être* of the Trannon Group mudstone drape system has been outlined in Part 2. Though recognised as forming a single overarching system, formational nomenclature and outcrop patterns allow its intergradational shallower and deeper components to be distinguished, and their initially separate northern and southern sub-basinal developments to be assessed.

*Shallow water facies: Marginal Belt and Midland Platform (Newbridge Subgroup)*

Formation-scale divisions distinguish the separate elements of the spectrum of Trannon Group shallower water facies that accumulated across Marginal Belt and platformal settings, including the North Powys Sub-platform. As with the earlier Corris Group drape system, there is a case to view these as the components of a discrete subgroup here termed the **Newbridge Subgroup**. The latter is named after the hamlet Newbridge-on-Wye close to where the subgroup's most complete succession is developed. Emblematic of the distal blanket and ramp-like facies that characterise this outer Marginal Belt region are the green, but locally purple mudstones of the **Cerig Formation**. Davies *et al*. (2013) identify a new type locality for this widespread division which only locally yields shelly faunas and was principally deposited beneath the colonising depths of contemporary Telychian benthos. In its type region, the easterly sourced mud succession appears to spans the whole of the Telychian and offers evidence of accumulation during a time of increased rates of regional subsidence (see Part 2; Woodcock *et al*., 1996; Davies *et al*., 2016). Only in the Llandovery area does the **Mwmffri Sandstone Member** offer evidence of significant and sustained local sand input. Mudstones with preserved graptolites widely developed in the uppermost part of the formation are viewed as precursor to the changes in facies and biota which mark the base of the CII Systems Tract (Eppynt Group). Evidence of fault-triggered instability at the onset CI Systems Tract deposition is recorded in the Llandovery area by the extensive **Glyn-moch Slide Complex** that affected much of the local late Aeronian succession (Davies *et al*., 2013).

The upfolded and upfaulted rocks of the Tywi Anticline largely intervene between the principal southern crop of the Cerig Formation and coeval basinal facies. Moreover, any lateral passage was disrupted by extensive mass-wasting of the associated marginal slope (see below). However, such a passage must occur between the synonymous, now defunct 'Tarannon Mudstone Formation' of the Welshpool area (Cave, 2008) and the deep-water Dolgau Mudstone Formation of the adjacent Dinas Mawddwy district (Plate 10). Work to investigate the precise nature of this transition and the role of contemporary mass-wasting is needed, but it serves to emphasise the seemingly gradational nature of Trannon Group facies. The Telychian **Millin Mudstone Formation** is the local equivalent and probable synonym of the Cerig Formation in the Haverfordwest area.

Fault-initiated uplift within the Marginal Belt account for the attenuated and condensed Cerig Formation successions recognised along the western flank of the Builth High as the 'Trecoed Beds' (e.g. Cocks *et al*., 1992). Cave (2008) recognises a comparable interval in the region of the Guilsford Horst and Severn Valley Fault Zone as **Ty-brith Mudstone Member**.

Traced eastwards, the Cerig Formation passes laterally into the shelly and shallower mudstones and sandstones of the **Purple Shales Formation**. On Long Mountain and around the flanks of the Shelve Inlier, this unit forms part of the CI Systems Tract succession of the Marginal Belt, but extends eastwards in the form of the synonymous Hughley Shales to form part of the Midland Platform succession of the Church Stretton district. Throughout these areas, the formation onlaps the BIII System Tract facies of the Castell Powys Group (Fig. 19) (see Part 2). A conglomeratic unit in the Pedwardine area that abuts earlier Llandovery and Tremadoc strata, yields species of *Pentameroides* and *Dolerorthis* that suggest a late Telychian age (Boynton and Holland, 1997; Ray *et al*., 2021). Taken to represent proximal facies of the Purple Shales Formation this unit, here rebranded the **Letton Member**, appears to succeed a significant non-sequence. However, its relationship to younger rocks is unknown and the poorly preserved fauna, possibly reworked, could post-date the boundary event of the CII Systems Tract. The relationships at Pedwardine would then compare to other upfaulted sites within the Church Stretton Fault Zone (e.g. Cheney Longville, Presteigne and Old Radnor) where CII Systems Tract divisions overstep earlier rocks and CI Systems Tract deposits are absent. The Collington No. 1 Borehole (Fig. 13), encountered a thick Telychian mudstone succession which, contrary to Penn (1987), is best placed in the Purple Shales Formation. In the borehole, a capping unit of partly purple siltstones and mudstones is separated from the underlying bulk of the formation by an interval of sandy Yartleton Subgroup rocks (see below). Working on the Malverns succession, Groom (1900) recognised a comparable finer-grained division as the 'Tarannon Shales'. Squirrell and Tucker (1960) labelled the Woolhope Inlier equivalent the 'Upper Haugh Wood Beds'. Based on other accounts (e.g. Pocock, 1930; Phipps and Reeves, 1967; Barclay *et al*., 1997) and recently Ray *et al*. (2025, in press), the name **Woolhope Shale Member** (adapted usage) is recommended. The distribution of this member and of sandy Yartleton Subgroup facies provides evidence of an intertonguing of Newbridge and Yartleton subgroup facies (Figs. 9 and 13). Clorinda Community benthic assemblages in the Woolhope Shale Member record the local culmination of Trannon Group deepening (Zeigler *et al*., 1968).

In the Woolhope, May Hill, Malverns and Abberleys inliers, sand-prone blanket facies of the **Yartleton Subgroup** (adapted nomenclature) are known to date from the *griestoniensis* Biozone (Cocks *et al.,* 1992). However, in the May Hill and Woolhope areas, including in the Fownhope Borehole, where thick successions of the subgroup overlie a conformable contact with BIII Systems tract rocks of the Castell Powys Group (e.g. Zeigler *et al*., 1968) (Fig. 9), the onset of Trannon Group deposition was likely earlier. For the calcareous and micaceous sandstones and siltstones of these areas, BGS (2000b) introduced the label **Haugh Wood Formation**. The significant non-sequence present beneath Yartleton Subgroup rocks in the Malverns and Abberleys areas confirms that, though late Telychian marine conditions extended well to the east (Cherns *et al*., 2006), this remained a site prone to erosion and shoal deposition. The term **Wyche Formation** (spelt Wych in some accounts) should be limited to the succession of interbedded sandstones, siltstones and mudstones seen in these eastern settings (Zeigler *et al*., 1968; Barclay *et al*., 1997). Self-evidently, and contrary to current practice, rocks assigned to the Purple Shales Formation's Woolhope Shale Member should now be excluded from these Yartleton Subgroup divisions. Mapping to accommodate this change is required.

The unconformable Coralliferous Formation of the Skomer Sub-basin has commonly been taken also to provide a record of late Telychian subsidence (e.g. Veevers *et al*., 2024 and references therein), but the dating of this unit is problematical and the case is made here to exclude these strata from the CI Systems Tract (see Marloes Group below).

*Deep-water facies: South Wales Sub-basin*

As outlined in Part 2, and discussed more fully in Part 4, it is the green and locally maroon Telychian slope apron mudstones of the amended **Rhayader Mudstones Formation** that record the decoupling of deposition from eustatic influences and increasing rates of subsidence that are the features of the CI Systems Tract deposition. In accord with the exclusion of the M. sedgwickii Shales Member (see above), the new base for the formation in its type area is taken at base of the distinctive succession of rhythmically bedded manganese carbonate-rich mudstones (Copus, 1997; Davies *et al*., 1999). Based on its overlooking type locality, the newly named **Claerwen Dam Member** is appropriate for strata that likely continue to fall within the *sedgwickii-halli* biozonal interval. Similar amendment to the base of the formation should be made to its now defunct Aberystwyth area synonym, the Cwmsymlog Formation (Cave and Hains, 1986). Other formations describe the invasion and blanketing of the Trannon Group slope apron by sandy sub-systems linked to the tectonic rejuvenation of multiple sediment source areas (e.g. Davies *et al*., 1997, 2006a,b, 2007; Schofield *et al*., 2006b; Wilson *et al*., 2016). The **Nant Brianne Formation**, here redefined to exclude earlier conglomeratic and slumped facies (see Llyn Brianne Formation), reoccupied an earlier BIII Systems Tract supply route to deliver the easterly derived turbidite sands of the **Devil's Bridge Formation**. The **Foel Fadian Formation** and **Erwan Fach Formation** (Plate 12) were supplied with sand from the west and south respectively.

In the CI Systems Tract succession of the South Wales Sub-basin, mud-prone slope apron growth was temporarily interrupted by the advance and expansion of the Central Wales Grits Group sandstone lobe system (see below). However, this sand-prone system was abandoned during the *griestoniensis* Biozone allowing green and periodically red slope apron mud deposition to resume its dominance. It was to the resulting mudstone unit in the Trannon area that the anglicised label 'Tarannon Pale Shales' was first applied, and the subsequent widespread depiction of which on early Geological Survey maps of Wales that led to so much confusion (see Part 2). The work of Wood (1906) largely resolved these issues, and it is her name, **Dolgau Mudstones Formation**, for this younger development of green and red Trannon Group facies that it now widely applied throughout areas where sandstone-lobe deposition had been previously prevalent (Plate 10). In the south-western region of the Berwyn Dome and northwards along both flanks of the Llandderfel Syncline, it is this unit that oversteps earlier rocks to overlie a significant disconformity (see below). As in the preceding systems tract, the lateral transition between this overstepping succession and the complete, shallow water CI

Systems Tract succession seen along the northern limb of the Brogan Anticline, west of Welshpool, requires a fuller understanding.

Erosion along the course of the Tywi Anticline and the flanks of the North Powys Sub-platform, west of Welshpool, destroyed the connection between shallower blanket facies (Cerig Formation) and deeper slope apron (Rhayader Mudstones Formation) as these areas evolved into a confining slope that limited the eastwards spread of Telychian sandstone lobe systems. In the Rhayader district, the eroded material is preserved locally as a foot-of-slope succession of debrites, coarse-grained turbidites and slumped strata, recognised as the **Cwm Barn Formation**, that interfinger with onlapping fringing facies of the sandstone lobe systems. The younger and more easterly **Henfryn Formation** grades upwards into enveloping slope apron facies (Dolgau Mudstones Formation) that redeveloped across the region in response to late Telychian subsidence (Davies *et al*., 1997). The products of the extensive and coincident mass-wasting associated with the Berwyn-Derwen Axis have not been identified but may find local expression in the poorly dated successions linked to the putative Foel Ddu and Garn Prys 'canyons' (Cave *et al*., 1992). The subsequent late Telychian merging of the northern and southern sub-basins and the reconnection of their slope apron facies with shallower counterparts (Newbridge Subgroup), marked the maximum development of the Trannon Group drape system (see Part 2).

*Deep-water facies: North Wales Sub-basin*

In North Wales, in the Conwy Valley region, no such interruption occurred, and slope apron mud deposition persisted throughout Telychian times. The oxic green mudstones that dominate this interval, previously termed the Pale Slates (Warren *et al*., 1984), have more recently been included in the Bettws Formation. This seems ill advised as the latter term was first erected for the restricted and disconformable succession of the Derwen Anticline area where the use of Dolgau Formation seems more appropriate. The Conwy Trannon Group succession comprises the upper part of the abandoned Gyffin Shales of Elles (1909) and the latter's partial readoption in the form **Gyffin Formation** is offered as a modern label for these Telychian rocks. Though well documented evidence of provenance is lacking, the likelihood is that this slope apron succession had links to the sub-basin's northern margin. The possibility that comparable Telychian facies that crop out to the north of the Berwyn Dome and around the Cyrn-y-brain and Mynydd Cricor inliers were sourced from a different sector requires confirmation, but justifies a separate local name. Despite the reservations of Wills and Smith (1922), the term Ty Draw Slates Formation has remained in widespread use (e.g. Cocks *et al*., 1992; BGS, 1992b). The graptolite faunas listed by Wills and Smith (1922) require urgent reassessment in the light of recent taxonomical and stratigraphical advances, however, they appear to show that late Aeronian to earliest Telychian graptolite (sub)zones are absent from the local succession. Whether or how this non-sequence relates to the more significant mass-wasting episode that preceded Dolgau Formation deposition further west (Llandderfel Syncline) is unknow. However, the presence of shell-bearing levels in the Mynydd Cricor succession hint at similarities to the shallower water Cerig Formation and to deposition in a transitional setting comparable that seen on the south side of the Berwyn Dome (see above). Pending the resolution of these uncertainties the term **Ty Draw Slates Formation** is retained for these Llangollen region Telychian rocks.

The Dwfor Formation of the Llanystumdwy area (BGS, 2015) and the Llanymawddwy Formation of the Bala district (BGS, 1986) conflate units of the BIII Systems Tract that are Aeronian in age, with Telychian mudstone facies of both slope apron and sandstone lobe fringing type. The work of Baker (1981), by identifying the Telychian portion of the Llŷn succession, permits the recognition of an '**Upper Dwfor Formation**'. The ill-defined 'Llanymawddwy Formation' of the Bala district undoubtedly includes Telychian levels equivalent both to the slope apron facies of the Rhayader Mudstones Formation and to the lobe fringing Gelli Shale Subgroup (see below) and remapping to achieve their separate recognition is required.

### 4.1.2 Central Wales Grits Group (new name)

The architecture of the tectonically controlled, Telychian sandstone-lobe turbidite systems in mid-Wales is now well documented following the recent work of BGS (e.g. Wilson *et al*., 1992; Davies *et al*., 1997; 2006a; 2006b) and its co-workers (e.g. Smith, 1987a and b, 2004; Clayton, 1994; Woodcock *et al*., 1996). The recognition of a range of facies within a series of complex inter-tonguing sandstone lobes, together with their mudstone-dominated distal and fringing facies, forms the basis of a robust formational scheme. However, the group terminology currently employed for these temporally and palaeogeographically related sand-rich divisions (Davies *et al*., 1997) requires revision in the light of this report. These former groups can now be recognised as subordinate subsystems of the Central Wales Grits System and, accordingly, are downgraded to subgroups. Thus, the earliest and most westerly sandstone lobe subsystem is represented by the **Aberystwyth Grits Subgroup**, which includes the **Mynydd Bach Formation** (sandstone lobe facies) and **Trefechan Formation** (sandy lobe fringe facies). Work in progress suggests that, within the lower part of the Mynydd Bach Formation, it will be possible to distinguish a basal, thick-bedded **Cwmtydu Member** (Plate 12) from an overlying more mud-prone **Grogal Member**. Separate developments of lobe facies in the younger and more easterly **Cwmystwyth Grits Subgroup** are represented by the **Rhuddnant Grits Formation**, including the thick-bedded **Llyn Teifi Member**, and the **Pysgotwr Grits** and **Doethei formations**. The corresponding sandy fringing facies are recognised as the **Glanyrafon Formation**. The turbidite mudstone facies that fringe and interfinger with these sand prone units include the **Borth Mudstones**, **Adail Mudstones**, **Blaen Myherin Mudstones** and **Caerau Mudstones formations**. In the Dinas Mawddwy and Bala districts, locations that were largely distal to the main areas of sandstone deposition, these units merge to form thick mudstone succession. And it is here in particular that amended Bassett (1955) term **Gelli Shale Subgroup** is seen to serve useful embracing purpose.

## 4.2 CII SYSTEMS TRACT (LATEST TELYCHIAN - EARLY LUDLOW)

### 4.2.1 Llangollen Group (new name)

Deep-water Wenlock and Ludlow facies of slope apron aspect form a substantial component of the successions seen in the North Wales type region of the Llangollen Group (Warren *et al*., 1984; Davies *et al*., 2004) and north-eastern reaches of the South Wales Sub-basin. In both regions (see Part 2), above units recognised as transitional with the underlying Trannon Group, thinly interbedded turbidite mudstones and laminated hemipelagites – the 'ribbon-banded mudstones' of Warren *et al*. (1984) - bear testimony to accumulation under anoxic bottom conditions. For these slope apron deposits the scope of the label 'Nantglyn Flags' has previously been extended from its North Wales type area to include deposits of this type in both sub-basins (e.g. Davies *et al*., 1997; Cave and Hains, 2001). The validity of this approach is problematic. The succession in North Wales was supplied by sediment from the westerly and northerly margins of the LPWB (Warren *et al*., 1984), whereas its southern counterparts had strong physical and supply links to the basin's eastern and southern margins. Davies *et al*. (1997) explain the need to distinguish the southerly sourced Penstrowed Grits from the coeval westerly sourced Denbigh Grits of North Wales (see below). The same logic implies that the slope apron successions that flanked and enveloped these different sand-prone units should also be labelled separately and, in both regions, the location of the sandy subsystems permits the subdivision of the slope apron successions. The Llangollen Group succession of the Llangollen Syncline requires separate consideration.

In North Wales, the 'ribbon-banded' facies that intervene between the older Trannon Group succession and the succeeding Denbigh Grits Subgroup are here excluded from the latter and recognised as a discrete **Benarth Flags Formation** (revised status). Warren *et al*.'s (1984 p. 15) account of the poorly exposed 'passage beds' interval, if it is to be included in the systems tract (see Part 2), permit its naming as a basal **Benarth Hall Member** (new name) (Fig. 20). Use of the label **Nantglyn Flags Formation** is restricted to its Denbigh region type area for the late Sheinwoodian to early Ludlow succession that intervenes between the Denbigh Grits and Elwy subgroups.

Corresponding units are seen in the South Wales Sub-basin. Wood (1906) introduced the term 'Nant-ysgollon Shales' for deep-water facies in the Trannon area that intervene between the Dolgau Mudstones Formation and overlying Penstrowed Grits Subgroup (her Fynyddog Grits). The adapted form **Nant-ysgollon Mudstones Formation** was subsequently used in the Rhayader district and in the Llangollen Syncline region of North Wales (e.g. Davies *et al*., 1997; BGS, 1992b). In detail, this division is hybrid in nature. In addition to 'ribbon-banded' slope apron deposits, it includes facies transitional with the Trannon Group, but also thicker bedded mudstones that represent fringing facies of the succeeding sandstone lobe system (Davies *et* *al*., 1997). Additionally, and confusingly, in the sections where Wood (1906) first established its presence, the division comprises a lithofacies unlike that seen in other areas, in which lenses and laminae of siltstone and fine sandstone are abundant (Wilson *et al*., 2016). The proposal here is to restrict the Nant-ysgollon Mudstones Formation to its original stratigraphical sense. Its facies and relationships make it comparable to the Benarth Flags Formation of North Wales (see above). The name **Esgair Hir Member** is offered as a new label to distinguish the atypical local facies of the Trannon Syncline succession (Plate 13). Cave's (2008) application of the term 'Nant-ysgollon Mudstone Formation' to strata west of Welshpool, in a region of transition with distal facies of the Welsh Borderland Group and where the Penstrowed Grits are absent, is rejected (see below) (Fig. 19).

For the palaeogeographically distinct 'ribbon-banded' succession of the Newtown and Welshpool regions that were previously labelled the Nant-glyn Flags Formation (e.g. Cave and Hains, 2001; Cave, 2008), but that succeed the Penstrowed Grits Subgroup, the Dimberline and Woodcock (1987) term **Llanbadarn Formation** is recommended. The division takes its name from the extensive road cuttings in the vicinity of the eponymous hamlet. The revised relationship of this unit to adjacent divisions is shown on Figure 16. Disturbed strata seen in the Montgomery area, recognised as the **Gregynog Mudstone Member**, record instability on Llanbadarn Formation slopes present west of the Severn Valley Fault Belt that had initially served to limit the spread of early Wenlock sandstone lobe facies (Cave and Hains, 2001; Cave, 2008). A 2 m-thick vitroclastic tuff present in the lower levels of the reduced Llanbadarn Formation succession seen north-west of Welshpool is recognised as the **Pentre'r beirdd Tuff Member** (Cave and Loydell, 1998).

The impact of the mid-Homerian (*nassa*-lower *ludensis* biozones) shoaling and basin-wide re-ventilation event is widely marked within these separate Llangollen Group slope apron successions by the presence of pale, burrow-mottled and shell-bearing mudstones that commonly occur as two separate (lower and upper) units. The universal use of the term Mottled Mudstone Member for these strata again seems ill advised, moreover it replicates the name used for a late Hirnantian BII Systems Tract division. New nomenclature is overdue. Here the terms **Esgair-Ebril Member** (new name) is offered as replacements for the units seen in North Wales based on sections listed by Warren *et al*. (1984); and **Dolygarn Member** (new name) for the comparable Llanbadarn Formation strata observed by Cave and Hains (2001) in road sections in the Newtown area. Levels of the Nantglyn Flags and Llanbadarn formations that succeed these oxic intervals record the re-imposition of anoxic bottom conditions and can be linked to the deepening that occurred during the late Homerian. The Dolygarn Member records the impact in deeper basinal settings of the oxygenation event recorded in the Marginal Belt successions by the Glyn Member of the Trewern Brook Mudstone Formation (see below). West of Welshpool, the eastwards spread of late Wenlock to early Ludlow Llanbadarn Formation facies records the local onlap of Welsh Borderland Group divisions by the Llangollen Group

(Fig. 19). This was also a further response to late Homerian base level change, but it also signalled the demise of the North Powys Sub-platform as an influential feature. The subsequent *nilssoni* Biozone transgression, though it was responsible for significant changes in shallow water successions (see below; Text Box 14), had minimal lithological impact on deeper successions. In North Wales, the use by Warren *et al*. (1984) of *nilssoni* Biozone graptolites to subdivide the Nantglyn Flags Formation into lower and upper units lacks lithostratigraphical validity and should be abandoned.

The early Wenlock renewal of collision-related tectonics is reflected in both sub-basins by increased sand input and the influence of faulting on the sedimentary geometries. Past practise has seen the name 'Denbigh Grits' has been used as a shared label for the sand-prone units developed in both sub-basins. However, previous authors were aware of clear differences in provenance (e.g. Cummins, 1957, 1969; Dimberline *et al*., 1990). Difference in facies composition further support more recent studies that recognise them as separate systems requiring separate names (Davies *et al*., 1997). Moreover, the facies milieu of the sandy units seen in the separate sectors of the basin also differ. In North Wales, isolated packets of sandstone-rich strata are enveloped in volumetrically dominant silt-laminated mudstone facies – the 'striped silty mudstones' of Warren *et al*. (1984) - in which extensive units of slump disturbed strata form a significant additional component. In contrast to the coeval sandstone lobe system seen in southern sectors of the basin, these northern units are viewed as integral parts of the Llangollen Group slope apron. And as such, the **Denbigh Grits Subgroup** and **Elwy Subgroup** record separate early Wenlock and Ludlow advances of such facies respectively. For both divisions, sediment supply was predominantly from the west with the Conwy Valley Fault Belt an active influence (Warren *et al*., 1984). Their rank reflects the view of Warren *et al*. (1984) that that their subdivision into component formations is feasible (Fig. 20). The role of the Garn Prys Canyon, as a possible sediment supply route for parts of the Denbigh Grits Subgroup (Cave *et al*., 1992), requires further investigation, but it seems unlikely that this was the only input point.

Early Wenlock sandy facies of the South Wales Sub-basin, although a response to the same episode of renewed tectonism, evolved independently from those to the north. Thus, the **Penstrowed Grits Subgroup** (rank upgraded) testifies to a resurgence of sediment supply from the south and the outbuilding of a large-scale sandstone-lobe system more closely comparable to those seen during the Telychian (Plate 14). The Garth Fault and subsequently the Cwmysgawen Fault exercised significant control on the subsystem's development in the northern region of the Tywi Anticline (Davies *et al*., 1997). These relationships contrast with those seen to the west of the Welshpool where, along the margins of the North Powys Sub-platform, facies distributions testify to the passive onlap of the Llanbadarn Formation slope apron surface (Fig. 19), and to a westward withdrawal of sandstone lobe facies as their locus of deposition shifted to a region centred on the Llandderfel Syncline (Fig. 14). At the time of its maximum development, the sand-prone facies belt extended beyond the Berwyn Dome and into the Llangollen Syncline region (see below). The subgroup's upgraded status reflects the possibility for subdivision. Coeval mudstone fringing facies are included in Nant-ysgollon Mudstones Formation of the Rhayader district and, arguably in the Llanbadarn Formation succession (Gregynog Mudstone Member) of the Montgomery and Welshpool areas. Future remapping should seek to delineate these as component facies of the Penstrowed Grits Subgroup. The products of volcanic eruptions from unknown sites during deposition of the subgroup, labelled by Cave and Loydell (1998) **The Moat Tuff** and **Domen-ddu Tuffaceous Mudstone**, warrant recognition as local **members**.

There is a lithostratigraphical case, implicit in numerous earlier studies (e.g. Smith, 2004), to view this Wenlock sandstone-lobe system as a younger component of the Telychian Central Wales Grits Group (BIII Systems Tract). Sandy facies present in the upper part of the Dolgau Mudstones Formation and in the newly named Esgair Hir Member (see above; BGS, 2010; Wilson *et al*., 2016), point to a belt centred on the Trannon Syncline where sand supply to Central Wales was paused for the shortest period time. Nevertheless, abandonment of the Telychian phase of sandstone-lobe deposition, linked to a reduction in fault activity, the onset of regional (thermal) subsidence and resulting spread of the Trannon Group drape system mudstones, all bear testimony to a significant event during the collision-related phase of the LPWB's development. Collectively, these impacts are seen as sufficient to justify the exclusion of the Wenlock sandstone lobe system from the Central Wales Grit Group.

#### 4.2.2 Llangollen Syncline

Geological maps covering the CII Systems Tract succession preserved in the Llangollen Syncline area, including its region of intersection with the Llandderfel Syncline, are in need of revision and, predictably, it is here that facies with affinities to both sub-basins and the transitions between them must occur. Numerous problems are evident:

1. The relationship between the Denbigh Grits Subgroup and the Penstrowed Grits Subgroup around the nose of the Derwen Anticline requires urgent resolution. Disconformable contacts with the underlying Trannon Group (Dolgau Mudstones) shown as present at the bases of both units attest to an area of early Wenlock mass-wasting. The Llanelidan Fault likely has a greater westwards range than depicted on the current maps and, as a curvilinear extension of the Conwy Valley Fault Belt, may have been critical in sustaining this structurally positive area and, subsequently, as a facies dividing line.

2. The Denbigh Grits Subgroup appears to be absent from the main Llangollen Syncline succession to the east. Modern BGS digital maps recognise sand-prone units previously assigned to the latter (BGS, 1992b) as the northernmost outcrops of the Penstrowed Grits Subgroup (= Pen y Glog Grits of Wedd *et al*.,1927). Their presence also permits the local recognition of the Nant-ysgollon Mudstones Formation. Though currently

excluded from the latter, line work exists for the underlying 'passage beds' for which the label **Crenulatus Member** (adapted from Wedd *et al*., 1927) could be used (Fig. 20). Where the overlying grit unit fails, the latter merges with the thick succession described by Wills and Smith (1922) in which they recognised a series of informal subdivisions. 'Ribbon-banded' mudstones of slope apron aspect exposed in extensive slate workings, recognised by Wills and Smith's (1922) as their Glyn-Dyfrdwy Group, have obvious affinities to either the Nantglyn Flags or the Llanbadarn formations. In the absence of systematic data on sediment supply the assignment of strata to either division is problematic, and the succession may prove to be of mixed provenance.

3. BGS (1991) recognised strata equivalent to the 'Nant-y-Bache' and 'Vivod' groups of Wills and Smith (1922) as the 'Elwy Group' of the Denbigh region. However, Warren *et al*. (1984) questioned whether the latter was recognisable in the Llangollen area where they suspected a lateral passage into 'ribbon-banded' facies. Cave and Hains (2001), in contrast, considered the interbedded sandstones and mudstones of the 'Nant-y-Beche Group' (Fig. 20) to be distal facies of the southerly sourced Bailey Hill Formation (see below) and contend that this extended north of the Llanelidan Fault into the Clwydian Range area. If confirmed, there would be a case to include these parts of the Llangollen succession in the Epynt Group.
4. There are features of the uppermost levels of the Llangollen Syncline succession - the Dinas Brân Formation - that invite its exclusion from the Llangollen Group. The lithostratigraphical affinities of these strata are assessed below.

Earlier accounts make clear that the Llangollen Syncline succession embraces much lithological variation, yet the published maps and nomenclature (see summary by Warren *et al*., 1984) that sought to describe this were seen as lacking the precision or rigour required for adoption by BGS (see Fig. 20). Much work is needed to address these unresolved mapping and nomenclature issues. For now, with the exception of the mapped outcrops of the Penstrowed Grits Subgroup and underlying Nant-ysgollon Mudstones Formation, the remainder of the Llangollen Syncline succession below the Dinas Brân Formation is best labelled **Llangollen Group undivided**.

### 4.2.3 Welsh Borderland Group (new name)

The significant changes seen in shallower water Wenlock and Ludlow facies as they are traced from west to east away from an interface with the deep-water Llangollen Group, record the growth of the calcareous blanket system that constitutes the Welsh Borderland Group (Figs 19 and 21). Such changes are well seen in the Newtown and Welshpool districts and the current BGS mapping of the Knighton Sheet will doubtless shed further light on the nature of these transitions. Simply put, a west to east transect though the Wenlock and Ludlow successions of these regions describes a passage from deeper, anoxic facies into a spectrum of shallower water facies that display progressively greater levels of bioturbation and are increasingly more calcareous; a progression that culminated, periodically, in widespread limestone deposition. These facies variations are mirrored by changes in the preserved biota from assemblages dominated by planktonic and nektonic forms (graptolites, orthocones, epiplanktonic bivalves) to benthic assemblages that comprise a diverse range of brachiopods, trilobites, molluscs of various kinds, corals, bryozoa and stromatoporoids, as well as ostracods. Lateral variations in these assemblages allow a variety of fossil communities or associations to be identified. These are believed to reflect differences in depth and/or substrate, and they also evolved over time (e.g. Calef and Hancock, 1974; Boucot and Lawson, 1999, and references therein). The extensively studied Wenlock and Ludlow rocks of the Ludlow Anticline region constitute the newly named group's type succession.

Facies changes associated with the CI/CII systems tract boundary, that preceded the Ireviken Event, have been described in Part 2 and serve to define the base of the Welsh Borderland Group. At the base of the group in more northerly and distal settings, is a succession of burrow-mottled and laminated mudstones that record the alternation of oxic and anoxic bottom conditions. For the succession of these rocks in the Builth and Llandovery areas, the name 'Dolfawr Mudstones Formation' (BGS, 1993a; Davies *et al*., 1997; Schofield *et al*., 2004, 2009a) has been preferred in place of Harris' 'Hafod-yr-ancr Member'. The stratigraphically equivalent strata are elsewhere considered basal members of overlying otherwise Wenlock successions and there appears merit in bringing the Builth and Llandovery area successions into alignment by redesignating the **Dolfawr Mudstones** as a **member**. The corresponding rocks in the Welshpool area, labelled the 'Banwy Member' by Loydell and Cave (1996), though they display fewer and thinner anoxic levels, were recognised as synonymous with the Builth unit, which has priority. The predominantly laminated and graptolitic mudstone succession, but of which the revised Dolfawr Mudstones Member would now form a part, comprises the **Builth Mudstones Formation**. This is also the label applied here to the expanded 'Nant-ysgollon Mudstone Formation' succession mapped by Cave (2008) to the west of Welshpool (see Fig. 19). The formation marked the start of a period of anoxic mud deposition across outer Marginal Belt and North Powys Sub-platform settings that was sustained with only minor interruptions until late Ludlow times (Davies *et al*., 1997; Schofield *et al*., 2004; Barclay *et al*., 2005; Schofield *et al*., 2009a). It is the Builth Mudstones Formation, and its synonyms, that evidence the ramp-like distal interface between the basinal Llangollen Group slope apron and the calcareous blanket facies that now began to accumulate to the east. It was also into and across this initially widespread region of distal calcareous mud accumulation that delta sourced Epynt Group facies prograded from the south-west (see below; Fig. 21). For anomalous, mid-Wenlock facies associated with the Builth Mudstones Formation in the west of the Knighton district (unpublished BGS field data) that include shell-rich event beds, the label **Cefn Member** is offered as a holding term pending their fuller investigation. Future workers may come to view this as the Wenlock equivalent of the Bailey Hill Formation and, hence, also part of the Epynt Group.

The impacts of Homerian shoaling and increased levels of ventilation are well seen in the Welsh Borderland Group. Burrow-mottled facies cap the Builth Mudstone Formation succession of the Montgomery and Welshpool areas. Though also labelled 'Mottled Mudstone Member' on the published maps, these oxic strata occupied a shallower setting than the Llangollen Group's Dolygarn Member and require separate nomenclature. The Long Mountain term Glyn Member (see below) is extended to include these rocks (Fig. 19). The instability of outer Marginal Belt settings is reflected in extensive slumping as exemplified by the early Wenlock **Cefn Cerig Slide Complex** of Llandovery (Davies *et al*., 2011), and Homerian slump units seen in the Welshpool region (Cave and Loydell, 1998) and in Builth district in the form of the **Caer-beris Member** (Schofield *et al*. 2004). The presence, in the latter, of disturbed units of mottled-mudstone confirms its overlap with the level of Homerian shoaling seen elsewhere. There is a case, explored in Figure 21, to assign these disturbed units in the Epynt Group.

Cave (2008) was content to include the **Butterley Mudstone Member** (Loydell and Cave, 1993) of the Long Mountain succession in the Banwy Member, but the two units differ lithogically. The blocky calcareous mudstones of former are arguably more comparable to the Buildwas Formation (see below). The member occupies a basal position in a succession to which Cave and Hains (2008) gave name the 'Bromleysmill Shales Formation'. This was later abandoned by Cave (2008) in favour of its Palmer's (1970) senior Long Mountain area synonym the **Trewern Brook Mudstone Formation**. The lateral westwards passage between the latter and the Builth Mudstones Formation underlines their close physical and genetic affinities. Laminated mudstones remain prevalent in the Trewern Brook Mudstone Formation, but it also offers evidence of periodic burrowing and colonisation by shelly benthos (Wang et al., 2024a), and such effects become more prevalent as it is traced eastwards. The Knucklas-Pontesford Linley belt of faulting may serve as an arbitrary western limit to the Trewern Brook Mudstone Formation in the Knighton area. In the Montgomery and Welshpool districts, the more westerly Severn Valley Fault Zone serves this purpose. The formation forms a key element of the lateral transition into coeval platformal divisions that comprise the more obviously oxic and bioturbated **Buildwas** and overlying **Coalbrookdale formations** (Bassett *et al*., 1975; Bassett, 1989). It has proved convenient, as a mapping device, to confine both these units to the east of the Church Stretton Fault Zone, although Cave and Hains (2001) acknowledge that facies of Coalbrookdale type are present to the west.

In seeking to define the base of the predominantly grey Buildwas Formation, previous authors have been keen to align it with the base of the Wenlock Series as defined at the latter's Hughley Brook stratotype section. Thus, in their succession of rock units A to I, Bassett *et al*. (1975) took the base of Unit G to mark the Series GSSP and the base of the formation. Both the selection of the Hughley Brook section as the series stratotype and the criteria used to define the series base there are contested. That the base of the Buildwas Formation is transitional with the underlying Purple Shale Formation is well understood and the lithological changes that mark the onset of this transition occur at a lower level in the section. It appears reasonable to extend the base of the Buildwas Formation downwards to include the metre-thick interval of mottled and green mudstones that comprise units B to F of Bassett *et al*. (1975) and to recognise these beds as a discrete newly erected basal division, the **Hughley Brook Member**. Graptolites are absent from this interval, but conodonts and chitinozoa, and fossils from the under and over lying successions (see summaries by Aldridge *et al*., 2000; Loydell, 2011) endorse its use to define the local base of the basal CII Systems Tract (see Part 2).

Mid-Homerian oxic facies seen along the limbs of the Long Mountain Syncline, inter-tongue with mixed oxic-anoxic Trewern Brook Mudstone Formation facies. These too are labelled 'Mottled Mudstone Member' by BGS (2008a), but they were recognised by Parmer (1970) as the **Glyn Member** (Fig. 19). This oxic interval together with the succeeding interval of more typical Trewern Brook Mudstone Formation facies, pass eastwards and southwards in an oxic, locally shelly succession that expands to form the whole of mid-late Homerian succession that crops out to the west and south of the Shelve Inlier. There, such rocks comprise the **Aston Mudstone Formation**. To the east, it is levels of nodular limestone present within this division in the Montgomery district, and near Edgton in the Church Stretton district, that record mid-Homerian shallowing. Cave and Hains (2001) recognise these calcareous strata as the **Edgton Limestone Member** (Fig. 19) and comment on the confusion caused by Bassett's (1989) erection of a Edgton Member within the Much Wenlock Limestone Formation (see below). To the east of the Church Stretton Fault Zone, similar and in part coeval rocks occupy the upper part of the platformal Coalbrookdale Formation. For these, in place of the Church Stretton term Tickwood Beds (Pocock *et al*., 1938; Greig *et al*., 1968), the name **Farley Member** has gained widespread acceptance (e.g. Bassett *et al*., 1975; Bassett, 1989; Ray *et al*., 2010). In the south of the Church Stretton district (BGS, 1967), linework for the top of the member (in the form of the Tickwood Beds) may require adjustment in light of the reported inclusion of Gorstian facies (Bassett *et al*., 1975; Aldridge *et al*., 2000). The role of regional intra-Homerian and basal Gorstian events played in shaping these platform edge successions and their implications for regional correlation are summarised in Text Box 14.

In platformal successions of the south-eastern Silurian inliers, use of the Coalbrookdale Formation appears to have gained widespread acceptance as a replacement term for previously used local names (e.g. Cocks *et al*., 1992). The distinctive facies assigned the underlying Buildwas Formation appear confined to the Apedale and Ludlow region of north Shropshire, there being a general acknowledgement that this unit passes laterally into the **Woolhope Limestone Formation** seen to the south. Squirrell and Tucker (1960) recognised the thin underlying transitional succession that hosts the ***Petalocrinus* Limestone Bed** (formerly 'Band' of Pocock, 1930) as the uppermost part of their Upper Haugh Wood Beds. Phipps and Reeve (1967) recognised the *Petalocrinus* Limestone near the top of their Woolhope Shale Member. However, as outlined above, in appearing to mark the onset of facies changes taken to mark the base of the CII Systems Tract (see above), the recommendation here is to exclude these transitional strata from the underlying Llandovery divisions and recognise them as a basal unit of the Woolhope Limestone, as Ray *et al*. (2021) appear to have done.

**Text Box 14. Wenlock-Ludlow boundary events and correlations:** Cave and Hains (2001) question long held assumptions re the correlation of Wenlock-Ludlow boundary successions in the Welsh Basin and on Midland Platform. They suggest strata that span the upper *ludensis* Biozone in the basin, including in successions of the Marginal Belt, correlate with the platformal 'Lower Elton Beds' (Pitch Coppice Mudstone Member of this account). They argue it is the anoxic, graptolitic facies of the 'Middle Elton Beds' (lower Goggin Road Formation) that mark the well documented *nilssoni* Biozone flooding episode seen in the basin (see also Shergold and Bassett, 1970). The Much Wenlock Limestone Formation would then record the basin wide mid Homerian shoaling event, and the Pitch Coppice Mudstone Member the gradual deepening that followed.

However, the recovery of *Seatograptus (Colonograptus) colonus* and fragments assigned to *Neodiversograptus nilssoni* and *S. varians* from the 'Lower Elton Beds', close to the Ludlow Series and Gorstian Stage GSSP, is widely taken as proof of the *nilssoni* Biozone and to endorse long held correlations (Loydell and Fone, 1999; Thomas and Ray, 2011; Melchin *et al*., 2020). Recent sequence stratigraphical and isotope studies confirm that the Much Wenlock Limestone Formation locally spans the whole of the *nassa* to *ludensis* biozonal interval and demonstrate its links to the Mulde isotope excursion (e.g. Ray *et al*., 2010; Marshall *et al*., 2012; Blain *et al*., 2016; Fry *et al*., 2017). Such studies imply that carbonate production on the Midland Platform was able to keep pace with slowly rising late Homerian marine base levels. The spread of anoxic graptolitic facies in wake of the mid-Homerian shoaling and oxygenation event was evidently diachronous. Such facies returned to deeper parts of the LPWB, including outer Marginal Belt settings, during the *ludensis* Biozone. The *nilssoni* Biozone flooding event extended their range as far as the Church Stretton Fault Zone. The same event curtailed regional Wenlock carbonate production on the Midland Platform, but the accumulation of graptolitic facies on outer parts of the platform, evidenced by the well-preserved Goggin Road Formation faunas, was delayed until a higher level in the biozone.

The upfaulting of isolated blocks within the Church Stretton Fault Zone accounts for unconformable relationships seen in the Old Radnor and Presteigne inliers between latest Telychian to Wenlock facies and rocks as old as Neoproterozoic in age. Boreholes demonstrate subsurface continuity of the limestone units seen at the two quarry sites and that underlies the local Coalbrookdale Formation succession. For this calcareous division, the name Nash Scar Limestone Formation appears to have historical precedence, but the term **Dolyhir Limestone Formation** is already in published use (BGS, 2004) and preferred in place of the 'Dolyhir and Nash Scar Limestone Formation' of Ray *et al*. (2021). The **Dolyhir Rudite Member**, locally present below the main limestone unit was clearly the product of local mass wating. Though Ray *et al*. (2021) suggest that it correlates with the Wyche Formation of the Malverns area, and hence belongs in the Trannon Group, its resedimented nature appears to favour of a basal Welsh Borderland Group assignment. A hardground at the top of the Dolhir Limestone hints at a local non-sequence. A basal Homerian bentonite in the overlying Coalbrookdale Formation hosts the exceptionally well-preserved fauna of the Herefordshire Lagerstätte (Siveter *et al*., 2020).

At a higher level, most authors seem content to view the prominent limestone unit that succeeds the Coalbrookdale Formation in the Welsh Borderland and West Midlands as the **Much Wenlock Limestone Formation** (e.g. Cocks *et al*., 1992; Ray *et al*., 2010). The base of the latter is everywhere gradational and known to be diachronous. However, the mapping of an underlying transitional unit equivalent to the Farley Member of the Wenlock Edge succession appears widely to have been resisted, perhaps for the reasons outlined below. Several authors have sought to subdivide the limestone into a series of separate reef and non-reef bearing facies (e.g. Phipps and Reeve, 1967; Lawson, 1955; Bassett, 1989; Ray *et al*., 2010). Dorning's (1983) **Lower Quarried**, **Nodular** and **Upper Quarried members** are evidently widely recognisable throughout the West Midlands, and Ray *et al*.'s (2010, 2019) detailed event stratigraphy has established regional correlations (see Text Box 14). Of these, it is the Lower Quarried Member that appears to record the basin wide mid-Homerian shoaling and reventilation episode. Bassett (1989) introduced the terms **Longville Member** and Edgton Member for separate limestone facies in the formation's Wenlock Edge succession. His naming of the latter reflected the view that it included nodular facies comparable and contiguous with the more westerly 'Edgton Limestone' of Greig *et al*., (1968). However, by implying that this unit forms part of the Much Wenlock Limestone Formation, this interpretation was contradictory. Cave and Hains (2001) endorse Greig *et al*.'s (1968) analysis and explain the need to exclude the Edgton area facies from the main limestone division (see above). They recommend the renaming of Bassett's (1989) Wenlock Edge unit and, based on his account, the label **Wilderhope Member** (new name) may serve this purpose. Ray *et al*. (2010) show that the Wenlock Edge divisions are unrelated to those of Dorning (1983).

Depiction of the Much Wenlock Limestone Formation on BGS paper and digital maps of north Shropshire paints a misleadingly simple picture. The use on the Church Stretton sheet of the same colour for the nodular and mud-prone 'Tickwood Beds' (Farley Member) and the main Wenlock Edge limestone outcrop contributes to this confusion. Yet Greig *et al*. (1968) were clear that the former, though transitional, should properly be included in the 'Wenlock Shales' succession that subsequently became the Coalbrookdale Formation. BGS's (2000c) inclusion on the Ludlow provisional sheet of facies equivalent to the Farley Member in a redesigned Much Limestone Formation that also includes the Wigmore Rolls Formation of Whitaker (1994) and the 'atypical Wenlock Limestone facies' of Lawson (1973) was therefore in error. Some and locally all the nodular Homerian rocks that crop out in the Leintwardine, Wigmore Rolls and Aymestry areas, as part of an extended use of the Farley Member, should properly be reallocated to the Coalbrookdale Formation. Limited remapping is required to accommodate this change.

Squirrell and Downing (1969) sought also to apply the standard nomenclature erected in the Wenlock and Ludlow type areas to the coeval rocks of the Usk Inlier. However, Barclay (1989) recognised the onset of southward facies changes and felt it prudent erect new nomenclature. The oldest rocks to crop out comprise calcareous mudstones and siltstones with limestone nodules that range from mid Sheinwoodian to early Homerian in age. Barclay (1989) labels these the 'Glascoed Mudstone Formation', but they appear to differ little from their Coalbrookdale Formation correlatives. However, the overlying succession of interbedded sandstones, siltstones and mudstones contrasts with Wenlock successions seen to the north and east and deserves differentiation as the **Ton Siltstone Formation**. It includes the intercalated **Trostrey Limestone Member**. Barclay (1989) followed Hurst (1975) in labelling the succeeding Homerian carbonate unit the 'Usk Limestone Formation', but most authors appear content to include these strata in the Much Wenlock Limestone Formation (e.g. Squirrell and Downing, 1969; Bassett, 1974; Cocks *et al*., 1992).

The southwards change in Wenlock facies becomes fully manifest in Cardiff area Rumney Inlier succession assessed by Waters and Lawrence (1987). In contrast to northerly locations, a thick Homerian limestone division is absent from a succession and, in contrast, reflects the elevated levels of siliciclastic sediment supplied to a Welsh Borderland Group coastal setting (Cherns *et al*., 2006). Sheeted sandstone-mudstone facies of the early Homerian age comprise the **Pen-y-lan Mudstone Formation**. The overlying **Rhymney Grit Member**, at the base of the **Cae Castell Formation**, testifies to the subsequent mid-Homerian shoaling event. Succeeding parts of the latter, a succession of interbedded sandstones and mudstones, appear as elsewhere to record the impacts of late Homerian base level changes, with shallower conditions being briefly reestablished during deposition of the fossiliferous **Newport Road Member** and its basal oolitic ironstone.

Late Homerian deepening initiated the eastwards withdrawal of Welsh Borderland Group facies from much of Wales, but it was the early Ludlow expansion of the Epynt Group linked to the evolution of the Clun Forest Sub-basin (see below), that confined the accumulation of calcareous blanket system facies to the Midland Platform. Transgression linked to the regional appearance of *nilssoni* Biozone graptolites introduced the weakly-burrowed basal Gorstian **Oakeley Mynd Shale Formation**, the last vestige of the Welsh Borderland Group to be deposited to the west of the Church Stretton Fault Belt. To the east, there now accumulated the well documented Ludlow succession of the type area and the inliers at Woolhope, Gorsely, May Hill, the Malverns and Abberleys, and of Usk and Rumney. Numerous local names have been erected for these various successions that record the Gorstian phase of the Welsh Borderland Group calcareous blanket system. Facies that were predominantly influenced by Ludfordian changes in tectonic regime and sediment provenance form part of the succeeding CIII Systems Tract.

Holland *et al*., (1963) introduced a terminology for Ludlow rocks of the Welsh Borderland that became widely adopted. They viewed their divisions as 'combined units' that involved both lithology and biota in their definitions. Phipps (1962) and subsequently Phipps and Reeve (1967) and Dorning (1982) suggested that the Holland *et al*. (1963) divisions were essentially biostratigraphical. Holland *et al*. (1963; 1980; see also Lawson, 1982) vigorously defended their scheme and it continues to influence modern accounts. However, Holland and Lawson (1963) presented a more rigorously lithological account of Ludlow facies that illustrated very clearly how their 'combined units' differed from divisions that might be viewed as strictly lithostratigraphical. Subsequent studies confirmed this and showed how divisions recognised solely on their rock characteristics differ and diverge from those erected by Holland *et al*. (1963), when the latter are traced away from their type setting. For these various reasons, it seems appropriate to erect new, more rigorously defined lithostratigraphical nomenclature for these rocks. Hillier *et al*. (2024) show the plethora of local names that have been used for local successions of Ludlow-aged rocks in the Welsh Borderland. Together with the work of Watkins (1979) and Cherns and Bassett (1999), this provides a starting point for a rationalisation that seeks, where appropriate, to distance the new nomenclature from the older scheme. Doing so allows the chronostratigraphical divisions proposed by Holland *et al*. (1963) – Eltonian, Bringewoodian, Leintwardinian and Whitcliffian - to be re-adopted. Cherns and Bassett (1999), Waters and Lawrence (1986) and Hiller *et al.* (2024) recognise these as regional chronostratigraphical substages, or chronozones of the international Gorstian and Ludfordian stages.

The oxic mudstone facies recognised by Holland et al. (1963) in the Ludlow area as the 'Lower Elton Beds' evidently expand southwards so that in the Woolhope area they span the whole of the Eltonian. The name **Wootton Formation**, an adaption of Squirrell and Tucker's (1960) term, is suggested as a more appropriate regional label for these strata. However, it remains useful to adapt a suggestion by Lawson (1982) and to distinguish the succession in the Ludlow area as the **Pitch Coppice Mudstone Member**. The base Ludlow (and base Gorstian) GSSP is currently located at the base of these strata in the Ludlow area. For the laminated and graptolitic mudstones that comprise the 'Middle' and 'Upper Elton' beds in the Ludlow and Wenlock Edge, Lawson (1982) proposed the terms 'Owney Shales' and 'Mary Knoll Flags' as lithostratigraphical alternatives. However, Watkins' (1979) account implies that a single term would be more appropriate and sections described by Lawson and White (1989; see also Aldridge *et al*., 2000) point to the name **Goggin Road Formation** as appropriate. Alternative correlations have been entertained (see Text Box 14), but currently accepted alignments imply a link between these laminated Eltonian facies developed east of the Church Streton Fault Zone, and the Epynt Group's Irfon or Knucklas Castle formations to the west (see below). Atkins (1979), working in the Knill area of the Knighton district, also to the east of the fault zone, a westerly succession recognisable as the Goggin Road Formation, but which ranges into the Bringewoodian (Fig. 21); a finding that further underlines the unsatisfactory nature of earlier nomenclature. The 'Middle Elton' of the Pedwardine area (Boynton and Holland, 1997) should be also assigned to this easterly division. Use of the term Wootton Formation for Usk Inlier divisions that Walmsley (1958) labelled 'Lower Forest Beds' may also prove warranted. For the isolated Eltonian to Bringewoodian succession of the Rumney Inlier, that appears to record accumulation in a more proximal southern setting, retention of the **Hill Gardens Formation** of Waters and Lawrence (1987) appears sensible.

Holland *et al.*'s (1962) 'Lower Bringewood Beds' comprise a succession of bioturbated and increasingly calcareous siltstones that underlies the limestone dominated 'Upper Bringewood Beds'. It was the introduction of the latter term in place of the previously widely used 'Aymestry Limestone' that attracted some of the most robust criticism for the Holland *et al*. scheme. That facies of 'Aymestry Limestone' type locally persist above the first appearance datum FAD of faunas that Holland et al. (1963) took to be diagnostic of their 'Lower Leintwardine Beds' was seen to provide some of the clearest evidence that their scheme was essentially biostratigraphical (e.g. Phipps and Reeve, 1967; Watkins, 1979). The confusion this has led to is exemplified at Sunnyhill Quarry, where different accounts recognise the level of base Ludfordian GSSP as lying either within the 'Aymestry Limestone' (Cherns, 1988; Cherns *et al*., 2006), or as marking the base of the 'Lower Leintwardine Formation' (e.g. Cherns, 2011; Melchin *et al*., 2020).

Phipps and Reeve (1967) and Greig *et al*. (1968) explain why blanket use of the term 'Aymestry Limestone Formation' on BGS maps for Bringewoodian to Leintwardinian calcareous rocks is unwarranted. Use of the term and linework used for the 'Aymestry Group' (see Greig *et al*., 1968) is also inappropriate. Alexander and Calder (1936), Phipps and Reeve (1967) and Cherns and Bassett (1999) show that the siltstone-rich facies typically present below, also passes laterally into Aymestry Limestone facies and that the latter locally spans much of the Bringewoodian. This is reflected in Phipps and Reeve's (1967) recognition of an **Aymestry Formation** that includes, where they are developed, lower siltstone and upper limestone divisions. The names **Vinnals Siltstones Member** and **Aymestry Limestone Member** offer a constructive rebranding that accords with the suggestions of Lawson (1982). Cross-bedded Aymestry Limestone Formation facies that include levels composed of crowded valves of the brachiopod *Kirkidium knightii* have been cited as evidence for wave resistant barrier located across the outer part of the Midland Platform behind which the more widespread nodular and argillaceous limestone facies accumulated (Fig. 14). It may prove possible to recognise these as a further member of the formation. There are also locations in the Ludlow and Mortimer Forest areas and in northern parts of the Malverns succession where deposition of the Aymestry Limestone Member persisted into the Ludfordian (Leintwardinian) (Cherns, 1988; Phipps and Reeve, 1967). Elsewhere, however, levels previously seen to form the uppermost part of the some 'Aymestry Limestone' successions, that include beds of bored, limestone-clast conglomerate (e.g. Elles and Slater, 1906; Shergold and Shirley, 1968; Cherns, 1980), overlie the erosion surface here taken to mark the base of the succeeding CIII Systems Tract (see Part 2). These levels should reasonably be excluded from the limestone formation (see Hillier *et al*., 2024).

Facies of 'Aymestry Limestone' type are absent from the May Hill and Usk inlier successions. In the former area, a significant non-sequence accounts for the absence of late Bringewoodian strata, but Lawson (1955) was happy to view the facies and fauna of his Upper Flaxley Beds as comparable to facies here included in the Vinnals Siltstone Member. The levels of attenuation and omission seen in the south of the Woolhope Inlier and at May Hill attest to an axis of relative uplift, linked to the Woolhope Fault Belt and centred on the Gorsley area, that was active throughout much of the Ludlow (Lawson, 1954; Hillier *et al*., 2024).

At Usk, where no such non-sequences have been recorded, Walmsley (1959) recognised that his Lower Llanbadog Beds, a feature forming unit comprising tough calcareous siltstones with thin coral-bearing limestone beds, whilst containing a comparable fauna, differed from the Ludlow area 'Aymestry Limestone'. He was also aware that the lateral passage between the Llanbadog Beds and the underlying, less calcareous Upper Forest Beds bore similarities to the transition from limestone and silt rich Bringewoodian facies seen in northerly successions. Walmsley's (1959) nomenclature is inappropriate for these closely related facies, which he was happy to group together on his map of the inlier. As to the north, these separate facies are better viewed as members of a single formation for which the published accounts of the inlier (e.g. Walmsley, 1959; Squirrell and Downing, 1969; Barclay, 1989) suggest the term **Llandegfedd Formation** may be appropriate. The **Porth-llong Member** and **Llancaeo Hill Member** are offered as names for the less calcareous and more calcareous facies respectively. Ground investigations are required to confirm the usefulness of these terms.

Late Bringewoodian levels of the Rumney Inlier succession, noted to be richer in corals, are recognised by Waters and Lawrence (1987) as a basal member of their Llanedeyrn Formation. However, the assignment of strata that form the upper part of the latter to the CIII Systems Tract (Mortimer Group) renders this name untenable. The late Bringewoodian to early Leintwardinian interval, previously given member status, is here redesignated the **Eastern Avenue Formation**. It contrasts with coeval levels of the Welsh Borderland Group in testifying to deposition in a more mud-prone setting. Differences between the CII Systems Tract facies of Rumney and Usk inliers and Welsh Borderland Group successions seen elsewhere is in keeping with the former's location close to the Pretannia coastline (Cope and Bassett, 1987). In sharing this siliciclastic source, inclusion of some elements of the Rumney and Usk successions in the more westerly Epynt Group (see below) warrants consideration (Waters, pers. comm, 2024).

### 4.2.4 Epynt Group (new name)

The focus above has been on the west to east facies changes that characterise the Welsh Borderland Group. However, equally significant are those seen within CII Systems Tract succession that forms the prominent escarpment which extends south-westwards from Mynydd Epynt to Llandeilo. This type area of the Epynt Group hosts the Wenlock-Ludlow ramp and delta facies that are described by Schofield *et al*. (2004, 2009a) and Barclay *et al*. (2005). The succession, including its representatives in the Newtown and Welshpool, record the progradation of shallower proximal facies, supplied predominantly from the south-west, over the more distal facies that characterise more northerly sectors of the Marginal Belt (Fig. 21). The Clun Forest Sub-basin evolved and played a critical role in determining the pattern and location of Ludlow-aged Epynt Group facies and their interface with the in-part coeval Mortimer Group (see below).

*Epynt Group rocks of pre-Ludlow age* - There is a strong argument to include both the Dolfawr and Builth Mudstones formations, and their local synonyms, in the Epynt Group as both attest to the region of deeper and distal mud accumulation into and across which the facies of this group prograded. This has been resisted for reasons outlined above. Rather, it is the entry of facies that, as they are traced south-westwards away from these distal deposits, record the advance of progressively more sandy, more bioturbated and increasingly more proximal deposits that characterise the Epynt Group (Fig. 21). The initial phase of progradation was a response, at least in part, to the Homerian global regression. The event is reflected in lateral and vertical progressions from the deeper, silt-striped outer ramp facies of the **Llangammarch Formation**, into the progressively more sandy and shallower mid ramp/pro-delta **Tirabad** and inner ramp/delta front **Sawdde Sandstone formations**. The latter's passage into the thick-bedded facies of the **Ffinant Sandstone Formation** records the seaward advance of an upper shoreface and wave-influenced delta (Schofield *et al*., 2009a). More calcareous and bioturbated sandstones and siltstones of the **Halfway Farm Formation** record the latest Wenlock deepening that impacted the Llangollen Group and Welsh Borderland Group further north, and that is evident in upper levels of the platformal Much Wenlock Limestone Formation (e.g. Davies *et al*., 2011). A bryozoan bioherm present at the base of the Halfway Farm Formation, to east of Llangadog warrants the name **Pwll-calch Limestone Member** (BGS, 2008b).

*Epynt Group rocks of Ludlow age and the Clun Forest Sub-basin* - The early Ludlow saw the inception of a broad N-S orientated region of subsidence that affected much of the Marginal Belt region that traverses the Knighton, Newtown and Welshpool areas as well as adjacent sectors of the former South Wales Sub-basin (Fig. 14). It was flanked to the east and south-east by the Church Stretton Fault Zone. Its western flank was sited in a region where Ludlow facies are no longer preserved but speculated to have had links to the Central Wales Lineament. The concept of a 'Montgomery Trough', active in confining both Wenlock and Ludlow sand-prone turbidite systems, as postulated by Cummins (1959), was rejected by Cave and Hains (2001). The region of greatest Ludlow subsidence was distinguished by Holland and Lawson (1963) as the 'Clun Forest Basin', and it is here redesignated a sub-basin.

The background to nomenclature changes to Ludlow facies of the Clun Forst Sub-basin area is provided in Text Box 15. The basal Ludlow (Gorstian) marine transgression signalled the start of the second Epynt Group progradational episode that included deposition of the complex Bailey Hill Formation (see below). As during the Wenlock, the progression of shallower, coarser and more oxic clastic facies is revealed by south-westward transitions (Fig. 21) (Schofield *et al*., 2004; Barclay *et al*., 2005; Schofield *et al*., 2009a). Anoxic and distal outer ramp/pro-delta Epynt Group facies, widely identified in earlier literature as the 'striped flags', are now recognised as the **Irfon Formation**. For the weakly bioturbated, silt-prone, outer ramp/pro-delta facies of the

**Text Box 15: Revisions to published Ludlow stratigraphy of the Builth Wells and Brecon sheets:** It is now known that the heavily bioturbated muddy siltstones and sandstones of the early Ludfordian Aberedw Formation (Schofield *et al*., 2005a) of the Builth district were miscorrelated with similar rocks at the top of the Gorstian Hafod Fawr formation in the adjacent Brecon district (Barclay et al., 2005b). This miscorrelation resulted from a graptolite fauna from the silt striped mudstones that overlie bioturbated sandstones and siltstones at Fibua Quarry, close to the eastern margin of the Brecon district, being identified as belonging to the *Bohemograptus* proliferation interval of the UK Silurian biozonal scheme (Zalasiewicz *et al*., 2009). As the Aberedw Formation is known to yield leintwardinensis Biozone graptolites (Straw, 1937), it was concluded that the bioturbated rocks at the base of the Fibua section belonged to that division rather than the Hafod Fawr Formation. Faulting to accommodate this conclusion was installed.

Subsequent work has shown these assumptions to be incorrect. At the request of BGS, Wilkinson (reported in Hillier *et al*., 2024) reassessed the Fibua graptolites. He reports the taxa present as *Bohemograptus bohemicus* together with the subspecies *B. b. tenuis*. Such an assemblage is not indicative of the *Bohemograptus* proliferation interval in the UK. Both taxa are known only to occur together rocks of mid to late Gorstian age. Evidence that the succeeding Cae'r mynach Formation ranges into the Leintwardinian (Potter and Price, 1965; Hillier *et al*., 2024) supports assignment of the Fibua graptolites to the late Gorstian *incipiens* Biozone.

Weakly bioturbated mudstones, siltstones and sandstones that crop out in the Builth Wells district, on Mynydd Epynt, closely resemble the Knucklas Castle Formation of the Knighton and Montgomery areas (Holland, 1959; Cave and Hains, 2002). In the Builth area, Schofield *et al*. (2005a), believing them to display stratigraphical relationships that differed from those to the north and east, erected the name Cwm Graig ddu Formation. This term was also utilised on the adjoining Brecon sheet (Barclay *et al*., 2005b) for Gorstian rocks that underlie the Hafod Fawr Formation. Subsequent dating of the Cwm Graig ddu Formation, in sections on the northern flank of Mynydd Epynt, shows that there the formation spans the *incipiens-leintwardinensis* biozonal boundary (Williams, 2003). These findings, when placed in the context of published dates from adjacent areas (e.g. Holland, 1959; Cocks *et al*., 1998; Cave and Hains, 2001) demonstrate the scale of diachroneity displayed by facies that envelope the Bailey Hill Formation, as captured by the new stratigraphical architecture (Fig, 21). They make clear the once contiguous nature of the Cwm Graig ddu and Knucklas Castle formational facies belts. The latter, having historical precedence, is recommended as the universal term for these sparsely burrowed rocks on the Montgomery, Knighton, Builth and Brecon sheets that are known now to range from early Gorstian to mid-Whitcliffian in age.

The Fibua Formation differs little lithologically from the Cwm Graig ddu Formation and, considering its revised age and the latter's renaming, is reclassified as a member of the Knucklas Castle Formation. The rocks at Fibua that were placed in the Aberedw Formation are now considered a bioturbated facies (Cam-rhiw Member) of the Hafod Fawr Formation. The new dating also demonstrates that the Fibua Member and the Cwm yr Hob Member of the Montgomery succession are essentially coeval. Cave and Hains (2001) placed the latter in the Bailey Hill Formation. However, Waters (pers. comm.) reports significant intervals that resemble the 'striped flags' of earlier authors and recognised by BGS as the Irfon Formation (Schofield *et al*., 2005a). There is a case, supported here, to view it as a member of that division. Both the Fibua and the Cwm yr Hob members are identifiable because they inter-tongue with adjacent stratigraphy (Fig. 21). Both record the impacts of the latest Gorstian-early Leintwardinian flooding event and confirm that, within the confines of the Clun Forest Sub-basin, an horizon elsewhere associated with the base of the Mortimer Group occupies a level within the Epynt Group. It follows from these collective findings that the geological linework and nomenclature used on the BGS maps coving Mynydd Epynt (BGS, 2005a, b) require targeted revision.

name **Knucklas Castle Formation** is here recommended as universal replacement for the Cwm Graig-ddu Formation of Schofield *et al*. (2004). Both these divisions give way southwards rocks that accumulated principally outside the subsidence-prone Clun Forest depocenter (Fig. 14). The mid ramp/delta-front **Hafod Fawr Formation** has capping units that comprise the bioturbated **Cam-rhiw Member** (new name) of the Fibua area and the more southerly, thicker-bedded, upper shoreface **Cwar Glas Member**. Conglomeratic deltaic mouth-bar facies are represented by the **Mynydd Myddfai Sandstone Formation**. The product of a global regression, this coarsening-sideways and upwards succession is capped in the south by terrestrial red-beds of the **Trichrug Formation** (Davies *et al*., 2008; Hillier *et al*., 2011). Barclay *et al*. (2015) viewed the Trichrug Formation as an early development of the Old Red Sandstone Supergroup. However, whereas the latter predominantly comprises far travelled Caledonian molasse, the Trichrug Formation was likely sourced from uplifted areas linked to the nearby Church Stretton Fault Belt or Carmarthen High (Hillier *et al*., 2011). Trichrug Formation facies rich in locally sourced angular acid volcanic clasts seen in the Cennen Road Cutting are here recognised as the **Llethr-garw Member** (new name)

*Bailey Hill Formation* - Within the confines of the Clun Forest Sub-basin, the mixed facies assemblage of the **Bailey Hill Formation** displays intimate relationships with, and shared, at least in part, the same sediment source as units of the Epynt Group (Figs 21 and 22). Though the formation's hybrid character warrants designation as separate subsystem, it is pragmatic to included it in the latter (see Part 2). Widespread slumping is evident along both margins of the Clun Forest Sub-basin affecting late Gorstian and Ludfordian rocks alike and reflects the viewed the latter as an early interval of tectonism that can be linked to the post-collisional reconfiguration of the LPWB. Deeply incised channels, slide scars, limestone conglomerate debrites and slumps (slope systems), testify to a steep eastern margin associated with an active Church Stretton Fault Zone (see below). Slump units present within western Bailey Hill Formation outcrops point to a nearby east-facing slope (e.g. Woodcock, 1976; Cave and Hains, 2001; Cave, 2008).

It was the central region of the Clun Forest Sub-basin that accommodated the shelly sandstone and silt-rich event beds of the Bailey Hill Formation as it expanded throughout the Gorstian (Cave and Hains, 2001) (Fig. 21). Though previously regarded as exclusively turbiditic in origin (e.g. Cummins, 1959; Bailey, 1969), an interpretation since re-emphasised by Cave and Hains (2001), Tyler and Woodcock (1987) argue that the formation also includes shelly event beds that were emplaced as storm sheet sands below a strongly stratified water column. Complex paleocurrent patterns allow for both emplacement processes to have played a part and suggest, moreover, that the Bailey Hill Formation was multi-sourced (see below). It is clear, nevertheless, that the Ludlow evolution of the Clun Forest Sub-basin, the arrival and spread of Bailey Hill Formation facies and the onset of the Gorstian phase of Epynt Group progradation served collectively to confine Welsh Borderland Group calcareous blanket facies to the Midland Platform.

Cave and Hains (2001) recognised the diachronous succession of early Gorstian (Eltonian) laminated hemipelagic mudstones with abundant sandstone and siltstone laminae, widely present below the Bailey Hill Formation in the western part of the Newtown district, as the 'Gyfenni Wood Shales Member' of their Nantglyn Flags Formation (Llanbadarn Formation). Cave (2008) considered them to be a separate **Gyffeni Wood Shales Formation** that, on Long Mountain, intervenes between the Trewern Brook Mudstone and Bailey Hill formations, and further east, between the Aston Mudstone and the Irfon formations. Both accounts show this basal Gorstian unit passing eastwards into early levels of the Bailey Hill Formation implying that some parts have no obvious link to coeval Welsh Borderland Group facies (see Cave, 2008, fig. 6). Its more sandy and silty composition confirms affinity to the northward prograding Epynt Group system (Fig. 19).

Initial deposition of the Bailey Hill Formation was centred on a narrow belt aligned along the Clun Forest Disturbance. The Gyfenni Wood Shales Formation was excluded from this region, where the Bailey Hill Formation sits directly on the Welsh Borderland Group (Aston Mudstone Formation). Its early eastwards expansion was at the expense of Oakeley Mynd Formation. To the west, where the **Dingle Mudstone Member** appears as an additional fringing component, it overlaps the Gyfenni Wood Shales Formation to displace upper levels of Llangollen Group (Llanbadarn Formation). It is in this region that slump fold vectors have been seen to offer evidence of a nearby south-eastwards facing slope, and the presence of the **Brynrorin Conglomerate Member**, of localised mass-wasting (Cave and Hains (2001). These incomplete Bailey Hill Formation successions comprise the youngest Silurian strata preserved to the west of the Severn Valley Fault Zone. It emerges from the improved understanding of their stratigraphical range (see Text Box 15) that the depositional belts of the Irfon and Knucklas Castle formations served, if only empirically, to flank the region of Bailey Hill Formation accumulation in the Clun Forest region and on Long Mountain (Figs 19, 21 and 22).

The extensively slumped Irfon Formation succession present to the east of the Bailey Hill Formation in the Knighton region had links to the system of slides and channels that affected the Clun Forest Sub-basin's eastern flank and that had a profound impact on the platformal succession (Welsh Borderland Group) seen immediately to the east of the Church Stretton Fault (see below). Cummins (1969) and Cave and Hains (2001) considered that sediment discharge via these incision features was a principal source for the Gorstian events beds of the Bailey Hill Formation and present supporting palaeocurrent data. However, Tyler and Woodcock (1987) show this was unlikely. A majority of their measured flute cast orientations, notably in their Brimmon Wood Member, testify to a supply of sediment from the active realm of Epynt Group progradation to the south-west.

*Eastern margin of the Clun Forest Sub-basin* – Evidence of extensive intra-Ludlow mass wasting in the Ludlow district affecting the region between Leintwardine and the Lugg valley, west of Aymestry, confirms that, over time, the unstable eastern flank of the Clun Forest Sub-basin migrated east of the CSFZ to consume outer regions of the Midland Platform (BGS, 2000). Whitaker (1962; 1994, fig. 5) identifies a series of channels and slump scars that cut down through Leintwardinian, Bringewoodian, Eltonian and locally Homerian divisions, and which are filled by displaced material (Fig. 21). These features merge westwards into a broad belt of slumped and displaced strata that includes units largely composed of resedimented limestone nodules sourced from excised Bringewoodian and Homerian carbonate facies. Boynton and Holland (1997) document the occurrence of such a conglomerate in the

Pedwardine area. The disturbed succession, which crops out on both the Ludlow and Knighton sheets, is here newly recognised as the **Lugg Member** of the Irfon Formation. It must once have passed downslope into the unnamed slumped units that feature in this division further west (e.g. Tyler and Woodcock, 1987). Undisturbed facies of the Irfon Formation, in the form of the Mocktree Shales Member (see below), are present to the east of the disturbed succession (Figs 21). Certainly, its origin and setting justify inclusion of the Lugg Member in the Epynt Group, and it confirms that material shed from easterly flanking regions was an additional source of sediment supplied to the Clun Forest Sub-basin (Fig.22).

**Text Box 16. Ludfordian CII Systems Tract facies** - The distribution and composition of the Fibua Member on Mynydd Epynt, the Mocktree Shales Member in the Leintwardine area, and of the Lugg Member astride the Knighton and Ludlow district boundary (BGS, 2000), all testify to the transitional relationships between facies of the CII and CIII systems tracts (Epynt and Mortimer groups) along the margins of the Clun Forest Sub-basin associated with the late Gorstian to early Leintwardinian episode of palaeogeographical reconfiguration (Figs 21 and 22). Deposition of coeval Bailey Hill Formation facies within a narrow axial region soon ceased. However, *Bohemograptus* proliferation Biozone graptolites (see text) confirm that the contracting sub-basin continued to host Epynt Group facies into the Whitcliffian. A remnant of Pretannia is the assumed sediment source with delivery via a pathway now largely concealed beneath younger rocks. Cae'r mynach Seaway facies accumulated on either side, in front of Mortimer Group deltaic shorelines advancing from separate northerly quadrants (Hillier *et al.*, 2024) (see below; Fig. 22).

Leintwardinian Bailey Hill Formation facies failed to extend into the Long Mountain area, but the presence of related Epynt Group divisions (Cave, 2008) shows that the northern transition between southerly supplied sub-basinal facies and pro-deltaic seaway sediments occurred north of the Severn Valley Fault Belt (Fig. 22).

*Ludfordian Clun Forest Sub-basin facies* - In addition to the Church Stretton Fault Zone, movements on contiguous structures such as the Leinthall Earl's Fault were likely instrumental in promoting instability throughout the Gorstian (Lawson, 1973; Whitaker, 1994). Slump-affected rocks of Eltonian and Bringewoodian age are known to be present in the vicinity of the Lugg Member outcrop (Atkins, 1979; Whitaker, 1994) and were they to be accurately mapped (see BGS, 2000), could be viewed as older components of this disturbed division. As it stands, and perhaps predicably, the bulk of preserved Lugg Member facies appear date from the final period of mass wasting and coincided with the changes associated with the late Gorstian-early Leintwardinian onset of CIII Systems Tract (Mortimer Group) deposition elsewhere on the platform (Hillier *et al.*, 2024).

The profound changes in sediment provenance recorded by the Mortimer Group had their origins in the latest Gorstian. East of the Church Stretton Fault Zone, Whitaker (1962, 1994) and Lawson (1973) recognised that undisturbed Leintwardinian facies in the region affected by mass-wasting (see above) were noticeably deeper in aspect than those of the coeval levels in the Ludlow Anticline and Wenlock Edge successions (Mortimer Group). Holland and Lawson (1963) acknowledged that they had more in common with facies of the Clun Forest region. The graptolitic laminated mudstones with *Dayia navicula* brachiopods that Whitacker and Lawson included in their 'Lower Leintwardine Beds' are equivalent to the *Dayia*-rich 'Mocktree Shales' facies of Elles and Slater (1906) and are here recognised as the **Mocktree Shales Member** of the Irfon Formation (see Lawson, 1982). Whitaker's (1962) record of a *B. bomemogratus* discovery from near the base of these beds in the Downton Gorge recalls the Fibua Member assemblage (Text Box 15) and may similarly imply a pre-*leintwardinensis* Biozone age (Fig. 21). The more bioturbated mudstones and siltstones of the 'Upper Leintwardine Beds' contain a modified *Shaleria ornatella* Association fauna (Lawson, 1973; Watkins, 1979). Arguably, they compare more closely with the deeper Knucklas Castle Formation facies than coeval levels of the Mortimer Group. These divisions demonstrate that Epynt Group facies onlapped and accumulated along the outer platform edge throughout the Leintwardinian.

Epynt Group facies continued to accumulate in central regions of the Clun Forest Sub-basin and a supply of sediment from the south evidently remained in place well into the Ludfordian (Text Box 16; Fig. 22). A deepening episode linked, but not everywhere coincident with the base of the Ludfordian, finds expression in the anoxic, *leintwardinesis* Biozone graptolite-bearing **Cwm-yr-hob Member** (Fig. 21), here assigned to the Irfon Formation (see Text Box 15). The distribution of the member records the advance of 'striped flags' facies across a rapidly contracting belt of Bailey Hill Formation facies. The coeval expansion of the contiguous outer ramp/pro-delta Knucklas Castle Formation across the distinctive Cam-rhiw Member facies of the earlier Hafod Fawr Formation is recorded on the westerly flank of Mynydd Epynt by the Knucklas Castle Formation's **Fibua Member** (status downgraded) (Text Box 15). A granule conglomerate lag at the base of this unit hints at a link to the basal Mortimer Group Cribyn Du Member present to the south (see below). The thoroughly bioturbated sandy mudstones of the **Aberedw Formation,** including the Knighton area Wern Quarry Beds of Holland (1959), are of outer to mid ramp transition zone aspect (Fig. 21).

The spread of the contiguous Knucklas Castle and Aberedw formation facies belts across the site of the sub-basin was a response to Ludfordian shoaling, but also a decline in the supply of sediment from the south (Figs. 21 and 22). The *Bohemograptus* proliferation Biozone assemblages found in these rocks are the youngest graptolite faunas preserved in the LPWB and the UK (Holland and Palmer, 1974; Cave and Hains, 2001; Cave 2008). Together, these Whitcliffian facies marked the final phase of Epynt Group accumulation, the gradual occlusion of the Clun Forest Sub-basin and, it can be argued, the final manifestation of the LPWB as palaeogeographical entity.

*Llangollen Syncline* - Cave and Hains (2001) suggest that strata recognised in the Llangollen Syncline as the 'Nant-y-Beche Group' (Wills and Smith, 1922) represent a southerly sourced unit comparable to the Bailey Hill Formation. Cocks *et al*. (1992) show these rocks as ranging in age throughout much of the Gorstian, whereas Warren *et al*. (1984) suggest that they may entirely pre-date the *incipiens* Biozone. Cave and Hains envisaged their accumulation at the distal end of a linear belt that extended northwards from the Clun Forest region, across the Berwyn Dome and the Llangollen Syncline, into the southern part of the Clwydian Range (Figs

20, 22). Such a belt cuts across structural features known to have been active during the earlier parts of the CII Systems Tract and, if justified, implies that these were no longer influential.

#### 4.2.5 Skomer Sub-basin and Marloes Group

Hillier and Morrissey (2010; also Hillier, 2000) view the **Coralliferous** and **Gray Sandstone formations** as lateral equivalents that record multiple phases of progradation of shallower shoreface and estuarine facies across their offshore counterparts within a region of active fault-controlled subsidence. The sediment source lay to the south (Pretannia). These findings justify their erection of an inclusive **Marloes Group** accommodated within the Skomer Sub-basin.

Within the Coraliferous Formation, Veevers *et al*. (2007, 2024) recognise a transgressive basal unit as the **Renney Slip Member** and succeeding off-shore facies as the **Deadman's Bay Member**. The Gray Sandstone Formation of south Pembrokeshire has been assessed by Hillier and Morrissey (2010). The formation is poorly dated but believed to be largely Wenlock in age. The overlying succession of predominantly red bed facies (Red Cliff and Albion Sands formations) is widely taken to record the early Ludlow onset and accommodation of ORS Supergroup rocks within the Skomer Sub-basin (e.g. Barclay *et al*., 2015; Cocks *et al*., 1992; Hillier, 2000 and *et al*., 2019) (Plate 16).

### 4.3 CIII SYSTEMS TRACT (LATE LUDLOW – (?)EARLY PRIDOLI)

#### 4.3.1 Mortimer Group (new name)

The changes outlined above highlight the need to recognise Ludfordian successions that accumulated, initially alongside, but that subsequently succeeded those of the Clun Forest Sub-basin as belonging to a separate systems tract and discrete depositional system, here identified as the Mortimer Group (see Part 2). The group takes its name from the former Medieval county that occupied parts of south Shropshire and north Herefordshire including Mortimer Forest, host to the Ludfordian type section and other well studied outcrops of shallow marine and deltaic Ludfordian to (?)Early Pridoli rocks. With the exception of an area in the vicinity of Llangollen, outcrops of the Mortimer Group are confined to the Marginal Belt and Midland Platform regions of South Wales and adjacent areas of England. The features that serve to define the base of the Mortimer Group and their broader implications have been assessed in Part 2.

As part of their study of the sedimentology of Ludfordian to early Pridoli facies in Wales and Welsh Borderland, Hillier *et al*. (2024) demonstrate the need for lithostratigraphical revision, and it is their findings, in conjunction with those of Barclay *et al*. (2015), that inform the nomenclature presented below (see Fig. 21). The marine deepening associated with the Gorstian-Ludfordian boundary interval established the extensive storm-influenced and pro-delta settings recorded by the blanket deposition of the **Cae'r mynach Formation**. The later has its type section on Mynydd Epynt, but Hillier *et al*. (2024, fig. 4) now recognise it as the dominant synonym for the closely comparable Ludfordian to (?)Early Pridoli facies that crop out in east

Carmarthenshire, Powys and throughout the Welsh Borderland region (Plate 15). Though initially excluded from Clun Forest Sub-basin, the subsequent spread of the formation's bioturbated muds, silts and storm sheet sands throughout the former Marginal Belt and across the Midland Platform completed the development of the extensive off-shore and pro-delta region – the Cae'r mynach Seaway of Hillier *et al*. (2024) - into which prograding Mortimer Group deltas were supplied from north-westerly and north-easterly Caledonian sources (see below; Figs 21 and 22). To the south of Mynydd Epynt, in the Sawdde Gorge area, the conglomeratic **Cribyn Du Member** overlies the transgressive base of the Cae'r mynach Formation.

In the Ludlow area, the base of the formation is recognised as conformable with the limestones of the CII Systems Tract. Here, evidence for the latest *incipiens* Biozone onset of deepening seen in the more westerly Epynt Group succession (see above) is lacking. In contrast, as at Sunnyhill Quarry, facies of the Aymestry Limestone Formation locally continued to accumulate well after the stage-defining FAD of *leintwardinensis* Biozone graptolites. Phipps and Reeve (1969) record a comparable development in northern parts of the Malverns succession. Elsewhere, as alluded to above, Leintwardinian strata previously included in the 'Aymestry Limestone' (e.g. Cherns, 1980), but that contain conglomerates of bored limestone clasts, are now viewed as a basal facies of the Cae'r Mynych Formation. These levels show that a widely felt interval of omission and erosion preceded the Leintwardinian inundation (see Hiller *et al*., 2024). Mapping to differentiate these conglomerate-bearing Mortimer Group members from the underlying Aymestry Limestone Formation is required. Lawson (1955) mapped and labelled the feature-forming development of these conglomeratic facies in the May Hill Inlier as the 'Lower Blaisdon Beds'. This unit, mistakenly shown as 'Aymestry Limestone' on some BGS digital maps, is here reclassified as the **Blaisdon Conglomerate Member** of the Cae'r mynach Formation. The **Clencher's Mill Member** of Phipps and Reeve (1969) has been reassessed by Worssam *et al*. (1989) and is evidently a comparable unit present in the southernmost part of the Malverns succession. At a higher level in the Cae'r mynach Formation, the *Shaleria ornatella* shell bank facies in the Malverns area, recognised by Phipps and Reeves (1967) as the **Woodbury Shale Member**, warrants retention.

Hillier *et al*. (2024) recognise that rocks in the Rumney area, previously included by Waters and Lawrence (1986) in the upper part of their Llanedeyrn Formation, also form part of the regional Cae'r mynach Formation succession. The transgressive **Chapel Wood Member** and upwards shoaling **Roath Park Lake Member** are retained as local subdivisions. The conformable base of the Chapel Wood Member on facies included in the underlying systems tract (Eastern Avenue Formation) shows that here too the establishment of Cae'r mynach Seaway conditions post-dated the first appearance of Leintwardinian faunas.

Hillier *et al*. (2024) recognise some strata that earlier authors (e.g. Bassett *et al*., 1982) included in the Downton Castle Sandstone Formation (see below) as indistinguishable from the Cae'r mynach Formation. Hence, it is in the latter that they include the **Ludlow Bone Bed** and

**Platyschisma Shale members**. The former includes its eponymous basal concentrate of bony fish fragments, the **Ludlow Bone Bed**; the latter, the locally developed **Downton Bone Bed**. Current controversy regarding the age of the Ludlow Bone Bed and its use as a proxy for the base of the Pridoli Series in the UK has been outlined in Part 1. Hillier *et al*. (2024) recognise an underlying, locally developed sand-prone packet, the **Aston Munslow Member**, as offering evidence of an episode of pre-Ludlow Bone Bed progradation. Lawson (1955) notes that the Ludfordian successions of the May Hill area, in common with those to the south (Tites Point) and south-west (Usk and Rumney) are as thinner than those to the north and contain more numerous bone and phosphate pebble beds. He saw this as evidence of sedimentation across a region that experienced greater levels of scour and shoaling, exemplified most dramatically by the extreme levels of attenuation associated with the Gorsley Axis (Lawson, 1954, 1955; Hillier *et al*., 2024). Widespread pebble beds recognised in the Gorsley and May Hill inliers, that were identified by Lawson (1954, 1955), but given formal names by Hillier *et al*. (2024) include the Whitcliffian **Lower Linton Pebble Bed**. In a departure from past practise, the Upper Linton Pebble Bed is argued to be of mid-(?)Early Pridoli age (see below).

It is equally clear that the changing spore assemblages present in these rocks describe the early evolution and spread of terrestrial vegetation set against a backdrop of regional environmental change. As deltas advanced into it, the parts of the Cae'r mynach Seaway that occupied Wales and Welsh Borderlands became increasingly constricted, and changes in salinity and turbidity would have attended a transition into an increasingly brackish water setting. Hence, rather than being a simply biostratigraphical event, the Ludlow Bone Bed evidently coincided with a threshold event within this environmental transition. It is certainly above this horizon that euryhaline gastropods and bivalves dominate preserved benthic assemblages and new spore and ostracod species make the first appearance.

Hillier *et al*. (2024) discuss the sedimentology of the micaceous sandstone bodies that provide a record of multiple phases of Ludfordian to (?)Early Pridoli delta advance. In recognising these as having greater sedimentological affinity to the marine Silurian, Barclay *et al*. (2015) excluded such facies from the ORS Supergroup. It follows that they form an integral part of the Hafren Supergroup and of the CIII Systems Tract and, hence, the Mortimer Group. River dominated deltaic facies characterise the highly diachronous, north-easterly sourced **Tilestones Formation** (synonymous with the Long Quarry Formation) that succeeds the Cae'r mynach Formation throughout the Mynydd Epynt region. Hillier *et al.* (2024) recognise the oldest phase of Tilestones Formation progradation as Leintwardinian and to have seeded on a perturbation of the earlier Carmarthen High, their Golden Grove Axis, which also served to limit the landward advance of the Ludfordian transgression. This acted as the local interface between the marine Mortimer Group and the terrestrial ORS Supergroup facies that began to accumulate across the previously denuded region to the west (Figs 21, 22). The Mortimer Group succession in this south-western region describes the easterly advance of successively younger 'Tilestones delta' progradations. It is only the youngest of these that extended into the Mynydd Epynt region and is still believed to be of (?)Early Pridoli age (see Hillier et al., 2024).

Micaceous sandstones previously labelled the ‘Yellow Downtonian’, that crop out in the Clun Forest and Long Mountain areas, display features consistent with river-dominated deltaic deposition in common with the Tilestones Formation further south. However, they shared the same north-easterly sediment source as the wave influenced facies that characterise the Ludlow area **Downton Castle Sandstone Formation** and it is that divisions that Hillier *et al.* (2024) include them (Fig. 21). Their recommendation to include the Ludlow Bone Bed and Platyschisma Shale members in the Cae’r mynach Formation, renders redundant the need for Bassett *et al.*’s (1982) ‘Sandstone Member’. Moreover, Hillier *et al*. (2024) show that strata in the Woolhope, May Hill and Usk areas are incorrectly labelled as Downton Castle Sandstone on some BGS maps (see below).

In south-west Wales, calcrete-bearing facies of the ORS Supergroup accumulated diachronously behind the prograding Tilestones Formation as part of an expanding Ludfordian terrestrial succession. Relevant divisions of the latter include the predominantly green wetland facies recognised as the **Temeside Mudstone Formation**, and the contemporary dryland red beds of the **Moor Cliffs Formation**. Both these divisions host the micaceous sandstone feeder channels that supplied the seaward facing Tilestones deltas (Figs 19, 21). In contrast, to the north, and throughout the Welsh Borderland, Hillier *et al*. (2024) advocate the presence of a significant hiatus between facies of the Mortimer Group and the ORS and it follows that in this region the latter are likely to be exclusively Pridoli in age. They view as mistaken the labelling of strata on the BGS maps of the Woolhope, May Hill and Usk inliers as the ‘Downton Castle Sandstone Formation’ for units that are dissimilar in facies and likely in age. In their favoured model, one likely to prove controversial, the type succession of the Temeside Mudstone Formation, the **Rushall Formation** of the Woolhope area (Brandon, 1989) and the **Clifford’s Mesne Sandstone Formation** of the Gorsley and May Hill inliers (Worssam, 1989) form elements of a mid-(?)Early Pridoli depositional regime that entirely post-dated the Downton Castle Sandstone Formation. Bone-bearing beds that rest on the basal erosion surface, including the **Upper Linton Pebble Bed** of the Gorsley and May Hill successions, are no longer considered to correspond to the Ludlow Bone Bed. The Clifford’s Mesne Sandstone Formation, in which Hillier *et al*. (2024) include only the northern, sand-prone portion of Lawson’s (1955) Clifford’s Mesne Beds, is recognised as a barrier sandbody that was anchored to the Woolhope Fault Belt. Facies deposited on the seaward side of this feature, as seen principally in the south of the May Hill Inlier and in the Usk Inlier (the former Speckled Grit Walmsley, 1959), they view as a younger development of Cae’r mynach Formation. Both these units exhibit relationships and characteristics consistent with their inclusion in the Mortimer Group and allow them to be seen as the terminal deposits of the Welsh Basin-Midland Platform Marine Mega-system. In contrast, just as calcretes in the Temeside Mudstone Formation support an assignment to the

ORS Supergroup, so does their presence in the coeval grey and green back-barrier facies (Rushall Formation) of the Woolhope area and in purple coastal plain deposits (**Pwll-Mawr Formation**) encountered in the Rumney Borehole and near Usk. Neither of these units are listed in Barclay *et al*.'s (2015) account of the early Pridoli strata of the region, for which Hiller *et al*.'s (2024) assessment provides a significant upgrade.

New dating reported by Hillier *et al*. (2019, and 2024) for the Pontar-Llechau Formation of the Sawdde Gorge region (Schofield *et al*., 2009a) has shown that this overlies an intra-ORS incision surface and should also be excluded from the Mortimer Group. It is this coeval erosion that accounts for the absence of Ludfordian rocks from parts of South Pembrokeshire where the Freshwater East Formation has also been shown to be Mid Pridoli in age.

Finally, the youngest Silurian strata preserved in the Llangollen Syncline, the **Dinas Brân Formation** (BGS, 1992b), comprise a succession of uncleaved, thinly bedded, bioturbated muddy siltstones and sandstones (Plate 11) that conformably overlie unburrowed and cleaved Llangollen Group facies. A detailed account of these rocks is provided by David Siveter in Aldridge *et al*. (2000). Because they contain *Dayia navicula* and succeed strata from which *S. leintwardensis* s.l. has been recovered, the division has long been held to be Leintwardinian in age (but see Warren *et al*., 1984). Swanson and Downing (reported in Aldridge *et al*., 2000) document what they considered to be an early Whitcliffian acritarch assemblages. As with much of the Llangollen Syncline succession, work is required to better assess the age and provenance of these strata before their lithostratigraphical affinities can be resolved. If confirmed as Ludfordian, these strata may form a preserved remnant of a previously more extensive Mortimer Group succession, though it is equally possible that they were deposited in a setting that was palaeogeographically distinct from that further south.

# Part 4 – Summary and recommendations

## 1 Summary

A principal purpose of this report is to rationalise and critically assess the diverse nomenclature that has evolved for rocks of Ordovician to Silurian age deposited in the Lower Palaeozoic Welsh Basin and on adjacent parts of the Midlands Platform over the course of their long history of research and geological mapping. In doing so, it offers an opportunity for regional synthesis and interpretation. This has been achieved by adopting a systems and systems tract approach to group and subgroup scale lithostratigraphical nomenclature. Rocks of Tremadoc and mid-late Pridoli age are excluded from this account and doubts relating to the dating of early Pridoli strata are highlighted. The limits of the basin are defined, previous use of the terms basinal, shelfal and platformal are reassessed and the principal structural and palaeogeographical features of the region are summarised.

The systems tract approach enacted in the report is outlined and its divergence from standard sequence stratigraphical analysis explained. It essentially utilises the major events that shaped the region's stratigraphy. These included regional tectonic forcing events, linked to contemporary plate movements and interactions, as well as global sea level and climatic episodes. These key events are outlined. The systems tract boundaries typically utilise regional changes (paradigm shifts) in facies composition and distribution. The impacts of these changes were not always coeval throughout the region and were not always the result of a single forcing mechanism or event. Some tract boundaries record the overlapping effects of different events and different processes and are highly diachronous. Some of the issues - practical and semantic - that arise from the new systems tract approach are alluded to in the text and revisited below.

Each of the eight systems tracts recognised comprise a series of systems that form the basis for group and subgroup scale nomenclature. In addition, three tract assemblages recognise the major phases of the region's post-Tremadoc Lower Palaeozoic evolution: a rifting and volcanic phase; a post-volcanic phase dominated by the impacts of thermal subsidence and eustasy; and a final phase that records the impacts of plate collision and the region's subsequent transformation into the ORS Anglo-Welsh Basin.

Some new group and subgroup nomenclature is introduced, and other terms have been redefined and reworked. However, and critically, the scheme advanced has sought wherever possible to utilise existing formation and member level nomenclature and, by inference, the linework used on BGS maps (paper and digital). The recognition of synonyms permits significant rationalisation, but the aim has been to allow existing BGS map coverage easily to be brought into alignment with the new scheme and thereby minimise the need for new mapping. However, for some stratigraphical levels in some areas this has not proved possible, and those deemed in need of re-evaluation are identified.

## 1.1 DISCUSSION

If the above sets out the perceived strengths of the new scheme, it is important also to address its key weaknesses. A central problem is the new scheme seeks to impose a template that is to a greater or lesser extent interpretive. Yes, many of the key system and system tract boundaries are linked to mapped boundaries between units of differing lithological composition. But in some instances, these contacts are gradational and the selection of some as significant tract assemblage, systems tract and group boundaries appears subjective. Similarly, the local reassignment of formations to new or different sub-groups and groups is clearly also model-driven.

There are examples where critical event horizons linked to systems tract definition have been viewed as subordinate to lithostratigraphical best practice and established usage. This is to be anticipated. The dynamic sedimentology of some systems may enable them to resist or delay the impacts of regional and global events that, elsewhere, resulted in widespread tract-defining facies changes. Lithostratigraphical priority demands that the system tract is adapted to accommodate contiguous local facies. For example, channel and lobe facies of the Caban-Ystrad Meurig Subgroup continued to accumulate across the event horizon that marks the BIII-CI Systems tract boundary in the adjacent slope apron succession. Within the confines of the Clun Forest Sub-basin, sediment supply to southerly sourced Epynt Group deltaic facies (CII Systems Tract) resisted the changes in basin configuration and sediment provenance that marked the onset of CIII Systems Tract Mortimer Group accumulation in other sectors. In these cases, the local ranges of their host systems tracts have had to be adapted. Some will see the allowing established lithostratigraphical criteria locally to trump model-driven subjectivity as evidence of necessary and praiseworthy pragmatism - the view taken in this report. Others may feel that by allowing some systems to extend across the event horizons used elsewhere to recognise the systems tracts undermines one of the schemes unifying objectives. Yet the blanket imposition of systems tract criteria can lead to the problems seen in Snowdonia associated with Tract Assemblage A and the Nant Ffrancon Subgroup (see Text Box 3) and with the succession that spans the BIII-CI systems tract boundary in parts of mid Wales currently recognised as the Claerwen Group (see below).

**Text Box 17. Forcing factors associated with the CI Systems Tract:** The model advocated here, envisaging the diachronous installation of a Telychian tectonic systems tract, differs from ones that attribute regional facies and faunal changes primarily to global sea level movements. Neither forcing mechanism need be mutually exclusive, indeed elevated rates of regional subsidence might be expected to enhance the impacts of global transgressions. Such events, during the *guerichi, turricul*atus and *griestoniensis* biozones, could have facilitated the eastward expansion of the Trannon Group drape system across the Marginal Belt and Midland Platform (see Loydell, 1998; Ray *et al*., 2025). However, coincidental impacts are not obviously apparent in deeper water Welsh successions (e.g. Woodcock *et al*., 1996; Cherns *et al*., 2006). Moreover, there is, as yet, no fixed view on the timing or amplitude of Telychian eustatic events (see Melchin *et al*. 2020).

As an example, the widespread occurrence of *griestoniensis* Biozone faunas, including in platformal facies that are demonstrably transgressive (Wyche Formation), has been seen to provide the local evidence for the significant global deepening event recognised by Loydell (1998). Yet such an event finds no expression on other widely cited sea level curves, indeed, some associate the *griestoniensis* Biozone with an interval of depressed global sea levels (e.g. Woodcock *et al*., 1996, fig. 4). In the South Wales Sub-basin, this biozone marked a period of increased sediment supply and sandstone lobe expansion, and the subsidence of the regions that had previously experienced mass wasting (Figs 13 and 17) (e.g. Davies *et al*., 1997). Coincidental subsidence of the Marginal Belt and Midland Platform appears to offer a explanation for the faunal and facies relationships seen in these areas - with or without reference to a specific global sea level event.

A subsidence linked model appears at odds with data that associate the platformal Telychian succession with a period of declining subsidence rates (Butler *et al*., 1997). Such analysis relates specifically to the sites of the intra-platformal Woolhope and Usk sub-basins known to have experienced rapid rift-related subsistence during the Rhuddanian to Aeronian. Butler *et al*. (1997) attribute reduced Telychian rates of subsistence to post-rifting thermal decay. They do not differentiate strata assigned to the BIII and CI systems tracts and, hence, any associated rate differences, but their model allows the Telychian - or some part of it - to be viewed as a period when a regional subsidence regime overtook the local sub-basinal pattern.

The limited sedimentary and faunal data available for the concealed sub-basinal rocks, and for contiguous May Hill Inlier exposures, are insufficient to draw firm conclusions (Butler *et al*., 1997; Ziegler *et al*., 1968). However, eustasy may have played only a subordinate role in shaping the thick, sand-prone, Rhuddanian to early mid-Telychian succession (Figs 9, 10 and 13). The boundary between the BIII and CI systems tracts in these intra-platformal sub-basinal settings may mark a transition between two different types of tectonic systems tract. Firstly, an older rift to early post-rift systems tract that was characterised by the high subsidence and depositional rates associated with the May Hill Sandstone Subgroup. Secondly, the collision related tract that installed the regional subsidence regime associated with Trannon Group drape system and impacted this region during the mid-Telychian *crispus* Biozone (Fig. 13). Latest Telychian CII Systems Tract facies in Wales and its borderlands appear to record the impact of global events, but even at this level the role of eustasy is debated (see Section 2).

These conflicting ideals are highlighted when dealing with the base of the CI Systems Tract, which also marks the base of the third and youngest of the overarching tract assemblages, Tract Assemblage C. This systems tract records the important sedimentary and structural changes that overtook the LPWB and Midland Platform during the mid-Telychian that are widely acknowledged to record the regional impact of tectonism associated with Iapetus Ocean closure and plate collision. The seemingly most dramatic of these changes was the introduction to the southern sub-basin of the huge volumes of southerly derived turbiditic sand that built the sandstone lobe systems of the Central Wals Grit Group. These systems were accommodated within newly active, axially orientated fault troughs. The onset of intra-basinal faulting, which also initiated instability and mass wasting, is seen as a further indicator of the CI Systems Tract's collision-related credentials. Some may feel that, in seeking to identify a new systems tract boundary, it is the striking facies contacts linked to these changes in sedimentary regime that offer the most appropriate location. However, an arguably more significant marker of regional change was the accumulation of green and purple mud-prone facies not just in the South Wales Sub-basin, but also in North Wales and across the Marginal Belt and adjacent platform; facies that collectively record the development of the Trannon Group mudstone drape system. These successions confirm that it was enhanced rates of regional subsidence leading to a decoupling from eustatic influences that was key to the installation of a tectonic systems tract.

Yet, far from being an abrupt and synchronous regional event, this change in sedimentary and tectonic regime was diachronous (Text Box 7; Fig. 9). Collision-linked systems exhibit relationships with the deposits of the BIII Systems Tract that prove challenging in terms of system and system tract definition in ways that call into question the systems tract methodology (see Woodcock *et al*., 1996). In Marginal Belt settings, late Aeronian to mid-Telychian off-shore CI Systems Tract mud facies (Cerig or Purple Shale formations) accumulated alongside near shore, sand-prone facies of the BIII Systems Tract (Castell Powys Group). However, rather than marking a transition between coeval near shore and coeval off-shore facies, the diachronous expansion of the Trannon Group drape system can be argued to chart the eastwards progress of a collision-related subsidence front (see Fig. 13) (see Text Box 17). It is when viewed as such that its selection as the Tract Assemblage C basal boundary appears credible. Nevertheless, some may see the need to view contiguous sandy and muddy facies as belonging not only to separate depositional systems and groups, but to entirely different systems tracts and tract assemblages as questionable.

However, the need for a group-scale lithostratigraphy for the LPWB to capture one of the most fundamental events to affect it is surely compelling. Moreover, a significant caveat applies both in the context of the CI Systems Tract and to the systems tract approach as a whole. In the vast majority of cases, the boundaries of the formation scale lithostratigraphical units listed in this report are already shown on BGS maps. In the case of the CI Systems Tract, for example, aside from the very few areas where the Claerwen Group has been mapped as undivided, the upper boundary of the M. sedgwickii Shales Member has been identified. Hence, linework for the base of the redefined Rhayader Mudstones Formation and for the new Trannon Group already exists. In the Marginal Belt and platformal successions further east, the existing boundaries between the Pentamerus Grits and the Purple Shales formations and, in the south, between the Huntley Hill and Haugh Wood formations serve to locate the only significant early to mid-Telychian facies changes. In seeking to identify the earliest impacts of a collision-related systems tract and tract assemblage lithostratigraphically, no other readily mappable alternatives exist.

The new classification will, as was intended, have minimal impact on many map faces, although the recognition of synonyms will require the alteration of the map symbols used on some. Only in areas in need of resurvey will significant changes arise, and the hope there is that the new scheme provides an 'oven ready' classification to aid remapping. It is not intended that the new tract assemblage and system tract scheme will appear on large scale BGS maps, although adoption of the recommended group scale classification will make that self-evident. Use of this hierarchical nomenclature is optional, but it would principally appear on GVSs rather that map faces. Possible exceptions are where, in the short term and pending the results of remapping, some local outcrops may need to be designated undivided (e.g. Llangollen Group undivided) and an appropriate symbol devised. It is on smaller scale regional BGS maps that the new group and supergroup scheme has the potential to have the greatest impact, and, in aiding regional interpretation, achieve one of is overarching objectives.

# 2 Recommendations

## 2.1 NOMENCLATURE

An urgent recommendation is that the revisions to lithostratigraphical nomenclature identified in the report should be the subject of a rigorous review. This should seek to determine whether the scheme as whole should be adopted and enacted on BGS geological maps, or whether only a selection of the new terminology should be accepted. Appendix 2 lists all the lithostratigraphical units assessed in the report and identifies those that are new and those for which usage has been amended. A separate list is given of lithostratigraphical terms that are now considered redundant. These lists inform the principal categories of change:

1. Where synonymy has been recognised and an existing name that has priority has been identified. Since in most cases the defining linework already exits, this should be easily achievable within digital datasets. In some instances limited ground truthing to confirm lithological similarity of the suggested synonyms should be undertaken.
2. Adoption of new and adapted older terms in place of terms in current use that the report identifies as incorrect or redundant. Defining linework exists for many of these, but the use of some new terms will require limited remapping. The recommended downgrading of many of the units identified on current maps, from groups to subgroups for example, is readily achievable and, in a majority of cases, will have no impact on map faces.
3. Consideration should be given to the application of new group and subgroup scale terminology. Erection of a systems-based group nomenclature is a highlight of the report and provides the template for regional understanding that has been one of its central aims. Enabling this nomenclature will impact principally on the GVSs that

accompany large-scale BGS maps (50k and greater), but has the potential to inform a new generation of small-scale regional maps.

## 2.2 REMAPPING, SECTION LOGGING AND DATING

The need for further work in particular geographical areas and on certain levels of LPWB stratigraphy has been alluded to throughout the report. However, there are areas where remapping and reinvestigation are seen as particularly critical for key decisions to be taken. Unsurprisingly, the principal areas of uncertainty centre on regions where the mapping of Lower Palaeozoic strata dates from prior to the 2nd World War and/or where maps have been released by BGS as 'provisional' sheets. The latter are typically desk compilations based on mapping of differing age and from a variety of sources and, arguably, of varied and uncertain quality. The key areas that fall into these categories, in North Wales, are the Bala and Corwen sheets and the Lower Palaeozoic mapping included on the Wrexham and Oswestry provisional maps. In south-west Wales, they include the St. Davids provisional sheet and Lower Palaeozoic successions depicted on the extant Haverfordwest and Carmarthen sheets. The resources need to upgrade these maps to meet modern Lower Palaeozoic stratigraphical standards would be considerable. However, the report has the potential to inform a targeted approach that requires less resources. In some instances, revisiting key sections and acquiring new dating information may suffice to confirm the presence key facies changes and the timings of key events.

Some of the principal areas in need of remapping, and those aspects of Welsh Lower Palaeozoic stratigraphy in need of restudy and potential revision are as follows:

**Haverfordwest, Carmarthen, Ammanford and Llandovery sheets**

1. **Foel Cwmcerwyn Group**: The Triffleton and Eastern Cleddau subgroups are erected as mapping devices for Arenig successions in south-west Wales where many formation-scale divisions recognised during recent academic studies are not shown on the extant BGS maps. Targeted remapping of rocks currently shown as 'Tetragraptus Beds' and 'Didymograptus bifidus Beds', including the adaption of already mapped lithological units, may, with minimal effort, allow these subgroups to be adopted throughout the Foel Cwmcerwyn Group outcrop in south-west Wales. To apply recently erected formational nomenclature to these sheets would require a full resurvey of their regions of outcrop. The Ffairfach Grit Formation was accurately defined and mapped in the Ammanford district by Strahan *et al*. (1907). However, following the reinstatement of its original definition, targeted remapping on the Llandovery Sheet is needed to distinguish this unit from overlying AII Systems Tract divisions (see Text Box 4).

2. **Montgomery Group**: In light of the above, mapping to determine the distribution of the Garn, Coed Duon Volcanic and Golden Grove formations and an investigation to determine the true age of the basal beds at Golden Grove is required. The validity of including strata in the Haverfordwest district that are now recognised as the Narbeth Formation in an overarching Llandeilo Flags Subgroup needs confirmation.
3. **Ceiriog Group**: The basal relationships of the Sholeshook Limestone require confirmation, the conformable passage from the underlying Mydrim Shales Formation in the Whitland road cutting seeming to contrast with accounts that testify to unconformity elsewhere. The basal relationships of the Slade and Redhill Formation, also reported to be locally disconformable, also require confirmation. Trenching and/or cored boreholes may serve as the best methods to establish the nature and age of these contact relationships.
4. Resurveying of parts of the Ammanford district to install the recommended divisions of the **Epynt** and **Mortimer groups** is also advised.

**Milford Haven, Pembroke and Linney Head sheets**

1. The validity of the Musselwick Bay and Musselwick Flags formations need the confirmation that targeted section logging and dating could provide. Whether the latter properly forms part of the Llandeilo Flags Subgroup needs to be addressed.

**Mid Wales sheets (including Knighton)**

1. If the **Trannon Group** is to be universally adopted as a regional term for the CI Systems Tract succession, based on the definitions presented in Part 2, identification and mapping of the M. sedgwickii Shales Member is needed in areas where the former ‘Claerwen Group’ is shown as undivided on the Llangranog and Dinas Mawddwy sheets.
2. Limited remapping is required on the Rhayader, Builth Wells and Brecon sheets following the reassignment of parts of the Tycwtta Mudstones and Chwefri formations to the BII Systems Tract. Levels recognised as transgressive mid-Hirnantian rocks should be included, as is appropriate, in either the **Yr Allt**, or **Scrach groups**.
3. Limited remapping and nomenclature changes are needed on the Lampeter and Builth sheets to accommodate erection of the Llyn Brianne Formation and redefinition of the Nant Brianne Formation.
4. Adjustments to the mapping of the **Epynt Group** succession in northern part of Mynydd Epynt (Builth Wells Sheet) are needed following the redating and redesignation of the Fibua Member (see Text Box 15).

5. The Knighton Sheet is the last unpublished Lower Palaeozoic sheet in Wales and is its survey is in progress. It includes rocks assigned to a range of the new groups and provides to ideal opportunity to test and implement the new systems-based scheme. Mapping and subdivision of local **Bailey Hill Formation** succession to better understand of its hybrid origins and lateral relationships should be a priority.

**Llangollen Syncline: parts of the Corwen, Wrexham and Oswestry sheets**

1. The Lower Palaeozoic successions in this region require re-evaluation. Key facies and palaeogeographical boundaries appear to occur in an area that occupied the northern sector of the North Powys Sub-platform. Detailed analysis of the Hirnantian rocks, here branded the **Ceiriog Group**, is needed to assess their affinities to either the southern, or northern sub-basin successions. Their transition into the overlying succession and the validity, distribution and potential subdivision of the **Capel Garmon Group** all require further exploration.
2. The type succession of the **Llangollen Group** appears to contrast with the well documented succession seen in the Denbigh district further north. However, published accounts differ in their attempts at subdivision. Targeted remapping and biostratigraphical reassessment is required. The Llangollen Syncline succession also includes the most northerly expression of the **Penstrowed Grit Subgroup** turbidite system and targeted remapping may offer insight into its lateral relationship to the coeval, but separately sourced **Denbigh Grits Subgroup**.

**Bala and Corwen sheets**

The provisional nature of these maps is reflected in the use of lithostratigraphical labels now recognised as inconsistent with regional terminology and which the nomenclature advanced herein has sought rectify. Specific issues remain which require targeted investigations:

1. The nature and location of the diachronous interfaces that exist between the **Eryri, Hengae** and **Nod Glas groups** requires ground truthing (see Text Box 10). In this context, an assessment of the sedimentology of the Porthmadog Formation is overdue and differences in metamorphic grade should be accounted for.
2. These maps cover the historical type area of the Hirnantian Series, yet our understanding of the host stratigraphy is incomplete. The transition between the Hirnantian successions of the Dinas Mawddwy and Bala districts requires urgent reinvestigation with mapping and dating needed to confirm the validity and definition of the newly proposed **Cwm Hirnant Group**.

3. The Corwen Sheet mapping of the Silurian rocks that crop out along the northern flank of the Derwen Anticline requires revisiting. The successions of the putative **Feol Ddu** and **Garn Prys canyons** both warrant further investigation. Rigorous facies analysis and dating of the local Llandovery **Bron y graig Formation** is long overdue.

**Southwest Oswestry and northwest Welshpool sheets**

1. Remapping to the south the Tanat Fault designed to extend the Welshpool **Montgomery Group** stratigraphy on to the Oswestry sheet and to confirm the nature and position of its transition with Berwyn Dome's **Eryri Group** succession is urgently needed.
2. Confirmation is needed that inclusion of the Meifod area Hirnantian succession in the **Scrach Group** and erection of the local **Fron-haul Formation** are both justified, and that the distribution of these mid Hirnantian rocks has been correctly mapped along the limbs of the Brogan Anticline. Determining the nature of the facies changes that must take place between the Llandovery **Castell Powys** and **Pont Ewyd groups** in this same area is key to a better understanding of this succession, and a parallel investigation should seek to determine the local limit of Telychian mass-wasting that must exist in this, or closely adjoining settings.

**Snowdon, Bangor and Llandudno sheets**

1. The Llanvirn-early Caradoc succession of the northern Snowdonia region stands apart as the only one in North Wales where the erosional signature of the Mid-Ordovician Unconformity and/or the impacts of associated sedimentary events are seemingly unrecognisable. The succession may, in their absence, offer evidence for the late Abereiddian-Llandeilian deepening event seen in South Wales to confirm that the AI-AII systems tract boundary has basin wide sedimentary and lithostratigraphical expression (see Text Box 3). A targeted re-examination including the dating of key late Llanvirn parts of the local stratigraphy is required. Exposures from which *teretiusculus* Biozone faunas have been listed in the past (e.g. Williams, 1927; Greenly, 1944), and which are a source of confusion (e.g. Tryhall, 1993 and references therein), should be an initial focus for study. Pending these results of these investigation, the expression **Criccieth and Porthmadog formations undivided** could be deployed. Findings may lead to the restatement of the former **Maesgwm Slates Formation** in place of the new Criccieth Formation (see Text Box 3).
2. The Conwy area Ashgill to early Llandovery succession requires limited remapping to confirm the conceptual validity of the local **Conwy Group** and

**Capel Garmon Group** successions, and their recommended subdivisions. Warren *et al*.'s (1984) account of these strata suggests that, in the upper parts of the Conwy Group, the newly named **Colcon Mudstone Formation** offers a rare opportunity to obtain, and for the first time to classify graptolite faunas from mid Hirnantian strata in the LPWB - an option not possible in South Wales, where equivalent levels are barren of graptolites. In the first instance, a search should be undertaken to ascertain whether samples from the Colcon Road boreholes in which Warren *et al*. (1984) recognised fragmentary graptolites remains are still held by BGS and available for re-examination.

**Midland Platform sheets**

1. Mapping in this region in generally in good order, but the recommended nomenclature changes to divisions within the **Welsh Borderland Group** require approval and installation. Reassignment of some strata currently included in the outcrop of the Much Wenlock Limestone Formation that should correctly be included in the Coalbrookdale Formation requires enforcement.
2. Confirmation of the biozonal and isotopic credentials of the Ludlow Series GSSP is required to confirm regional correlations.
3. The proposal here to move away from the established nomenclature in place for the region's Ludlow rocks is a radical one that requires careful consideration. The approbation of senior academics familiar with these rocks and their history of research might be viewed as prerequisite to adoption of the newly proposed **Mortimer Group** and its component formations. Limited section logging may be required to confirm some new local formational assignments.
4. Rigorous dating of the **Rushall** and **Clifford's Mesne Sandstone formations** that form part of the Woolhope Inlier and May Hill Inlier successions is needed. This is to confirm their age and lithostratigrahical alignment for which, in addition to their favoured option (see above), Hiller *et al*. (2024) offer testable alternatives. It appears certain that the depiction of these, and of their Usk area correlative, on BGS paper and digital maps as 'Downton Castle Sandstone' is mistaken.

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# Appendix 1. List of BGS maps (see Fig. 2) and associated publications for the report area, including type of survey and adequacy of Ordovician and Silurian linework

Notes: 'Full survey' indicates that mapping was undertaken at the 1:10,560 or 10,000 scales; 'pre-war' relates only to Lower Palaeozoic linework; the term 'adequate' is used where existing linework requires little or no modification to enact the recommendations of this report (additional linework may be required and alternative linework may be available from other sources) (does not imply adequacy for other purposes). RapMap1 and 2 refer to different phases of the BGS rapid mapping programme in mid-Wales. 1, including the former Geological Survey of Great Britain and Institute of Geological Sciences; 2, dates of most recent and relevant older editions; 3, only those publications cited in the main text are included in the References; for details of the remainder, and of other published BGS material relevant to the report area, visit www.bgs.ac.uk>data collections.

| **BGS[1] 1:50,000 or 1:65360 scale sheets** | | | | |
|---|---|---|---|---|
| **No.** | **Name** | **Date[2]** | **Associated publication[3]** | **Comments on Lower Palaeozoic linework** |
| **94** | Llandudno | 1983 | Warren *et al.*, 1986 | Full survey; adequate |
| **95** | Rhyl | 1970 | Warren *et al.*, 1986 | Full survey; adequate |
| **105** | Caernarfon | 2015 | | See 118 |
| **106** | Bangor | 1985 | Howells et al., 1985 | Full survey; adequate |
| **107** | Denbigh | 1973 | Warren *et al.*, 1986 | Full survey; adequate |
| **108** | Flint | 1924; 1999 | Davies *et al.*, 2004 | Full survey; adequate |
| **118** | Nefyn | 2015 | | Full survey (includes part of 105); adequate |
| **119** | Snowdon | 1997 | Howells & Smith, 1997 | Full survey; adequate |
| **120** | Corwen | 1993 | See map face | Desk compilation; adequate |
| **121** | Wrexham | 1927; 1992 | Wedd *et al.*, 1927 | 1992 desk compilation (Provisional) |
| **133** | Aberdaron | 1994 | Gibbons & McCarroll, 1993 | Full survey (university contract); adequate |
| **134** | Pwllheli | 1999 | Younge *et al.*, 2004 | Full survey (university contract); adequate |
| **135** | Harlech | 1982 | Allen & Jackson, 1985 | Predominantly desk compilation; adequate |
| **136** | Bala | 1986 | | Desk compilation; adequate |
| **137** | Oswestry | 1928; 2000 | Wedd *et al.*, 1929 | Desk compilation (Provisional); adequate |
| **149** | Cadir Idris | 1995 | Pratt *et al.*, 1995 | Full survey (university contract); adequate |
| **150** | Dinas Mawddwy | 2012 | | RapMap2; adequate |

| | | | | |
|---|---|---|---|---|
| **151** | Welshpool | 2008 | Cave, 2008 | Full survey; adequate |
| **152** | Shrewsbury | 1932; 1978 | Pocock *et al.*, 1938; Hamblin, 1995 | Full survey (partially post-war); adequate |
| **153** | Wolverhampton | 2001 | Bridge *et al.*, 2003 | Full survey; adequate |
| **163** | Aberystwyth | 1984 | Cave & Hains, 1986 | Full survey; adequate |
| **164** | Llanidloes | 2010 | Wilson *et al.*, 2016 | RapMap2; adequate |
| **165** | Montgomery | 1984 | Cave & Hains, 2001 | Full survey; adequate |
| **166** | Church Stretton | 1967 | Greig et al., 1968 | Full survey; inadequate |
| **167** | Dudley | 1971 | Waters 2013 | Full survey; adequate |
| **177** | Aberaeron | 2006 | | RapMap1; adequate |
| **178** | Llanilar | 1994 | Davies *et al.*, 1997 | RapMap1; adequate |
| **179** | Rhayader | 1993 | Davies *et al.*, 1997 | RapMap1; adequate |
| **180** | Knighton | Under survey | | |
| **181** | Ludlow | 2000 | | Desk compilation (Provisional sheet) |
| **182** | Droitwich | 1976 | Mitchell, 962 | Full survey; adequate |
| **193** | Cardigan & Dinas Island | 2003 | Davies *et al.*, 2004 | Full survey (includes part of 210); adequate |
| **194** | Llangrannog | 2006 | Davies *et al.*, 2006 | RapMap2; adequate |
| **195** | Lampeter | 2007 | Davies *et al.*, 2006 | RapMap2; adequate |
| **196** | Builth Wells | 2005 | Schofield *et al*. 2004 | RapMap1; adequate |
| **197** | Hay-on-Wye | 2004 | Wilby, 2005 | Desk compilation (Provisional) |
| **198** | Hereford | 1989 | Brandon, 1989 | Dest compilation (Provisional) |
| **199** | Worcester | 1993 | Barclay et al., 1997 | Full survey; adequate |
| **209** | St. David’s | 1992 | | Desk compilation (Provisional); adequate |
| **210** | Fishguard | 2010 | Burt *et al.*, 2012 | RapMap2; adequate |
| **211** | Newcastle Emlyn | 2007 | Wilby *et al.*, 2007 | RapMap2; adequate |
| **212** | Llandovery | 2008 | Schofield *et al.*, 2009 | Part full survey, part RapMap2; adequate |
| **213** | Brecon | 2005 | Barclay *et al.*, 2005 | RapMap1; adequate |
| **214** | Talgarth | 2004 | Barclay & Wilby, 2003 | Desk compilation; inadequate |
| **215** | Ross-on-Wye | 2000 | Barclay & Smith, 2003 | Part full survey, part desk compilation; inadequate |
| **216** | Tewksbury | 1988 | Worssam *et al.*, 1989 | Full survey; adequate |
| **226/227** | Milford | 1922; 1978 | Cantrill *et al.*, 1916 | Full survey (pre-war); inadequate |
| **228** | Haverfordwest | 1920; 1976 | Strahan *et al.*, 1914 | Full survey (pre-war); inadequate |
| **229** | Carmarthen | 1910; 1967 | Strahan *et al.*, 1909 | Full survey (pre-war); inadequate |

| | | | | |
|---|---|---|---|---|
| **230** | Ammanford | 1907; 1977 | Strahan *et al.*, 1907; Squirrell & White, 1978 | Full survey; adequate |
| **232** | Abergavenny | 1902; 1990 | Barclay & Jackson, 1989 | Full survey; adequate |
| **233** | Monmouth | 1981 | Welsh &Trotter, 1961 | Full survey; adequate |
| **234** | Gloucester | 1975 | | Full survey; adequate |
| **244/245** | Pembroke & Linney Head | 1921; 1983 | Dixon, 1921 | Full survey (pre-war); adequate |
| **249** | Newport | 1902; 1987 | Squirrell *et al.*, 1969 | Full survey; adequate |
| **250** | Chepstow | 1981 | Welsh & Trotter, 1961 | Full survey; adequate |
| **263** | Cardiff | 1988 | Waters & Jackson, 1987 | Full survey; adequate |

| **Selected BGS[1] 1:25,000 scale sheets** | | | | |
|---|---|---|---|---|
| **No.** | **Name** | **Date** | **Associated publication[3]** | **Comments on Lower Palaeozoic linework** |
| **1** | Church Stretton | 1970 | Wright, 1968 | Full survey; adequate |
| **4** | Craven Arms | 1969 | Hains, 1969 | Full survey; adequate |
| **5** | Wenlock Edge | 1969 | Hains, 1971 | Full survey; adequate |
| **9** | Usk-Cwmbran | 1981 | | Full survey; adequate |
| **13** | Central Snowdonia | 1972 | | Superseded desk compilation |
| **14** | St. David's | 1973 | | Superseded desk compilation |
| **16** | Leintwardine-Ludlow | 1973 | | Full survey; adequate |
| **22** | Capel Curig & Betws-y-Coed | 1976 | Howells *et al.*, 1978 | Full survey; adequate |
| **26** | Llandrindod Wells | 1977 | | Superseded desk compilation |
| **28** | Telford | 1978 | | Full survey; adequate |
| **29** | Dolgarrog | 1981 | Howells *et al.*, 1981 | Full survey; adequate |
| **34** | Nant Ffrancon & Llanberis | 1985 | | Full survey; adequate |
| **35** | Bethesda & Foel-Fras | 1986 | | Full survey; adequate |
| **38** | Llyn Padarn | 1988 | | Full survey; adequate |
| **40** | Snowdon | 1989 | | Full survey; adequate |
| **41** | Conwy | 1989 | | Full survey; adequate |
| **44** | Shelve | 1991 | | Full survey; adequate |

# Appendix 2: Hierarchical list of system-based lithostratigraphical terms proposed and adopted in this report

Note: predominantly listed in the order they appear in the text; formation numbers as used on Figure 9.

## **PRESELI SUPERGROUP** (new name):

**Systems Tract Assemblage A:**

**AI SYSTEMS TRACT: DEPOSITIONAL SYSTEMS**

**FOEL CWMCERWYN GROUP** (new name):

**Triffleton Subgroup**:

1. Ogof Hên Formation
   - Allt Cystanog Member
   - Bolahaul Member
2. Carmarthen Formation
   - Pibwr Member
   - Cwmffrwd Member
   - Cwm yr Abbey Member
3. Abercastle Formation
4. Blaen cediw Formation
5. Afon Ffinant Formation
6. Roch Volcanic Formation

**Eastern Cleddau Subgroup** (new name)

7. Penmaen Dewi Shales Formation
8. Pontyfenni Formation
9. Llanfallteg Formation
10. Ysgoborwen Formation
11. Foel Tyrch Formation
12. Colomendy Formation
    - Rhyd Henllan Member
    - Castell-draenog Member
    - Whitland Abbey Member
13. Cwmfelin Boeth Formation
14. Capel Dewi Shales Formation
15. Sealyham Volcanic Formation

**Foel Cwmcerwyn Group formations outside subgroups:**

16. Aber Mawr Formation
17. Abergwilli Formation
18. Ffairfach Grit Formation
    - Carbery Mount Member (new name)
19. Porth Llauog Formation
20. Carn Llundain Formation
21. Musselwick Bay Formation (new name)

**SHELVE HILL GROUP** (new name):

22. Stiperstones Quartzite Formation
23. Mytton Flags Formation
24. Hope Shale Formation
    - Hyssington Volcanic Member
25. Weston Flags Formation
26. Stapeley Volcanic Formation
27. Camnant Mudstones Formation
    - Gelli Tuff Member

**CADIR IDRIS GROUP** (new name):

28. Allt Lŵyd Formation
    - Garth Grit Member
    - Graianog Sandstone Member
    - Llyfnant Member
    - Henllan Ash Member
    - Olchfa Member
    - Aran Boulder Bed Member
29. Bryncroes Formation
30. Wig Bach Formation
    - Wig Member
    - Trwyn Cam Member
31. Porth Meudwy Formation
32. St. Tudwal's Formation
    - Pared Mawr Member
    - Trwyn-yr-Wylfa Member
    - Penrhyn Du Member
    - Machroes Member

33. Llanengan Formation
34. Criccieth Formation
    - Hen-dy-capel Ironstone Member
    - Llandegai Ironstone Member
35. Trygarn Formation
    - Mynydd Rhiw Tuff Member
36. Cregennen Formation

## AI SYSTEMS TRACT: VOLCANIC SYSTEMS

**LOWER ARAN VOLCANIC GROUP** (adapted name) (see Rushton and Howells, 1998)

**FISHGUARD VOLCANIC GROUP:**

37. Porth Maen Melyn Formation
38. Strumble Head Volcanic Formation
39. Goodwick Volcanic Formation
40. Llanrhian Volcanic Formation
    - Lower Rhyolitic Tuff Member
    - Cyffredin Shale Member
    - Abereiddi Tuff Member

**BUILTH VOLCANIC GROUP:**

41. Llandrindod Tuff Formation
42. Gilwern Volcanic Formation
43. Carneddau Volcanic Formation
44. Llanelwedd Volcanic Formation
45. Cwm-amliw Tuff Formation

## AII SYSTEMS TRACT: DEPOSITIONAL SYSTEMS

**HENGAE GROUP** (revised usage):

46. Ty’r Gawen Formation
    - Fron Newydd Member
47. Ceiswyn Formation
    - Craig Hen-gae Member
    - Bwlch Siglen Member
48. Penyraber Mudstone Formation
    - Castle Point Member

Saddle Point Member

49. Cwm-y-Eglwys Mudstone Formation
50. Dinas Island Formation
    - Carreg Bica Mudstone Member
    - Cwm Degwel Mudstone Member
51. St. Cynthlo's Church Formation
    - Pistyllgwyn Member
52. Llanwrtyd Volcanic Formation
    - Kilsby Tuff Member
    - Nant Cerdin Tuff Member

**MONTGOMERY GROUP** (new name):

53. Bretton Shale Formation
54. Meadowtown Formation
55. Rorrington Shale Formation
56. Spy Wood Sandstone Formation
57. Aldress Shale Formation
58. Hagley Volcanic Formation
59. Hagley Shale Formation
60. Whittery Volcanic Formation
61. Whittery Shale Formation
62. Hoar Edge Grits Formation
63. Harnage Shales Formation
    - Hope Bowdler Pebble Bed
    - Smeathen Wood Member
    - Glenburrell Member
64. Chatwall Formation
    - Chatwall Flags Member
65. Cheney Longville Formation
    - Alternata Limestone Member
    - Glynboro Member
    - Crosspipes Member
66. Acton Scott Formation
    - Ragton Member
    - Henley Member
    - Wistanstow Member
67. Onny Formation

68. Stone House Shale Formation

    Middletown Quarry Member

69. Pwll-y-glo Formation
70. Gaerfawr Formation
71. Forden Mudstone Formation
72. Bulthy Formation
73. Hill Farm Formation
74. Newmead Sandstone Formation
75. Llanfair Mudstones Formation
76. Trelowgoed Volcanic Formation

**Llandeilo Flags Subgroup** (revised usage and rank):

77. Garn Formation (new name)
78. Coed Duon Volcanic Formation

    Rhyolitic Conglomerate Member (new name)

79. Golden Grove Formation (revised usage and rank)
80. Narbeth Formation (revised rank)

    Gilfach Member

    Bryn Glas Member

    Bryn Sion Member

    Bryn Banc Limestone Member

81. Musselwick Flags Formation (adapted name)

**Drefach Subgroup**:

82. Felin-wen Formation
83. Asaphus Ash Formation
84. Hendre Shales Formation
85. Mydrim Limestone Formation
86. Mydrim Shales Formation
87. Caerhys Shale Formation
88. Castell Limestone Formation

**ERYRI GROUP** (new name):

89. Porthmadog Formation (new name)

    Penrhyndeudraeth Member (new name)

    Rhyd Melange Member

    Moelfre Tuff Member

    Derfel Limestone Member

90. Moelfryn Volcanic Formation

Upper Moelfryn Volcanic Member

Lower Moelfryn Volcanic Member

91. Penamnen Tuff Formation

92. Cwm Eigiau Formation

    Prenteg Sandstone Member

    Moel Hebog Sandstone Member

    Blaen Eidda Member

93. Dwyfach Formation

    Plastirion Member

    Bodwrog Member

94. Yoke House Formation

95. Glyn Gower Siltstones Formation

    Cefn Gwyn Tuff Member

    Frondderw Tuff Member

96. Allt Ddu Formation

97. Gelli-grin Calcareous Ashes Formation

    Pont-y-ceunant Ash Member

    Cymerig Limestone Member

98. Craig-y-glyn Formation

    Pen-y-graig Tuff Member

    Mynydd Mawr Limestone Member

99. Llangynog Formation

100. Pen plaenau Siltstone Formation

    Cwm Clwyd Tuff Member

101. Terw Siltstone Formation

    Swrch Gorge Tuff Member

102. Bryn Siltstone Formation

    Pandy Tuff Member

    Pen-y-graig Tuff Member

103. Pen-y-garnedd Limestone Formation

**NOD GLAS GROUP** (revised usage and rank)

104. Pen-y-garnedd Phosphorite Formation (revised rank)

105. Nant-y-Nod Formation (new name)

106. Gwern-y-Brain Formation (new name)

**AII SYSTEM TRACT: VOLCANIC SYSTEMS** (see Rushton and Howells, 1998)

**UPPER ARAN VOLCANIC GROUP** (adapted name)

**LLEWELYN VOLCANIC GROUP**

**SNOWDON VOLCANIC GROUP**

**UPPERLODGE VOLCANIC GROUP**

**LLANBEDROG VOLCANIC GROUP**

## HAFREN SUPERGROUP (new name)

### Systems Tract Assemblage B:

### BI SYSTEMS TRACT: DEPOSITIONAL SYSTEMS

**CORRIS GROUP** (new name):

**Tresaith Subgroup** (new name):

107. Nantmel Mudstones Formation
    - Llwyncus Member
    - Eglwyswrw Member
    - Cefn Nantmel Member
108. Broad Vein Formation
109. Narrow Vein Formation
110. Nant-y-moch Formation
111. Doldowlod Formation
112. Bryn Nicol Formation
113. Taliaris Formation

**Llandillio Subgroup** (new name):

114. Dolhir Formation
    - Dolhir Limestone Member
    - Rhiwlas Limestone Member
    - Hafod Ifan Limestone Member
    - Glyn Limestone Member
115. Bodeidda Mudstones Formation (revised usage)
116. Crugan Mudstone Formation

**Whithybush Subgroup** (new name):

117. Sholeshook Limestone Formation
    Robeston Wathen Limestone Member
    Birdshill Limestone Member
    Crûg Limestone Member
118. Slade and Redhill Formation
119. Tridwr Formation
120. Cribarth Formation
    Penrhiwmoch Member

**BII SYSTEMS TRACT: DEPOSITIONAL SYSTEMS**

**YR ALLT GROUP** (adapted usage and rank):

121. Drosgol Formation
    Pencerrigtewion Member
    Dol-y-fan Conglomerate Member
122. Bryn-glâs Formation
    Lluest-Y-Graig Member
123. Lower Garnedd-wen Formation
    Aberangell Member
124. Upper Garnedd-wen Formation
125. Garclwyd Formation
126. Nodwydd Formation
127. St. Crannog Formation

**SCRACH GROUP** (adapted usage and rank):

128. Ciliau Formation
129. Cwmcringlyn Formation
130. Cwm Clyd Sandstone Formation
131. Gasallt-fawr Sandstone Formation
132. Garth House Formation
133. Portfield Formation
    Scotchwell Shale Member
    Cethings Sandstone Member
    Cuckoo Shales Member
134. Meifod Limestone Formation
135. Graig-wen Sandstone Formation
136. Fron-haul Formation (new name)

**CWM HIRNANT GROUP** (new name):

137. Lower Foel-y-dinas Formation (revised name pending confirmation)
    - Hirnant Limestone Member (parent to be confirmed)
138. Upper Foel-y-dinas Formation (revised name pending confirmation)
    - Calettwr Quartzite Member (parent to be confirmed)

**CEIRIOG GROUP** (new name)

139. Glyn Grit Formation
140. Corwen Grit Formation (revised rank)

**CONWY GROUP** (new name)

141. Conwy Castle Grit Formation
142. Colcon Mudstones Formation (new name)

## BIII SYSTEMS TRACT: DEPOSITIONAL SYSTEMS

**PONT ERWYD GROUP** (reinstated name):

143. Cwmere Formation
    - Mottled Mudstone Member
144. Cwm yr Aethen Mudstones Formation
145. Derwenlas Formation
    - M. sedgwickii Shales Member (revised parent)
146. Llyn Brianne Formation (new name)
    - Ystradffin Member (revised rank)
    - Dinas Member (revised rank)
147. Rhyddlan Formation
148. Allt Goch Formation
149. Glaslyn Formation
150. Tycwtta Mudstones Formation
    - Allt-y-clych Conglomerate Member

**Caban-Ystrad Meurig Subgroup**:

151. Caban Conglomerate Formation
    Cerig Gwynion Grits Member (adapted name)
152. Ystrad Meurig Formation

**CWM RHUDDAN GROUP** (new name):

153. Bronydd Formation
154. Chwefri Formation

Ystradwalter Member

155. Crychan Formation

156. Trefawr Formation

Ty Gwylim Sandstone Member

157. Rhydings Formation

158. Cefngarreg Sandstone Formation

159. Wormwood Formation

Ydw Member

Rhyd-y-saint Member

160. Haverford Mudstone Formation (parent to be confirmed)

St. Martin’s Cemetery Bed

161. Gasworks Sandstone Formation (parent to be confirmed)

**CASTELL POWYS GROUP** (new name):

162. Powis Castle Conglomerate Formation

163. Laundry Mudstone Formation

164. Pentamerus Sandstone Formation

Bog Quartzite Member

Kenley Grit Member

165. Trecoed Sandstone Formation (revised usage and rank)

166. Folly Sandstone Formation

167. Comin Coch Formation

Tyncoed Sandstone Member

168. Ty-mawr Formation

169. Derwyddon Formation

**May Hill Sandstone Subgroup** (revised usage and rank):

170. Fownhope Formation

Huntley Quarry Volcanic Member

171. Huntley Hill Formation

172. Cowleigh Park Formation

**CAPEL GARMON GROUP** (new name):

173. Bryn Dowsi Formation

174. Llanystumdwy Formation

175. Lower Dwfor Formation (adapted new name)

176. Bron y graig Formation

177. Fron Frys Formation

**BIII SYSTEMS TRACT: VOLCANIC SYSTEM**

**SKOMER VOLCANIC GROUP:**

178. Skomer Volcanic Group undivided
179. Cable Bay Formation (new name)
180. Rosemarket Formation (new name

**Systems Tract Assemblage C:**

**CI SYSTEMS TRACT: DEPOSITIONAL SYSTEMS**

**TRANNON GROUP** (new name):

**Newbridge Subgroup** (new name):

181. Cerig Formation
    - Mwmffri Sandstone Member
    - Glyn-moch Slide Complex
    - Ty-brith Mudstone Member
182. Millin Mudstone Formation
183. Purple Shales Formation
    - Letton Member (revised rank; tract assignment uncertain)
    - Woolhope Shale Member (adapted usage)

**Yarleton Subgroup** (adapted usage):

184. Haugh Wood Formation (amended usage)
185. Wyche Formation

**Trannon Group formations outside subgroups:**

186. Rhayader Mudstones Formation
    - Claerwen Dam Member (new name)
187. Nant Brianne Formation (amended usage)
188. Devil's Bridge Formation
189. Foel Fadian Formation
190. Erwan Fach Formation
191. Dolgau Mudstones Formation
192. Gyffin Formation
193. Ty Draw Slates Formation
194. Upper Dwfor Formation (adapted new name)
195. Cwm Barn Formation
196. Henfryn Formation

**CENTRAL WALES GRITS GROUP** (new name):

**Aberystwyth Grits Subgroup** (revised rank):

197. Mynydd Bach Formation

  Cwmtydu Member (status to be confirmed)

  Grogal Member (status to be confirmed)

198. Trefechan Formation

**Cwmystwyth Grits Subgroup** (revised rank):

199. Rhuddnant Grits Formation

  Llyn Teifi Member

200. Pysgotwr Grits Formation

201. Doethei Formation

202. Glanyrafon Formation

**Gelli Shale Subgroup** (revised rank):

203. Borth Mudstones Formation

204. Adail Mudstones Formation

205. Blaen Myherin Mudstones Formation

206. Caerau Mudstones Formation

## CII SYSTEMS TRACT: DEPOSITIONAL SYSTEMS

**LLANGOLLEN GROUP** (new name):

207. Benarth Flags Formation (adapted name)

  Benarth Hall Member (new name)

208. Nantglyn Flags Formation

  Esgair-Ebril Member

209. Nant-ysgollon Mudstones Formation

  Esgair Hir Member

  Crenulatus Member (adapted name)

210. Llanbadarn Formation

  Gregynog Mudstone Member

  Dolygarn Member

  Pentre’r beirdd Tuff Member (new name)

**Llangollen Group divisions known to comprise unmapped formations:**

211. **Denbigh Grits Subgroup** (revised rank)

212. **Elwy Subgroup** (revised rank)

213. **Penstrowed Grits Subgroup** (revised rank)

  The Moat Tuff Member (new name)

  Domen-ddu Tuffaceous Mudstone Member (new name)

214. **Llangollen Group undivided** (of the Llangollen Syncline region)

**WELSH BORDERLAND GROUP** (new name):

215. Builth Mudstones Formation
    - Cefn Member (new name)
    - Dolfawr Mudstones Member (revised rank)
    - Caer-beris Member
    - Cefn Cerig Slide Complex
216. Trewern Brook Mudstone Formation
    - Butterley Mudstone Member
    - Glyn member
217. Buildwas Formation
    - Hughley Brook Member (new name)
218. Coalbrookdale Formation
    - Farley Member
219. Aston Mudstone Formation
    - Edgton Limestone member
220. Much Wenlock Limestone Formation
    - Lower Quarried Member
    - Nodular Member
    - Upper Quarried Member
    - Longville Member
    - Wildehope Member (new name)
221. Woolhope Limestone Formation
    - *Petalocrinus* Limestone Bed
222. Nash Scar Limestone Formation
    - Dolyhir Rudite Member
223. Ton Siltstone Formation
    - Trostrey Limestone Member
224. Pen-y-lan Mudstone Formation
225. Cae Castell Formation
    - Rhymney Grit Member
    - Newport Road Member
226. Oakeley Mynd Shale Formation
227. Wootton Formation (adapted name)
    - Pitch Coppice Mudstones Member (adapted name)
228. Goggin Road Formation (new name)

229. Hill Gardens Formation

230. Aymestry Formation
    - Vinnals Siltstones Member (revised rank)
    - Aymestry Limestone Member (revised rank)

231. Llandegfedd Formation (new name)
    - Porth-llong Member (new name)
    - Llancaeo Hill Member (new name)

232. Eastern Avenue Formation (revised usage and rank)

**EPYNT GROUP** (new name):

233. Llangammarch Formation

234. Tirabad Formation

235. Sawdde Sandstone Formation

236. Ffinnant Sandstone Formation

237. Halfway Farm Formation
    - Pwll-calch Limestone Member

238. Irfon Formation
    - Cwm-yr-hob Member (revised parent)
    - Lugg Member (new name)
    - Mocktree Shales Member (adapted name)

239. Knucklas Castle Formation
    - Fibua Member (revised rank and parent)

240. Hafod Fawr Formation
    - Cam-rhiw Member
    - Cwar Glas Member

241. Mynydd Myddfai Sandstone Formation

242. Trichrug Formation
    - Llethr-grarw Member (new)

243. Aberedw Formation

244. Gyffeni Wood Shales Formation

245. Bailey Hill Formation (usage in need re-evaluation)
    - Dingle Mudstone Member
    - Brynrorin Conglomerate Member

**MARLOES GROUP** (of the Skomer Sub-basin)

246. Coralliferous Formation

247. Gray Sandstone Formation

Renney Slip Member
Deadman’s Bay Member

**CIII SYSTEMS TRACT: DEPOSITIONAL SYSTEMS**

**MORTIMER GROUP** (new name):

248. Cae’r mynach Formation
    - Cribyn Du Member
    - Blaisdon Conglomerate Member
    - Clencher’s Mill Member
    - Woodbury Shale Member
    - Chapel Wood Member
    - Roath Park Lake Member
    - Ludlow Bone Bed Member
    - Ludlow Bone Bed
    - Platyschisma Shale Member
    - Downton Bone Bed
    - Aston Munslow Member
    - Lower Linton Pebble Bed
    - Upper Linton Pebble Bed
249. Tilestones Formation
250. Downton Castle Sandstone Formation
251. Clifford’s Mesne Sandstone Formation
252. Dinas Brân Formation

## OLD RED SANDSTONE SUPERGROUP (see Barclay *et al.*, 2016)

Selected divisions only:

253. Red Cliff Formation
254. Albion Sands Formation
    - Lynsway Bay Member
255. Abercynfor Formation
256. Temeside Formation
    - Temside Bone Bed
257. Moor Cliffs Formation
258. Rushall Formation
259. Pwll-Mawr Formation
260. Freshwater East Formation
261. Pont ar Llechau Formation

# Appendix 3: Alphabetical list of lithostratigraphical terms proposed and adopted in this report map including map symbols, parent units and system tract affiliations

Notes re numbers shown in superscript: 1, as used on published BGS paper maps and in this report – other symbols are in use in BGS digital data sets and in published reports and papers, those shown in standard brackets are older symbols no longer considered appropriate and those in square brackets are for symbols that only appear on figures in this report; 2, symbols used for component facies not recognised as formal lithostratigraphical divisions; 3, symbol also used for the now defunct Cardiff Group; 4, non-alphabetical; 5, not currently shown on BGS maps of Dol-y-fan Conglomerate Member outcrop area; 6, units inadvertently given the same map symbol. Divisions without symbols are those recommended for adoption that are either only listed in published papers, or newly proposed herein

| UNIT NAME | BGS map symbol[1] | PARENT UNIT | Systems tract/tract assemblage |
|---|---|---|---|
| **Aberangell Member** | - | Lower Garnedd-wen Formation | BII |
| **Aber Mawr Formation** | Abm | Foel Cwmcerwyn Group | AI |
| **Abercastle Formation** | - | Trffleton Subgroup | AI |
| **Abercynfor Formation** | [AyF] | Old Red Sandstone Supergroup | - |
| **Aberedw Formation** | AbF | Epynt Group | CII |
| **Abereiddi Tuff Member** | - | Llanrhian Volcanic Formation | AII |
| **Abergwilli Formation** | Ab | Foel Cwmcerwyn Group | AI |
| **Aberystwyth Grits Subgroup** | AG | Central Wales Grits Group | CI |
| **Acton Scott Formation** | (b3e) | Montgomery Group | AII |
| **Adail Mudstones Formation** | AdI | Gelli Shale Subgroup | CI |
| **Afon Ffinant Formation** | - | Triffleton Subgroup | AI |
| **Albion Sands Formation** | [AS] | Old Red Sandstone Supergroup | - |
| **Aldress Shale Formation** | AdSh | Montgomery Group | AII |
| **Allt Cystanog Member** | - | Ogof Hên Formation | AI |
| **Allt Ddu Formation** | ADM | Eryri Group | AII |
| **Allt Goch Formation** | AIG | Pont Erwyd Group | BIII |
| **Allt Lŵyd Formation** | Alt | Cadir Idris Group | AI |
| **Allt-y-clych Conglomerate Member** | AyC | Tycwtta Mudstones Formation | BIII |
| **Alternata Limestone Member** | - | Cheney Longville Formation | AII |
| **Aran Boulder Bed Member** | (c) | Allt Lŵyd Formation | AI |
| **Asaphus Ash Formation** | AA | Drefach Subgroup | AII |
| **Aston Mudstone Formation** | ATS | Welsh Borderland Group | CII |
| **Aston Munslow Member** | [AMM] | Cae'r mynach Formation | CIII |
| **Aymestry Formation** | - | Welsh Borderland Group | CII |

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| **Aymestry Limestone Member** | AL | Aymestry Formation | CII |
| **Bailey Hill Formation** | BAI | Epynt Group | CII |
| **Benarth Flags Formation** | - | Llangollen Group | CII |
| **Benarth Hall Member** | - | Benarth Flags Formation | CII |
| **Bettws Tuff Member** | Btw | Camnant Mudstones Formation | AI |
| **Birdshill Limestone Member** | - | Sholeshook Limestone Formation | BI |
| **Blaen cediw Formation** | - | Trffleton Subgroup | AI |
| **Blaen Eidda Member** | Beid | Cwm Eigiau Formation | AII |
| **Blaen Myherin Mudstones Formation** | BMM | Gelli Shale Subgroup | CI |
| **Blaisdon Conglomerate Member** | [BlM] | Cae’r mynach Formation | CIII |
| **Bodeidda Mudstones Formation** | - | Llandillio Subgroup | BI |
| **Bodwrog Member** | - | Dwyfach Formation | AII |
| **Bog Quartzite Member** | - | Pentamerus Sandstone Formation | BIII |
| **Bolahaul Member** | - | Ogof Hên Formation | AI |
| **Borth Mudstones Formation** | BMF | Gelli Shale Subgroup | CI |
| **Bretton Shale Formation** | Bet | Montgomery Group | AII |
| **Broad Vein Formation** | BV | Tresaith Subgroup | BI |
| **Bron y graig Formation** | Brng | Capel Garmon Group | BIII |
| **Bronydd Formation** | BrF | Cwm Rhuddan Group | BIII |
| **Bryn Banc Member** | - | Narbeth Formation | AII |
| **Bryn Dowsi Formation** | BDo | Capel Garmon Group | BIII |
| **Bryn Glas Member** | - | Narbeth Formation | AII |
| **Bryn Nicol Formation** | (ClF/BD)[2] | Tresaith Subgroup | BI |
| **Bryn Siltstone Formation** | Bryn | Eryri Group | AII |
| **Bryn Sion Member** | - | Narbeth Formation | AII |
| **Bryncroes Formation** | Br | Cadir Idris Group | AI |
| **Bryn-glâs Formation** | BGF | Yr Allt Group | BII |
| **Brynrorin Conglomerate Member** | - | Bailey Hill Formation | CII |
| **Buildwas Formation** | [Bui] | Welsh Borderland Group | CII |
| **Builth Volcanic Group** | BVG | Preseli Supergroup | AI |
| **Builth Mudstones Formation** | BMd | Welsh Borderland Group | CII |
| **Bulthy Formation** | Bu | Montgomery Group | AII |
| **Butterley Mudstone Member** | [ButM] | Trewern Brook Formation | CII |
| **Caban Conglomerate Formation** | CCF | Caban-Ystrad Meurig Subgroup | BIII |
| **Caban-Ystrad Meurig Subgroup** | - | Pont Erwyd Group | BIII |
| **Cable Bay Formation** | [CBF] | Skomer Volcanic Group | BIII |
| **Cadir Idris Group** | - | Preseli Supergroup | AI |
| **Cae Castell Formation** | CCa | Welsh Borderland Group | CII |
| **Cae’r mynach Formation** | Car[3] | Mortimer Group | CIII |
| **Caerau Mudstones Formation** | CaM | Gelli Shale Subgroup | CI |
| **Caer-beris Member** | Cbs | Builth Mudstones Formation | CI |

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| **Caerhys Shale Formation** | Chy | Drefach Subgroup | AII |
| **Calettwr Quartzite Member** | - | Upper Foel-y-dinas Formation | BII |
| **Camnant Mudstones Formation** | Cte | Shelve Hill Group | AI |
| **Cam-rhiw Member** | [CrM] | Hafod Fawr Formation | CII |
| **Capel Dewi Shales Formation** | - | Eastern Cleddau Subgroup | AI |
| **Capel Garmon Group** | - | Hafren Supergroup | BIII |
| **Carmarthen Formation** | Cmn | Trffleton Subgroup | AI |
| **Carn Llundain Formation** | Lnd[4] | Foel Cwmcerwyn Group | AI |
| **Carneddau Volcanic Formation** | Cdu | Builth Volcanic Group | AI |
| **Carreg Bica Mudstone Member** | CBi | Dinas Island Formation | AII |
| **Castell Limestone Formation** | CL | Drefach Subgroup | AII |
| **Castell Powys Group** | - | Hafren Supergroup | BIII |
| **Castell-draenog Member** | - | Colomendy Formation | AI |
| **Castle Point Member** | Cap | Penyraber Mudstone Formation | AII |
| **Cefn Member** | - | Builth Mudstones Formation | CII |
| **Cefn Cerig Slide Complex** | - | Builth Mudstones Formation | CII |
| **Cefn Gwyn Tuff Member** | CGT | Glyn Gower Siltstones Formation | AII |
| **Cefn Nantmel Member** | Cnt | Nantmel Mudstones Formation | BI |
| **Cefngarreg Sandstone Formation** | Ceg | Cwm Rhuddan Group | BIII |
| **Ceiriog Group** | - | Hafren Supergroup | BII |
| **Ceiswyn Formation** | Csw | Hengae Group | AII |
| **Central Wales Grits Group** | - | Hafren Supergroup | CI |
| **Cerig Formation** | Cer | Newbridge Subgroup | CI |
| **Cethings Sandstone Member** | Ceth | Portfield Formation | BII |
| **Chapel Wood Member** | [CWM] | Cae'r mynach Formation | CIII |
| **Chatwall Formation** | (b3c) | Montgomery Group | AII |
| **Chatwall Flags Member** | - | Chatwall Formation | AII |
| **Cheney Longville Formation** | (b3d) | Montgomery Group | AII |
| **Chwefri Formation** | ChF | Cwm Rhuddan Group | BIII |
| **Ciliau Formation** | CiF | Scrach Group | BII |
| **Claerwen Dam Member** | [CDM] | Rhayader Mudstones Formation | CI |
| **Clencher's Mill Member** | - | Cae'r mynach Formation | CIII |
| **Clifford's Mesne Sandstone Formation** | - | Mortimer Group | CIII |
| **Coalbrookdale Formation** | Cbrd | Welsh Borderland Group | CII |
| **Coed Duon Volcanic Formation** | (Z, R)[2] | Llandeilo Flags Subgroup | AII |
| **Colcon Mudstones Formation** | - | Conwy Group | BII |
| **Colomendy Formation** | Cmd | Eastern Cleddau Subgroup | AI |
| **Comin Coch Formation** | CoC | Castell Powys Group | BIII |
| **Conwy Castle Grit Formation** | CCG | Conwy Group | BII |
| **Conwy Group** | - | Hafren Supergroup | BII |
| **Coralliferous Formation** | (b6) | Marloes Group | CII |

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| **Corris Group** | - | Hafren Supergroup | BI |
| **Corwen Grit Formation** | Cown | Ceiriog Group | BII |
| **Cowleigh Park Formation** | CPa | May Hill Sandstone Subgroup | BIII |
| **Craig Hen-gae Member** | CH | Ceiswyn Formation | AII |
| **Craig-y-glyn Formation** | CgF | Eryri Group | AII |
| **Cregennen Formation** | Crg | Cadir Idris Group | AI |
| **Crenulatus Member** | - | Nant-ysgollon Mudstones Formation | CII |
| **Cribarth Formation** | Cri | Llandillio Subgroup | BI |
| **Cribyn Du Member** | CrD | Cae'r mynach Formation | CIII |
| **Criccieth Formation** | - | Cadir Idris Group | AI |
| **Crosspipes Member** | - | Cheney Longville Formation | AII |
| **Crûg Limestone Member** | - | Sholeshook Limestone Formation | BI |
| **Crugan Mudstone Formation** | CM | Llandillio Subgroup | BI |
| **Crychan Formation** | CcF | Cwm Rhuddan Group | BIII |
| **Cuckoo Shales Member** | - | Portfield Formation | BII |
| **Cwar Glas Member** | CwG | Hafod Fawr Formation | CII |
| **Cwm Barn Formation** | Cbn | Trannon Group | CI |
| **Cwm Clwyd Tuff Member** | CCT | Pen plaenau Siltstone Formation | AII |
| **Cwm Clyd Sandstone Formation** | CCy | Scrach Group | BII |
| **Cwm Degwel Mudstone Member** | CwD | Dinas Island Formation | AII |
| **Cwm Eigiau Formation** | CEi | Eryri Group | AII |
| **Cwm Hirnant Group** | - | Hafren Supergroup | BII |
| **Cwm Rhuddan Group** | - | Hafren Supergroup | BIII |
| **Cwm yr Abbey Member** | - | Carmarthen Formation | AI |
| **Cwm yr Aethen Mudstones Formation** | CyA | Pont Erwyd Group | BIII |
| **Cwm-amliw Tuff Formation** | CaT | Builth Volcanic Group | AI |
| **Cwmcringlyn Formation** | CgF | Scrach Group | BII |
| **Cwmere Formation** | CeF | Pont Erwyd Group | BIII |
| **Cwmfelin Boeth Formation** | Cfb | Eastern Cleddau Subgroup | AI |
| **Cwmffrwd Member** | - | Carmarthen Formation | AI |
| **Cwmtydu Member** | - | Mynydd Bach Formation | CI |
| **Cwm-y-Eglwys Mudstone Formation** | CyE | Hengae Group | AII |
| **Cwm-yr-hob Member** | CyH | Irfon Formation | CII |
| **Cwmystwyth Grits Subgroup** | CGG | Central Wales Grits Group | CI |
| **Cyffredin Shale Member** | - | Llanrhian Volcanic Formation | AI |
| **Cymerig Limestone Member** | Cym | Gelli-grin Calcareous Ashes Formation | AII |
| **Deadman's Bay Member** | - | Gray Sandstone Formation | CII |
| **Denbigh Grits Subgroup** | DG | Llangollen Group | CII |
| **Derfel Limestone Member** | - | Porthmadog Formation | AII |
| **Derwenlas Formation** | DlF | Pont Erwyd Group | BIII |
| **Derwyddon Formation** | DDd | Castell Powys Group | BIII |

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| **Devil's Bridge Formation** | DBF | Trannon Group | CI |
| **Dinas Brân Formation** | DB | Mortimer Group | CIII |
| **Dinas Island Formation** | DI | Hengae Group | AII |
| **Dinefwr Subgroup** | - | Montgomery Group | AII |
| **Dingle Mudstone Member** | DiM | Bailey Hill Formation | CII |
| **Doethei Formation** | Dot | Cwmystwyth Grits Subgroup | CI |
| **Doldowlod Formation** | Dd | Tresaith Subgroup | BI |
| **Dolfawr Mudstones Member** | Dol | Builth Mudstones Formation | CII |
| **Dolgau Mudstones Formation** | Dgu | Trannon Group | CI |
| **Dolhir Formation** | Dolh | Llandillio Subgroup | BI |
| **Dolhir Limestone Member** | DL | Dolhir Formation | BI |
| **Dol-y-fan Conglomerate Member** | DCM | Drosgol Formation[5] | BII |
| **Dolygarn Member** | - | Llanbadarn Formation | CII |
| **Dolyhir Limestone Formation** | Dlh | Welsh Borderland Group | CII |
| **Dolyhir Rudite Member** | - | Dolyhir Limestone Formation | CII |
| **Domen-ddu Tuffaceous Mudstone Member** | - | Penstrowed Grits Subgroup undivided | CII |
| **Downton Bone Bed** | - | Platyschisma Shale Member | CIII |
| **Downton Castle Sandstone Formation** | DCS | Mortimer Group | CIII |
| **Drefach Subgroup** | Dr | Montgomery Group | AII |
| **Drosgol Formation** | DRF | Yr Allt Group | BII |
| **Dwyfach Formation** | Dwf | Eryri Group | AII |
| **Eastern Avenue Formation** | [EAF] | Welsh Borderland Group | CII |
| **Eastern Cleddau Subgroup** | - | Feol Cwmcerwyn Group | AI |
| **Edgton Limestone Member** | EL | Aston Mudstone Formation | CII |
| **Eglwyswrw Member** | (sa) | Nantmel Mudstones Formation | BI |
| **Elwy Subgroup** | Ey | Llangollen Group | CII |
| **Epynt Group** | - | Hafren Supergroup | CII |
| **Erwan Fach Formation** | ErF | Trannon Group | CI |
| **Eryri Group** | - | Preseli Supergroup | AII |
| **Esgir-Ebril Member** | - | Nantglyn Flags Formation | CII |
| **Esgair Hir Member** | - | Nant-ysgollon Mudstones Formation | CII |
| **Farley Member** | - | Coalbrookdale Formation | CII |
| **Felin-wen Formation** | Fw | Drefach Subgroup | AII |
| **Ffairfach Grit Formation** | - | Foel Cwmcerwyn Group | AI |
| **Ffinnant Sandstone Formation** | Ff | Epynt Group | CII |
| **Fibua Member** | Fib | Knucklas Castle Formation | CII |
| **Fishguard Volcanic Group** | FVG | Preseli Supergroup | AI |
| **Foel Cwmcerwyn Group** | - | Preseli Supergroup | AI |
| **Foel Fadian Formation** | FoF | Trannon Group | CI |
| **Foel Tyrch Formation** | FT | Eastern Cleddau Subgroup | AI |
| **Folly Sandstone Formation** | - | Castell Powys Group | BIII |

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| **Forden Mudstone Formation** | FMF | Montgomery Group | AII |
| **Fownhope Formation** | - | May Hill Sandstone Subgroup | BIII |
| **Freshwater East Formation** | [FEW] | Old Red Sandstone Supergroup | - |
| **Fron Newydd Member** | FrN | Ty'r Gawen Formation | AII |
| **Frondderw Tuff Member** | Fron | Glyn Gower Siltstones Formation | AII |
| **Fron Frys Formation** | FrFr | Capel Garmon Group | BIII |
| **Fron-haul Formation** | - | Scrach Group | BII |
| **Gaer Fawr Formation** | GFF | Montgomery Group | AII |
| **Garclwyd Formation** | - | Yr Allt Group | BII |
| **Garn Formation** | - | Llandeilo Flags Subgroup | AII |
| **Garth Grit Member** | GaG | Allt Lŵyd Formation | AI |
| **Garth House Formation** | GHF | Scrach Group | BII |
| **Gasallt-fawr Sandstone Formation** | Gll | Scrach Group | BII |
| **Gasworks Sandstone Formation** | (b4) | Cwm Rhuddan Group | BIII |
| **Gelli Subgroup** | - | Cwmystwyth Grits Subgroup | CI |
| **Gelli Tuff Member** | Glh | Camnant Mudstone Formation | AI |
| **Gelli-grin Calcareous Ashes Formation** | Gel | Eryri Group | AII |
| **Gilfach Member** | - | Narbeth Formation | AII |
| **Gilwern Volcanic Formation** | GwV | Builth Volcanic Group | AI |
| **Glanyrafon Formation** | Glr | Cwmystwyth Grits Subgroup | CI |
| **Glaslyn Formation** | Gly | Pont Erwyd Group | BIII |
| **Glenburrell Member** | - | Harnage Shales Formation | AII |
| **Glyn Grit Formation** | Glyn | Ceiriog Group | BII |
| **Glyn Member** | - | Trewern Brook Mudstone Formation | CII |
| **Glyn Gower Siltstones Formation** | GyG | Eryri Group | AII |
| **Glyn Limestone Member** | - | Dolhir Formation | BI |
| **Glynboro Member** | - | Cheney Longville Formation | AII |
| **Glyn-moch Slide Complex** | (db) | Cerig Formation | CI |
| **Goggin Road Formation** | - | Welsh Borderland Group | CII |
| **Golden Grove Formation** | - | Llandeilo Flags Subgroup | AII |
| **Goodwick Volcanic Formation** | GdV | Fishguard Volcanic Group | AI |
| **Graianog Sandstone Member** | Gra | Allt Lŵyd Formation | AI |
| **Graig-wen Sandstone Formation** | GwS | Scrach Group | BII |
| **Gray Sandstone Formation** | (b7) | Marloes Group | CII |
| **Gregynog Mudstone Member** | GYM | Penstowed Grits Subgroup | CII |
| **Grogal Member** | - | Mynydd Bach Formation | CI |
| **Gwern-y-Brain Formation** | - | Nod Glas Group | AII |
| **Gyffeni Wood Shales Formation** | GFS | Epynt Group | CII |
| **Gyffin Formation** | - | Trannon Group | CI |
| **Hafod Fawr Formation** | Hod | Epynt Group | CIII |
| **Hafod Ifan Limestone Member** | Half | Dolhir Formation | BI |

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| **Hafren supergroup** | - | Welsh Basin-Midland Platform Marine Mega-system | B & C |
| **Hagley Shale Formation** | HgSh | Montgomery Group | AII |
| **Hagley Volcanic Formation** | Hgy | Montgomery Group | AII |
| **Halfway Farm Formation** | HaF | Epynt Group | CII |
| **Harnage Shales Formation** | b3b | Montgomery Group | AII |
| **Haugh Wood Formation** | - | Yarleton Subgroup | BIII |
| **Haverford Mudstone Formation** | (b4) | Cwm Rhuddan Group | BIII |
| **Hendre Shales Formation** | HS | Drefach Subgroup | AII |
| **Hen-dy-capel Ironstone Member** | HdC | Criccieth Formation | AI |
| **Henfryn Formation** | Hen | Trannon Group | CI |
| **Hengae Group** | - | Preseli Supergroup | AII |
| **Henley Member** | - | Acton Scott Formation | AII |
| **Henllan Ash Member** | - | Allt Lŵyd Formation | AI |
| **Hill Farm Formation** | HiF | Montgomery Group | AI |
| **Hill Gardens Formation** | - | Welsh Borderland Group | CII |
| **Hirnant Limestone Member** | - | Lower Foel-y-dinas Formation | BII |
| **Hoar Edge Grits Formation** | (b3a) | Montgomery Group | AII |
| **Hope Shale Formation** | Hop | Shelve Hill Group | AI |
| **Hughley Brook Member** | - | Buildwas Formation | CII |
| **Huntley Hill Formation** | HH | May Hill Sandstone Subgroup | BIII |
| **Huntley Quarry Volcanic Member** | - | Fownhope Formation | BIII |
| **Hyssington Volcanic Member** | Hys | Hope Shale Formation | AI |
| **Irfon Formation** | IrF | Epynt Group | CII |
| **Kenley Grit Member** | (b5c') | Pentamerus Sandstone Formation | BIII |
| **Kilsby Tuff Member** | KiT | Llanwrtyd Volcanic Formation | AII |
| **Knucklas Castle Formation** | KC | Epynt Group | CII |
| **Laundry Mudstone Formation** | LdM | Castell Powys Group | BIII |
| **Letton Member** | - | Purple Shales Formation | ?CI |
| **Llanbadarn Formation** | - | Llangollen Group | CII |
| **Llanbedrog Volcanic Group** | LBV | Preseli Supergroup | AII |
| **Llancaeo Hill Member** | - | Llandegfedd Formation | CII |
| **Llandegai Ironstone Member** | - | ? Criccieth Formation | AI |
| **Llandegfedd Formation** | - | Welsh Borderland Group | CII |
| **Llandeilo Flags Subgroup** | LlF | Montgomery Group | AII |
| **Llandillio Subgroup** | - | Corris Group | BI |
| **Llandrindod Tuff Formation** | LdT | Builth Volcanic Group | AI |
| **Llanelwedd Volcanic Formation** | Ldd | Builth Volcanic Group | AI |
| **Llanengan Formation** | Lgn | Cadir Idris Group | AI |
| **Llanfallteg Formation** | Lfg | Eastern Cleddau Subgroup | AI |
| **Llanfawr Mudstones Formation** | LrM | Montgomery Group | AII |
| **Llangammarch Formation** | Llg | Epynt Group | AII |

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| **Llangollen Group** | - | Hafren Supergroup | CII |
| **Llangynog Formation** | LgF | Eryri Group | AII |
| **Llanrhian Volcanic Formation** | LV | Fishguard Volcanic Group | AI |
| **Llanwrtyd Volcanic Formation** | Lla | Hengae Group | AII |
| **Llanystumdwy Formation** | LIM | Capel Garmon Group | BIII |
| **Llethr-grarw Member** | [Lly] | Trichrug Formation | CII |
| **Llewelyn Volcanic Group** | LlV | Preseli Supergroup | AII |
| **Lugg Member** | - | Irfon Formation | CII |
| **Llwyncus Member** | (spm, db) | Nantmel Mudstones Formation | BI |
| **Llyfnant Member** | - | Allt Lŵyd Formation | AI |
| **Llyn Brianne Formation** | - | Pont Erwyd Group | BIII |
| **Llyn Teifi Member** | LyT | Rhuddnant Grits Formation | CI |
| **Longville Member** | - | Much Wenlock Limestone Formation | CII |
| **Lower Aran Volcanic Group** | - | Preseli Supergroup | AI |
| **Lower Dwfor Formation** | (DwM) | Capel Garmon Group | BIII |
| **Lower Foel-y-dinas Formation** | (Fyd) | Cwm Hirnant Group | BII |
| **Lower Garnedd-wen Formation** | - | Yr Allt Group | BII |
| **Lower Linton Pebble Bed** | [LLPB] | Cae’r mynach Formation | CIII |
| **Lower Moelfryn Volcanic Member** | LmV | Moelfryn Volcanic Formation | AII |
| **Lower Quarried Member** | - | Much Wenlock Limestone Formation | CII |
| **Lower Rhyolitic Tuff Member** | - | Llanrhian Volcanic Formation | AI |
| **Ludlow Bone Bed Member** | [LBBM] | Cae’r mynach Formation | CIII |
| **Ludlow Bone Bed** | - | Ludlow Bone Bed Member | CIII |
| **Lynsway Bay Member** | [LB] | Albion Sands Formation | - |
| **M. sedgwickii Shales Member** | (lhs) | Derwenlas Formation | BIII |
| **Machroes Member** | Mch | St. Tudwal’s Formation | AI |
| **Marloes Group** | - | Hafren Supergroup | CII |
| **Meadowtown Formation** | Mtn | Montgomery Group | AII |
| **Meifod Limestone Formation** | - | Scrach Group | BII |
| **Middletown Quarry Member** | MiQ | Stone House Shale Formation | AII |
| **Millin Mudstone Formation** | (b4) | Newbridge Subgroup | CI |
| **Mocktree Shales Member** | - | Irfon Formation | CII |
| **Moel Hebog Sandstone Member** | MoH | Cwm Eigiau Formation | AII |
| **Moelfre Tuff Member** | MT | Porthmadog Formation | AII |
| **Moelfryn Volcanic Formation** | MV | Eryri Group | AII |
| **Montgomery Group** | - | Preseli Supergroup | AII |
| **Moor Cliffs Formation** | [MC] | Old Red Sandstone Supergroup | - |
| **Mortimer Group** | - | Hafren Supergroup | CIII |
| **Mottled Mudstone Member** | MMb | Cwmere Formation | BIII |
| **Much Wenlock Limestone Formation** | WeL | Welsh Borderland Group | CII |
| **Musselwick Bay Formation** | (b2) | Foel Cwmcerwyn Group | AI |

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| **Musselwick Flags Formation** | (b2) | ? Llandeilo Flags Subgroup | AII |
| **Mwmffri Sandstone Member** | MfS | Cerig Formation | CI |
| **Mydrim Limestone Formation** | MLF | Drefach Subgroup | AII |
| **Mydrim Shales Formation** | MSF | Drefach Subgroup | AII |
| **Mynydd Bach Formation** | MBa | Aberystwyth Grits Subgroup | CI |
| **Mynydd Mawr Limestone Member** | (CgF) | Craig-y-glyn Formation | AII |
| **Mynydd Myddfai Sandstone Formation** | MyS | Epynt Group | AII |
| **Mynydd Rhiw Tuff Member** | ($Z^R$) | Trygarn Formation | AI |
| **Mytton Flags Formation** | My | Shelve Hill Group | AI |
| **Nant Brianne Formation** | NBr | Trannon Group | CI |
| **Nant Cerdin Tuff Member** | NCT | Llanwrtyd Volcanic Formation | AII |
| **Nantglyn Flags Formation** | NGF | Llangollen Group | CII |
| **Nantmel Mudstones Formation** | Ntm | Tresaith Subgroup | BI |
| **Nant-y-moch Formation** | NF | Tresaith Subgroup | BI |
| **Nant-y-Nod Formation** | - | Nod Glas Group | AII |
| **Nant-ysgollon Mudstones Formation** | Nyg | Llangollen Group | CII |
| **Narbeth Formation** | (b2) | ? Llandeilo Flags Subgroup | AII |
| **Narrow Vein Formation** | NV | Tresaith Subgroup | BI |
| **Newbridge Subgroup** | - | Trannon Group | CI |
| **Newmead Sandstone Formation** | Nwd | Montgomery Group | AII |
| **Nod Glas Group** | Nod | Presli Supergroup | AII |
| **Nodular Member** | - | Much Wenlock Limestone Formation | CII |
| **Nodwydd Formation** | - | Yr Allt Group | BII |
| **Oakeley Mynd Shale Formation** | OAK | Welsh Borderland Group | CII |
| **Ogof Hên Formation** | OgH | Trffleton Subgroup | AI |
| **Olchfa Member** | - | Allt Lŵyd Formation | AI |
| **OLD RED SANDSTONE SUPERGROUP** | | | - |
| **Onny Formation** | (b3f) | Montgomery Group | AII |
| **Pandy Tuff Member** | PaT | Bryn Siltstone Formation | AII |
| **Pared Mawr Member** | PM | St. Tudwal’s Formation | AI |
| **Pen plaenau Siltstone Formation** | Ppn | Eryri Group | AII |
| **Penamnen Tuff Formation** | PnT | Eryri Group | AII |
| **Pencerrigtewion Member** | PTM | Drosgol Formation | BII |
| **Penmaen Dewi Shales Formation** | PeD | Eastern Cleddau Subgroup | AI |
| **Penrhiwmoch Member** | PrM | Cribarth Formation | BII |
| **Penrhyn Du Member** | PD | St. Tudwal’s Formation | AI |
| **Penrhyndeudraeth Member** | - | Porthmadog Formation | AII |
| **Penstrowed Grits Subgroup** | PdG | Llangollen Group | CII |
| **Pentamerus Sandstone Formation** | PeS | Castell Powys Group | BIII |
| **Pentre’r beirdd Tuff Member** | - | Llanbadarn Formation | CII |

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| **Pen-y-garnedd Limestone Formation** | Pgd | Eryri Group | AII |
| **Pen-y-garnedd Phosphorite Formation** | [PPh] | Nod Glas Group | AII |
| **Pen-y-graig Tuff Member** | (CgF) | Craig-y-glyn Formation | AII |
| **Pen-y-lan Mudstone Formation** | Pyn | Welsh Borderland Group | CII |
| **Penyraber Mudstone Formation** | PeA | Hengae Group | AII |
| ***Petalocrinus* Limestone Bed** | - | Woolhope Limestone Formation | CII |
| **Pibwr Member** | - | Carmarthen Formation | AI |
| **Pistyllgwyn Member** | PiM | St. Cynthlo's Church Formation | AII |
| **Pitch Coppice Mudstones Member** | [PCMM] | Wootton Formation | CII |
| **Plastirion Member** | - | Dwyfach Formation | AII |
| **Platyschisma Shale Member** | [PShM] | Cae'r mynach Formation | CIII |
| **Pont ar Llechau Formation** | Pol | Old Red Sandstone Supergroup | - |
| **Pont Erwyd Group** | - | Hafren Supergroup | BIII |
| **Pont-y-ceunant Ash Member** | Pyc | Gelli-grin Calcareous Ashes Formation | AII |
| **Pontyfenni Formation** | Ptf | Eastern Cleddau Subgroup | AI |
| **Portfield Formation** | (b4) | Scrach Group | BII |
| **Porth Llauog Formation** | Pla | Foel Cwmcerwyn Group | AI |
| **Porth Maen Melyn Formation** | PMV | Fishguard Volcanic Group | AI |
| **Porth Meudwy Formation** | PMu | Cadir Idris Group | AI |
| **Porth-llong Member** | | Llandegfedd Formation | CII |
| **Porthmadog Formation** | - | Eryri Group | AII |
| **Powys Castle Conglomerate Formation** | PCC | Castell Powys Group | BIII |
| **Prenteg Sandstone Member** | Ps | Cwm Eigiau Formation | AII |
| **PRESELI Supergroup** | - | Welsh Basin-Midland Platform Marine Mega-system | A |
| **Purple Shales Formation** | PuS | Newbridge Subgroup | CI |
| **Pwll-calch Limestone Member** | - | Halfway Farm Formation | CII |
| **Pwll-Mawr Formation** | [Pwl] | Old Red Sandstone Supergroup | - |
| **Pwll-y-glo Formation** | Pyg | Montgomery Group | AII |
| **Pysgotwr Grits Formation** | Ptr | Cwmystwyth Grits Subgroup | CI |
| **Ragton Member** | - | Acton Scott Formation | AII |
| **Red Cliff Formation** | [RC] | Old Red Sandstone Supergroup | - |
| **Renney Slip Member** | - | Gray Sandstone Formation | CII |
| **Rhayader Mudstones Formation** | Rhs | Trannon Group | CI |
| **Rhiwlas Limestone Member** | RwL | Dolhir Formation | BI |
| **Rhuddnant Grits Formation** | Rdd | Cwmystwyth Grits Subgroup | CI |
| **Rhyd Henllan Member** | - | Colomendy Formation | AI |
| **Rhyd Melange Member** | Rhyd | Porthmadog Formation | AII |
| **Rhyddlan Formation** | Rhy | Pont Erwyd Group | BIII |
| **Rhydings Formation** | Ryg | Cwm Rhuddan Group | BIII |

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| **Rhyd-y-saint Member** | - | Wormwood Formation | BIII |
| **Rhyolitic Conglomerate Member** | (R) | Coed Duon Volcanic Formation | AII |
| **Roath Park Lake Member** | [RPLM] | Cae'r mynach Formation | CIII |
| **Robeston Wathen Limestone Member** | (b3) | Sholeshook Limestone Formation | BI |
| **Roch Volcanic Formation** | RV | Foel Cwmcerwyn Group | AI |
| **Rorrington Shale Formation** | Rrr | Montgomery Group | AII |
| **Rosemarket Formation** | (b5) | Skomer Volcanic Group | BIII |
| **Rhymney Grit Member** | Rhm | Cae Castell Formation | CII |
| **Rushall Formation** | RF | Old Red Sandstone Supergroup | - |
| **Saddle Point Member** | SaP | Penyraber Mudstone Formation | AII |
| **Sawdde Sandstone Formation** | Saw | Epynt Group | CII |
| **Scotchwell Shale Member** | (b4) | Portfield Formation | BII |
| **Scrach Group** | - | Hafren Supergroup | BII |
| **Sealyham Volcanic Formation** | Syhm | Foel Cwmcerwyn Group | AI |
| **Shelve Hill Group** | - | Preseli Supergroup | AI |
| **Sholeshook Limestone Formation** | SL | Whithybush Subgroup | BI |
| **Skomer Volcanic Group** | - | Hafren Supergroup | BIII |
| **Slade and Redhill Formation** | (b3) | Whithybush Subgroup | BI |
| **Smeathen Wood Member** | - | Harnage Shales Formation | AII |
| **Snowdon Volcanic Group** | SVG | Preseli Supergroup | AII |
| **Spy Wood Sandstone Formation** | SpW | Montgomery Group | AII |
| **Stapeley Volcanic Formation** | SyV | Shelve Hill Group | AI |
| **St. Crannog Formation** | - | Yr Allt Group | BII |
| **St. Cynthlo's Church Formation** | SCC | Hengae Group | AII |
| **St. Martin's Cemetery Bed** | - | Haverford Mudstone Formation | BIII |
| **St. Tudwal's Formation** | ST | Cadir Idris Group | AI |
| **Stiperstones Quartzite Formation** | StQ | Shelve Hill Group | AI |
| **Stone House Shale Formation** | SHV | Montgomery Group | AII |
| **Strumble Head Volcanic Formation** | SGT | Fishguard Volcanic Group | AI |
| **Swrch Gorge Tuff Member** | SGT | Terw Siltstone Formation | AII |
| **Taliaris Formation** | Tal | Tresaith Subgroup | BI |
| **Temeside Formation** | Tem | Old Red Sandstone Supergroup | - |
| **Terw Siltstone Formation** | Terw | Eryri Group | AII |
| **The Moat Tuff Member** | - | Penstrowed Grits Subgroup undivided | CII |
| **Tilestones Formation** | Til | Mortimer Group | CIII |
| **Tirabad Formation** | Tir | Epynt Group | CII |
| **Ton Siltstone Formation** | TS | Welsh Borderland Group | CII |
| **Trannon Group** | - | Hafren Supergroup | CI |
| **Trecoed Sandstone Formation** | Trc | Castell Powys Group | BIII |
| **Trefawr Formation** | TrF | Cwm Rhuddan Group | BIII |
| **Trefechan Formation** | Trf | Aberystwyth Grits Subgroup | CI |

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| **Trelowgoed Volcanic Formation** | TrV | Montgomery Group | AII |
| **Tresaith Subgroup** | - | Corris Group | BI |
| **Trewern Brook Mudstone Formation** | TBM | Welsh Borderland Group | CII |
| **Trichrug Formation** | Tug | Epynt Group | CII |
| **Tridwr Formation** | Tri | Whithybush Subgroup | BI |
| **Triffleton Subgroup** | Tri | Foel Cwmcerwyn Group | AI |
| **Trostrey Limestone Member** | TL | Ton Siltstone Formation | CII |
| **Trwyn Cam Member** | TnC | Wig Bach Formation | AI |
| **Trwyn-yr-Wylfa Member** | TW | St. Tudwal's Formation | AI |
| **Trygarn Formation** | Tgn | Cadir Idris Group | AI |
| **Tycwtta Mudstones Formation** | Tyc | Pont Erwyd Group | BIII |
| **Ty Draw Slates Formation** | TyS | Trannon Group | CI |
| **Ty Gwylim Sandstone Member** | TyG[6] | Trefawr Formation | BIII |
| **Ty'r Gawen Formation** | TyG[6] | Hengae Group | AII |
| **Ty-brith Mudstone Member** | Tyb | Cerig Formation | CI |
| **Ty-mawr Formation** | TM | Castell Powys Group | BIII |
| **Tyncoed Sandstone Member** | Tyn | Comin Coch Formation | BIII |
| **Upper Aran Volcanic Group** | - | Preseli Supergroup | AII |
| **Upper Dwfor Formation** | (DwM) | Trannon Group | CI |
| **Upper Foel-y-dinas Formation** | (Fyd) | Cwm Hirnant Group | BII |
| **Upper Garnedd-wen Formation** | - | Yr Allt Group | BII |
| **Upper Linton Pebble Bed** | [ULPB] | Cae'r mynach Formation | CIII |
| **Upper Lodge Volcanic Group** | ULV | Preseli Supergroup | AII |
| **Upper Moelfryn Volcanic Member** | UmV | Moelfryn Volcanic Formation | AII |
| **Upper Quarried Member** | - | Much Wenlock Limestone Formation | CII |
| **Vinnals Siltstone Member** | [VSM] | Aymestry Limestone Formation | CII |
| **Welsh Borderland Group** | - | Hafren Supergroup | CII |
| **Weston Flags Formation** | Wsn | Shelve Hill Group | AI |
| **Whithybush Subgroup** | - | Corwen Group | BI |
| **Whitland Abbey Member** | - | Colomendy Formation | AI |
| **Whittery Shale Formation** | WtSh | Montgomery Group | AII |
| **Whittery Volcanic Formation** | Wty | Montgomery Group | AII |
| **Wig Bach Formation** | WgB | Cadir Idris Group | AI |
| **Wig Member** | Wig | Wig Bach Formation | AI |
| **Wilderhope Member** | - | Much Wenlock Limestone Formation | CII |
| **Wistanstow Member** | - | Acton Scott Formation | AII |
| **Woodbury Shale Member** | - | Cae'r mynach Formation | CIII |
| **Woolhope Limestone Formation** | WoL | Welsh Borderland Group | CII |
| **Woolhope Shale Member** | [WoSh] | Purple Shales Formation | CI |
| **Wootton Formation** | - | Welsh Borderland Group | CII |
| **Wormwood Formation** | WoW | Cwm Rhuddan Group | BIII |
| **Wyche Formation** | Wy | Yarleton Subgroup | CI |

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| **Yarleton Subgroup** | Yt | Trannon Group | CI |
| **Ydw Member** | [Ydw] | Wormwood Formation | BIII |
| **Yoke House Formation** | YkH | Eryri Group | AI |
| **Yr Allt Group** | YA | Hafren Supergroup | BII |
| **Ysgoborwen Formation** | Ys | Eastern Cleddau Subgroup | AI |
| **Ystrad Meurig Grits Formation** | YGF | Caban-Ystrad Meurig Subgroup | BIII |
| **Ystradwalter Member** | Yst | Chwefri Formation | BIII |

# Appendix 4: North Powys, North Pembrokeshire and Llŷn sub-platforms

Note: location of these sub-platforms and their relationship to other important regional structural features is shown in Figure 6.

**North Powys Sub-platform**: This feature sustained shallow water deposition across a large sector of north-east Wales to the west of the Severn-Garth-Cwm Cynnen Fault Zone at a time when the deep-water North and South Wales sub-basins were evolving. In detail, it comprises several structural components. In the south, it includes the Guilsfield Anticlinal Horst and Brogan Anticline, and by inference the intervening synclines. Its dominant central or axial feature is the box-like Berwyn Dome (cryptic strike faults affecting the northern, western and southern flanks suggest the term 'Berwyn Block' may be a more appropriate label). The Dyfnant, Tanat and Cynlaeth faults form part of a set of *en echelon* fractures that traverse the dome's southern flank, where they serve to separate lithostratigraphical divisions. The successions of the Cyrn-y-Brain and Mynydd Cricor inliers, though sited to the north of the substantial Llangollen Syncline, display Tract Assemblage B successions that are comparable to other parts of the sub-platform. Hence, both the inliers and the synclinal region are recognised as elements a northern extension of the sub-platform.

The North Powys Sub-platform's central region forms part of the Derwen-Berwyn Axis, and for much of its active history the sub-platform served to connect this axis to the Marginal Belt and to extend their combined depositional influence. As a structurally positive region, though it failed to isolate the evolving South Wales Sub-basin from external oceanic influence, it acted to limit the spread of deeper water Systems Tract AII facies (Hengae Group). Only the Caradoc facies of the axial Berwyn Dome region offer a record of contemporary emergence linked to Eryri Group vulcanism (Brenchley *et al*., 2006). The sub-platform was influential during Nod Glas Group deposition in promoting condensation and phosphorite accumulation. It was a region of widespread non-deposition (or sediment removal) during the development of the Systems Tract BII drape system (Corris Group), and again it was the axial region that experienced greatest omission (Brenchley et al., 2006b, fig. 3.41). The sub-platform was a site of emergence and erosion during the Hirnantian glacioeustatic lowstand (Systems Tract BII) and contributed to the southern sub-basin's isolation (e.g. Davies *et al*., 2009). Much of the Berwyn Dome region may also have resisted the earliest phases of the post-glacial transgression. Shallow water conditions were maintained across the northern and southern parts of the sub-platform during the Rhuddanian (Systems Tract BIII).

The Telychian witnessed the final fragmentation and foundering of the North Powys Sub-platform during the development of Systems Tract CI. Mass-wasting destroyed any record of

BIII and early CI System Tract deposition across the Derwen-Berwyn axial region whereas subsidence allowed the early accumulation of Trannon Group deposits to the north and south. The axial region succumbed during the mid to late Telychian as the Trannon Group drape system obtained its maximum extent. There is little to suggest a Wenlock revival as southerly sourced sandstone-lobe facies (Penstowed Grits Sub-group) advanced well to the north of the former axis, across the site of the former sub-platform, and as far as the Llanelidian Fault. The area of the North Powys Sub-platform likely experienced renewed uplift during the late Ludlow reconfiguration of LPWB, but only as part of a much larger region of inversion.

**North Pembrokeshire Sub-platform:** Throughout the late Llanvirn and Caradoc, at a time when the SWSB was evolving into a site of deep-water turbidite deposition (Hengae Group), north Pembrokeshire acted as the structurally positive region here recognised as the North Pembrokeshire Sub-platform. The latter sustained distal graptolitic mud accumulation (Drefach Subgroup) until the close of the Caradoc. The boundary between these separate regimes, recognised today as the Aber Richard Fault, was seemingly abrupt. As the sub-basin developed, uplift along the northern edge of North Pembrokeshire Sub-platform promoted sites of shoal deposition. These were the source of material shed onto the sub-basin's foundered southern margin (Castle Point Member) (Davies *et al*., 2003). Subsequent, more pronounced mass wasting saw the local destruction of the margin's late Llanvirn to early Caradoc succession and the northward emplacement of melange-like mass-movement facies (Saddle Point Member). In contrast, the mud facies of the North Pembrokeshire Sub-platform passed seamlessly southwards into the Marginal Belt successions of south Pembrokeshire and Carmarthenshire forming part of an extensive region of distal mud accumulation across which anoxic bottom conditions were the norm.

During the Ashgill, the North Pembrokeshire Sub-platform region was onlapped by the turbiditic facies of the Corris Group drape system and the diving line between deep and shallow water deposition shifted south to the Cwm Cynnen Fault. The sub-platform's role subsequently can only be speculated on. It likely experienced some form of reactivation during the Shelveian deformation and may then then have served as region of shallow Scrach Group facies accumulation at the time of the Hirnantian glacial lowstand (Fig. 14). The Haverfordwest location of the southerly sourced Cwm Rhuddan Group ramp system implies that the sub-platform, located some distance to the north, became the site of deeper facies accumulation (Pont Erwyd Group) as the post-glacial transgression progressed. The location of proximal Telychian sandstone lobe facies suggests that their source deltas were positioned on the sub-platform and that its distal margins may have served to limit the extent of delta advanced (e.g. Smith, 1987; Wilson et al., 1990). However, in common with much of west Wales (see text), the North Pembrokeshire Sub-platform likely experienced partial inversion from late Telychian times onwards. This putative deltaic succession was subsequently denuded as the sub-platform's role as an independent structural feature ceased.

**Llŷn Sub-platform:** The Menai Strait Fault System intervenes between the Llŷn Sub-platform and the regionally important Irish Sea Platform that lay to the north-west (Fig. 5). However, lateral movements along the fault system render palispastic relationships of its adjoining regions uncertain. The Cwm Pennant Fault Belt (located further west than shown on BGS, 1997) and fractures that define the southern limit of Padarn Tuff Formation outcrops in the Bangor district (BGS, 1985) serve as the sub-platform's bounding structures to the east and north-east (Figs 12 and 15). Kokelaar (1988, p. 768) essentially recognised the Llŷn Sub-platform's margin when charting the north-western boundary of his 'Pitts Head Graben'. The St. Tudwal's Block, located south of the Sarn-Abersoc Thrust, strongly affected AI Systems Tract facies development during the Arenig and can be viewed as an early, south-westerly component of the subsequently more extensive sub-platform (Fig. 15). During the early Llanvirn, regional subsidence and deepening associated with the expansion of the Snowdon Trough promoted the subsequent accumulation of a thick mud-prone succession (Criccieth Formation), however, the sub-platform remained a site prone to shoaling and oolitic ironstone formation. Its most obvious expression was during the late Llanvirn and early Caradoc evolution of the AII Systems Tract in North Wales. Initially, at that time, the sub-platform formed part of much larger region of uplift that likely linked the Irish Sea Platform, via the Harlech Horst, to an embryonic Derwen Anticline (Smith *et al*., 1995). Much of this larger province then experienced the instability and foundering that was the prelude to Caradoc regional vulcanism. The emplacement of synsedimentary slides and melange-like mass-mass movement deposits, and the widespread excision of earlier stratigraphy accompanied these events (Smith *et al*., 1995). However, whereas deposition (Porthmadog Formation) had resumed throughout much of Snowdonia in the early Caradoc (Costonian), the Llŷn Sub-platform remained an area of sediment exclusion and/or erosion locally until Longvillian times (Young *et al*., 2002).

Kokelaar (1988) documented the influence of the Cwm Pennant Fault Belt and *en echelon* structures on the location and form of the Pitts Head Tuff Caldera and on the distribution of contemporary sedimentary and volcanic facies. However, the sub-platform and its bounding structures find little expression in subsequent Llongvillian to mid-Hirnantian stratigraphy. In common with areas to the east, the sub-platform hosted mid-late Caradoc eruptive centres (Upper Lodge and Llanbedrog Volcanic groups) as well as the Nefyn Cluster of igneous intrusions (BGS, 2015). Latest Caradoc (Nod Glas Group) and Ashgill (Crugan Mudstone Formation) rocks resemble closely those seen in more easterly areas of Snowdonia and the Conwy Valley. However, the sub-platform formed an emergent region once again during the

Hirnantian when its links to the Derwen-Berwyn Axis were likely reinstated. BIII and early CI Systems Tract facies resemble those of in the Conwy area. But from late Telychian (post-*crispus* Biozone) times onwards the Llŷn area merged with a larger region located to the west of the Conwy Valley Fault Belt that went on to supply sediment to the deep-water CII Systems Tract sub-systems of the North Wales Sub-basin (Denbigh Grits and Elwy sub-groups). Denudation of this source region, in common with much of west Wales, ensued (Fig. 14).

# Figures, plates and tables

# Figures

1, during the acme of the Homerian shoaling event, taxa belonging to the V. trewerna brachiopod biofacies were able to colonise large areas of contemporary slope apron systems (see text).

Figure 8. Schematic depiction of depositional systems recognised in the Preseli and Hafren supergroup successions of the LPWB and Midland Platform. Selected features and examples: 1, patch reefs (e.g. in Much Wenlock Limestone Formation); 2, platform margin shoals and shell banks (e.g. in Aymestry Formation); 3, alluvial fan (e.g. Trichrug Formation); 4, barrier sand body and back-barrier/estuarine mud belt (e.g. Clifford's Mesne Sandstone and Rushall formations); 5, submarine canyon (e.g. Garn Prys Canyon); 6, levee-bound, gravel-lined channels supplying sandy turbidite lobes (e.g. Caban Conglomerate-Ystrad Meurig Sandstone Subgroup); 7, intra-basinal site of mass-wasting & condensation (e.g. Nod Glas Group); 8, anoxic and distal sub-platformal graptolitic muds (e.g. Mydrim Shales Formation); 9, distributary mouth bars (e.g. in Tilestones Formation), 10, slump & slump scar (e.g. in Yr Allt Group); 11, synsedimentary slide with associated debrites/melange & olistoliths affecting shallow water facies (e.g. Glyn-moch Slide Complex); 12, channel-lobe transition zone (e.g. proximal Pysgotwr Grits Formation); 13, structurally located islands & shoals (e.g. Builth High); 14, basal unconformity (e.g. sub-Arenig Penobscotian Unconformity); 15, transgressive basal sand bodies (e.g. Ogof Hen Formation); 16, black muds with restricted trilobite fauna (e.g. Cwm yr Abbey Member); 17, sandy turbidites and other mass-flow deposits (e.g. Afon Ffinant Formation); 18, volcanic caldera (e.g. Pitts Head Tuff Formation); 19, volcano-clastic sand blanket (e.g. Cwm Eigiau Formation); 20, Marginal Belt sub-basin (e.g. Shelve-Builth Sub-basin); 21, intra-platformal sub-basin and volcanic centre (e.g. Skomer Volcanic Group); 22, foot-of-slope limestone accumulation (e.g. parts of Sholeshook Limestone Formation); 23, limestone resting on omission surface (e.g. Rhiwlas Limestone Member); 24, seamless transition from shallower storm-influenced to deeper turbiditic sand bed facies within mud-dominated drape system (e.g. Tridwr Formation); 25, region of uplift and peneplaination (e.g. Shelveian Unconformity); 26, sandy turbidites ponded in basin centre (e.g. Nant-y-moch Formation); 27, proximal sand-prone facies of mudstone drape system (e.g. Yarleton Subgroup).

Figure 9. Schematic systems based lithostratigraphical architecture for the LPWB and adjoining areas. GROUPS are indicted by upper case text and subgroups by lower case text; selected formations and members are labelled as such; numbers in parentheses refer to the list of formations in Appendix 2. Abbreviations: Conglom, Conglomerate; FfG, Ffairfach Grit; Fm, Formation; FVG, Fishguard Volcanic Group; In, Inlier; Is, Island; Lst, Limestone; Mbr, Member; plat, platform; Sst, Sandstone. * principally relate to AII-CII systems tracts; + North Powys Sub-platform acted as a structurally positive region linked to the Derwen-Berwyn Axis (see Appendix 4). Features in numbered circles: 1, basal AI System Tract deposits vary widely in age above rift-related irregularities in the Penobscotian Unconformity (see text); 2, range of omission associated with Haverfordwest Tilt-block; 3, in the Llangadog area, BII System Tract deposits overstep earlier rocks to rest on the Llandeilo Flags Subgroup; 4, level previously taken to represent the Ordovician-Silurian boundary (= FAD of persculptus Biozone graptolites in Wales); 5, range of basal relationships displayed by BIII, CI and CII systems tract rocks based on surface data only (NB: in part a reflection of palaeotopography, but principally synsedimentary tectonism); 6, range of omission linked principally to intra-Telychian mass-wasting; 7, composite range of omission linked to putative Foel Ddu and Garn Prys canyons (see Fig. 15); 8, range of omission linked to intra-Ludlow slump and channel incision along Clun Forest Sub-basin's eastern margin; 9, see

Figure 21 for a fuller insight into Mortimer Group & ORS relationships; 10, selected formations only (for a fuller account see Barclay *et al.*, 2015).

Figure 10. A) As Figure 9, showing depositional system types (see Table 3) (1, includes proximal sand-prone subsystems south the Vale of Neath Disturbance recognised as the May Hill Sandstone and Yarleton subgroups); B) As Figure 9, highlighting groups recognised in this report; C) As Figure 9, showing areas of stratigraphy assessed in detail on Figures 15, 17-21.

Figure 11. Palaeogeographical and structural features influential during the development of Tract Assemblage A (see Fig. 6 and Table 2). A) AI Systems Tract showing depositional realms of the principal groups; B) AII Systems Tract. Abbreviations: DA, Derwen Anticline; DI, Dinas Island Formation; DS, Drefach Subgroup; EG, Eryri Group; FVG, Fishguard Volcanic Group; HH, Harlech Horst; LS, L1ŷn Sub-platform; MG, Montgomery Group; NGG, Nod Glas Group; NPS, North Pembrokeshire Sub-basin; UAVG, Upper Aran Volcanic Group. Notes: outlines of subbasins do not show depositional limits, but are indicative of regions that experienced greater levels of subsidence as indicated by sedimentary thicknesses and, in shallower settings, enhanced levels of preservation; 1, laterally displaced outcrops of Wig Bach Formation within the Menai Straits Fault System; 2, form and extent of the Robell Fracture Belt, north of Vale of Ffestiniog Lineament, is disputed (see Campbell *et al.*, 1988); 3, expands in early Llanvirn to include St. Tudwal's Block area; 4, prior to mid Caradoc vulcanism; 5, possibly extended westwards to include much of the Harlech Block.

Figure 12. Palaeogeographical and structural features influential during the development of Tract Assemblage B (see Fig. 6 and Table 2). A) BI and BII systems tracts; B) BIII Systems Tract. See Figure 11 for comment on sub-basins. Abbreviations: BH, Benton Horst; CI, Collington No. 1 Borehole; CCG, Conwy Castle Grit Formation; D-BA, Derwen-Berwyn Axis; FDC, Foel Ddu Canyon; NPS, North Pembrokeshire Sub-platform; NPoS, North Powys Sub-platform. Notes: 1, putative region of shallower water deposition following the Hirnantian lowstand; 2; includes the level of Hirnantian lowstand.

Figure 13. Palaeogeographical and structural features influential during development of the Tract Assemblage C: A) CI Systems Tract; B) onset ages of principal depositional systems (groups) revealing patterns of subsidence and rifting. See Figure 11 for comment on sub-basins. Abbreviations: fm, formations; Rhy, Rhayader Mudstones Formation (see text for revised definition). Notes: 1, Bronnant Fault Zone; 2, Central Wales Lineament including Claerwen Fault (confined Cwmystwyth Grits Subgroup sandstone lobe facies prior to the mid-Telychian – see Fig. 17); 3, Garth Fault (= eastern limit of region of mid-Telychian mass-wasting); 4, region of intertonguing of Newbridge and Yartleton subgroup facies; 5, largely ineffective from mid Telychian times onwards; 6, region of possible onlap of Cerig Formation by Dolgau Mudstones Formation (see Fig. 18); 7, based on principal areas of outcrop and accurate dating; 8, region of lateral passage between Trannon Group and Castell Powys Group rocks of sedgwickii Bozone age; 9, area of detailed dating based on Davies *et al.* (1997, 2006 a,b, and unpublished BGS data); 10, Tywi Anticline region from which early Telychian Trannon Group deposits were removed during intra-Telychian mass-wasting, and where mid-Telychian Central Wales Grits Group facies underly and intertongue with griestoniensis Biozone Trannon Group facies (Dolgau Mudstones Formation) along the anticline's western limb (see Fig. 17); 11, anomalous region of onlap in vicinity of Cheney Longville (see text); 12, region of non-sequence at base Trannon Group linked to Malvern Lineament.

Figure 14. Palaeogeographical and structural features influential during development of Tract Assemblage C (excluding the Mortimer Group) (see Fig. 6 and Table 2).

A) CII Systems Tract; B) CIII Systems Tract. Notes: see Figure 11 for comment on sub-basins; confining faults in A exercised significant influence on Sheinwoodian sandstone lobe development (see Davies *et al.*, 1997; 2006 a,b). Abbreviations: AL, Aymestry Formation; Cbrd, Coalbrookdale Formation; CSFZ, Church Stretton Fault Zone; GPC, Garn Prys Canyon; IrF, Irfon Formation; KCB, Knucklas Castle Formation; LbF, Llanbadarn Formation; MWL, Much Wenlock Limestone Formation; NGF, Nantglyn Flags Formation; TBM, Trewern Brook Mudstone Formation; WBG, Welsh Borderland Group; I, Builth Mudstones/Trewern Brook Mudstone formation boundary; 2, western limit of Homerian Edgton Limestone Member; 3, maximum extent of Homerian Ffinant Sandstone Formation delta; 4, approx. south-western limit of Penstrowed Grits Subgroup outcrops; 5, eastern and southern limit of Bailey Hill Formation outcrops; 6, maximum western extent of early Gorstian Welsh Borderland Group facies (Oakeley Mynd Formation); 7, Laurentian mica arrives in south-west Wales in the Gorstian Red Cliff Formation (see Hillier *et al.*, 2024).

Figure 15. Schematic architecture for Systems Tract Assemblage A (Preseli Supergroup) succession of North Wales showing the relationships of the Cadir Idris, Eryri, Hengae and Nod Glas groups to the Mid-Ordovician Unconformity (MOU) and to contemporary volcanic groups (see Figs 9-10), adapted from Rushton and Howells (1998). For explanations of lithostratigraphical symbols see Appendix 3 and Rushton and Howells (1998). Other abbreviations: CCV*, pod facies of the Garth Tuff Member (Capel Curig Volcanic Formation); CEi*, BGS (1997) recognise volcaniclastic sediments intercalated with the Llewelyn Volcanic Group as an early development of Cwm Eigiau Formation facies; LF, Llanegryn Fault; *, new name for mudstones previously included in the Serw Volcanic Formation, now in the Benglog Volcanic Formation and which succeed the Mid-Ordovician (Zalasiewicz, 1992; and pers. comm.); Serw*, Serw Volcanic Formation is restricted to pre-Caradoc rocks (see Rushton and Howells, 1998). Notes: 1, Aran Fawddwy Formation volcanic rocks locally overstep on to Cambrian rocks in the vicinity of the Fynnon Eidda Fault (FEF); 2, ranges of local omission linked to volcanic excision; 3, Rushton and Howells (1998) offer evidence that the onset of Criccieth Formation deposition locally occurred in the late Arenig; 4, see Text Box 3; 5, linework for the Cwm Pennant Fault Belt (CPFB) and stratigraphical impacts of the Pitts Head Tuff Caldera is adapted to accommodate geographical distortions within the figure (see Appendix 4); 6, position of putative Llaethnant Siltstone Formation of Lockley (1980a,b) (see Text Box 10); 7, region of complex relationships and eruptive excision associated with the site of the Snowdon Caldera (see Howells *et a*l., 1991); 8, region of uncertain stratigraphical ages and relationships (see Text Box 10); 9, omission surface that conflates the impacts of the basal BI Systems Tract non-sequence, putative Llandovery and Wenlock canyon cutting and intra-Telychian mass-wasting.

Figure 16. Proposed nomenclature for the AI-AII Systems Tract boundary succession of the Llandeilo area showing its relationships to previous schemes (see also Text Box 4), centred on a plan view of the Ffairfach railway cutting adapted from Williams (1953). Notes: I, Abereiddian-Llandeilian boundary interval; 2, conodont assemblages of the Pygodus serra Biozone; 3, conodont assemblages of the Pygodus anserinus Biozone; 4, entry of strata containing Lloydolithus lloydii. Chrono- and biostratigraphical data from Williams (1953, also *et al.*, 1981), Owens (2000) and Ferratti and Bergström (2023).

Figure 17. Schematic architecture for the BIII, CI and CII systems tract successions of central Wales (see Figs 9-10) including the Pont Erwyd, Trannon, Central Wales Grits and Llangollen groups, and distal parts of the Welsh Borderland Group. Adapted

from Davies *et al.* (1997) and Cherns *et al.* (2006). Notes: I, base of the BIII Systems Tract and Pont Erwyd Group = level of first appearance of persculptus Biozone graptolites in the deep water succession of the South Wales Sub-basin, but believed significantly to post-date the global FAD of such faunas (see Davies *et al.*, 2009; James, 2014); 2, here included in the Derwenlas Formation with its top marking the base of the CI Systems Tract and the Trannon Group in central Wales (see text).

Figure 18. Sedimentary architectures for the type succession of the Cwm Rhuddan Group (BIII Systems Tract) in the Llandovery area (see Figs 9-10) based on: a) thickness, using the top of the Wormwood Formation as a datum, including inset showing location of transects; and b) chronostratigraphy and graptolite biostratigraphy, showing system tract boundaries and divisions included in other groups. Adapted from Davies *et al.* (2016, fig. 4), but including corrections to the distribution of the Ystradwalter Member (Chwefri Formation). See b for key to symbols used for formations and members; md, sandy mudstone in Goleugoed Formation. Symbols shown in the form Ceg0, Ceg1, DD1, DD2, etc refer to stratigraphically distinct levels (older to younger) of the divisions indicated. 1, stratigraphical position of the former GSSP for the base of the Aeronian Stage; 2, GSSP for the base of the Telychian Stage, but which is at odds with the criteria used for its international definition.

Figure 19. Schematic architecture for the BII, BIII, CI and CII systems tract successions of the North Powys Sub-platfom, northern Marginal Belt and outer Midland Platform (included in parts of the Dinas Mawddwy, Welshpool, Mongomery and Church Stretton districts; see Figs 9-10) including the Scrach, Castell Powys, Trannon, Llangollen and Welsh Borderland groups. Based on Bassett *et al.* (1996), Cave and Hains (2001) and Cave (2008). Only transgressive BII Systems Tract deposits are preserved. Notes: I, biozonal bases relate to the first appearance of diagnostic graptolites and/or correlative shelly and microfossil assemblages; 2, recognised by Cave (2008) as an un-named limestone in the Dolhir Formation; 3, previously the Butterley Mudstone Member (Loydell and Cave, 1993); 4, strata previously included in the Nant-ysgollon Mudstone Formation by Cave (2008; see also Loydell and Cave, 1996; Cave and Hains, 2001) (see text); 5, units labelled the 'Mottled Mudstone Member' on BGS sheets 151 and 165; 6, unless derived, the presence of E. intermedia in the basal bed of the PuS, near Sheinton, above Telychian graptolite-bearing levels in the PeS (Cocks and Rickards, 1968; Ziegler *et al.*, 1968), implies, contrary to previous assumptions (e.g. Cocks *et al.*, 1984; Davies *et al.*, 2013), that the range of this species extends significantly above the top of the Aeronian. For greater detail on the Wenlock to Ludlow succession east of the Church Stretton Fault Zone see Figure 21.

Figure 20. Summary sections though the CII system tract successions in North Wales that are included in the Llangollen Group showing currently informal subdivisions of Warren *et al.* (1984) for the Denbigh Grits and Elwy subgroups (see Figs 9-10). Lithostratigraphical names in bold are as recommended in this report, the remaining terms are as used in earlier literature. Note: 1, linework for the Crenulatus Member, in the form of the 'Crenulatus Beds' (Wedd *et al.*, 1927), is included on earlier versions of the Wrexham Sheet, but is absent from more recent paper (BGS, 1992) and digital maps.

Figure 21. Schematic chronostratigraphical and facies architecture focusing on the CII and CIII systems tracts of the central Marginal Belt and adjacent Midland Platform including the Epynt, Welsh Borderland and Mortimer groups, and showing the relationship of the ORS Supergroup (see Figs 9-11). For explanation of lithostratigraphical symbols see Appendix 3. Other abbreviations: B, Benton Fault; cong, conglomerate filled channels at base Temeside Mudstone

Formation; CSFZ, Church Stretton Fault Zone; GGA, Golden Grove Axis; GA, Gorsley Axis; KF, Knucklas Fault; MF, Musselwick Fault; ms, micaceous sandstone and/or conglomerate filled channels in western Moor Cliff Formation successions; RF, Ritec Fault; VND, Vale of Neath Disturbance. Notes: 1, onset level oflate Telychian (lapworthi Biozone) facies changes linked to the Ireviken Event; 2, FAD of nilssoni Biozone graptolites (= Base Ludlow); 3, FAD of Leintwardinian faunas within units that are predominantly Bringewoodian in age; 4, latest incipiens Biozone (latest Gorstian) graptolites occur close to the base of the Fibua Member at its type locality; 5, FAD of Upper Leitwardinian faunas; 6, LAD of Leintwardinian faunas (the interval between levels 5 and 6 equates to the stratigraphical the range of Watkins' (1979) Shaleria ornatella Association); 7, level of the Ludlow Bone Bed and its correlatives; 8, Early Pridoli erosion surface overlain locally by phosphatic pebble and bone-rich lags, including the Upper Linton Pebble Bed, previously viewed as equivalent to be the Ludlow Bone Bed (see Hillier *et al*., 2024); 9, complex patterns of omission and onlap are associated with the Church Stretton Fault Zone (e.g. Cave and Hains, 2001; Ray *et al*., 2019); 10, interface between region of net mass-wasting and stratigraphical omission, to the east, and of both slump and undisturbed sediment accumulation, to the west (see Whitaker, 1962, 1994); 11, 'flaggy limestone facies' of Holland & Lawson (1963) which, based on Watkins (1979), Hillier *et al*., (2024) include the Cae'r mynach Formation. Cave and Hains (2001) suggest the base of the Middle Eltonian (= base Elton Lane Formation) may correlate with the base of the Oakeley Mynd Shale Formation. Hillier *et al*. (2024) identify and label stratigraphically distinct levels of the Cae'r mynach, Tilestones, Downton Castle Sandstone, Temeside Mudstone and Moor Cliffs formations. *, Formerly Bromleysmill Shales Formation; **, excludes Pridoli Mortimer Group rocks included in the Cae'r mynach and the Clifford's Mesne Sandstone formations.

Figure 22. Leintwardinian (early Ludfordian) palaeogeography showing regions of contemporary CII Systems Tract (Epynt Group) and CIII Systems Tract (Mortimer Group) deposition (see also Fig. 21) relative to the remnant Clun Forest Sub-basin. Epynt Group divisions and locations that host Leintwardinian faunas: 1, Knucklas Castle Formation (Mynydd Epynt) (Williams, 2003); 2, Aberedw Formation (Wye Valley) (Straw, 1937; Schofield et al., 2004); 3, Irfon Formation (Mocktree Shales Member) (Leintwardine area) (Whitaker, 1962); 4, Irfon Formation (Lugg Member) (Leintwardine to Lugg Valley area) (Whitaker, 1994); 5, Bailey Hill Formation (multiple Clun Forest localities) (Cave and Hains, 2001); 6, Irfon Formation (Cwm-yr-hob Member) (type section and Long Mountain) (Cave and Hains, 2001; Cave, 2008). Other notes: 7, putative, now eroded Epynt Group oxic facies once present in the northern sector of Clun Forest Sub-basin; 8, putative concealed belt of shallow water deposition via which principally southerly-sourced Epynt Group sediment was supplied to the contracting sub-basin (see Text Box 16); 9, relict slump scars and channels filled by sub-basinal Leintwardinian facies (Whitacker, 1994) (see Lugg Member); 10, speculative Leintwardinian deltaic facies linked to the source that supplied the (?)Early Pridoli Downton Castle Sandstone Formation; 11, proximal feeder facies to the south, where they have escaped the impacts of contemporary slumping, are oxic; 12, migrating site of interdigitation and mixed provenance; 13, likely a region displaced laterally during Variscan deformation. Dinas Brân, location of the eponymous formation and used to constrain the northern extent of the Cae'r mynach Seaway (see text). Abbreviations: CSFZ, Church Stretton Fault Zone; GGA, Golden Grove Axis; VND, Vale of Neath Disturbance.

FIGURE 1

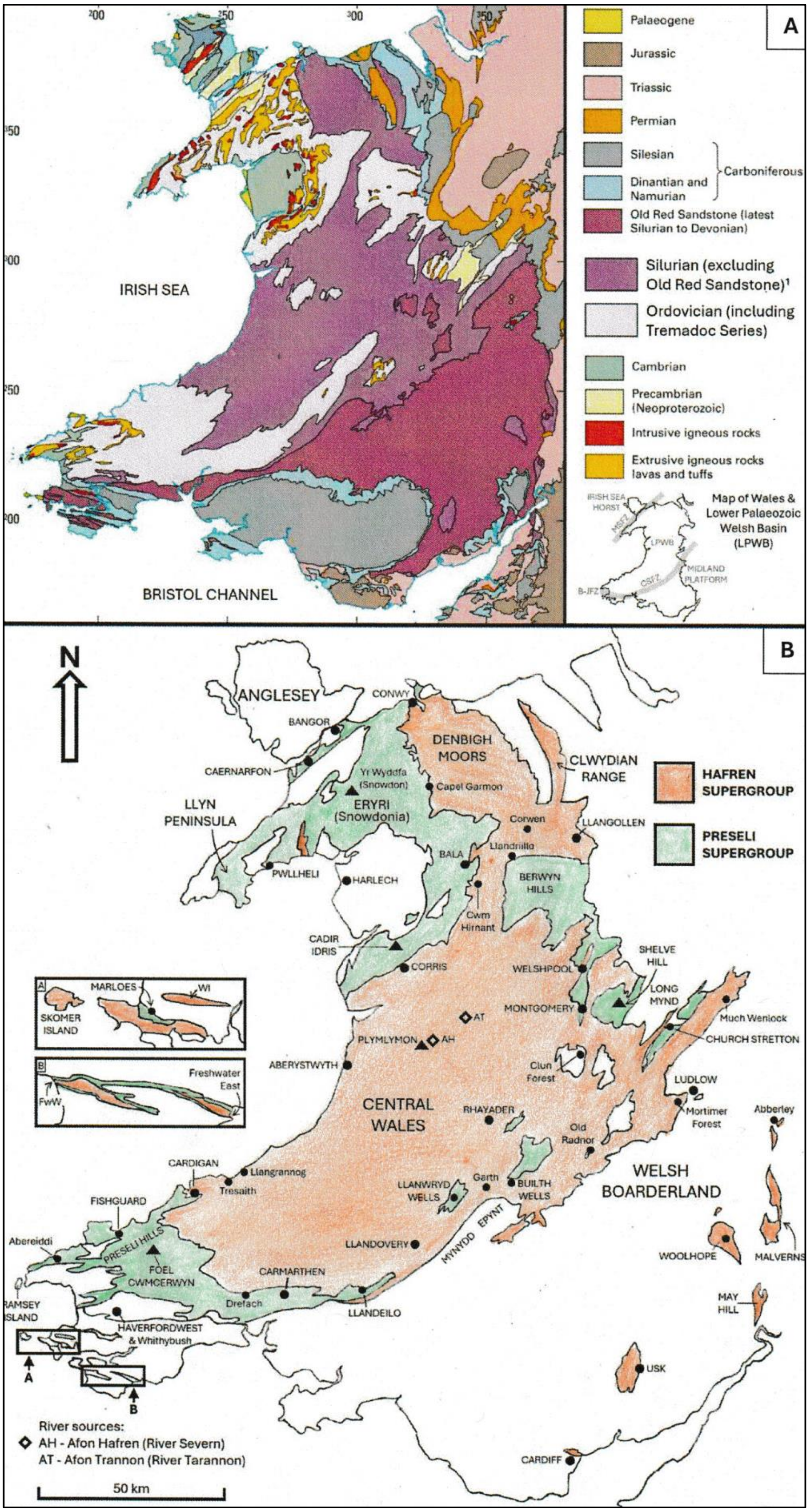

A
Palaeogene
Jurassic
Triassic
Permian
Silesian
Dinantian and Namurian
Carboniferous
Old Red Sandstone (latest Silurian to Devonian)
Silurian (excluding Old Red Sandstone)¹
Ordovician (including Tremadoc Series)
Cambrian
Precambrian (Neoproterozoic)
Intrusive igneous rocks
Extrusive igneous rocks lavas and tuffs
IRISH SEA
BRISTOL CHANNEL
Map of Wales & Lower Palaeozoic Welsh Basin (LPWB)
IRISH SEA HORST
LPWB
MIDLAND PLATFORM
B
N
ANGLESEY
CONWY
BANGOR
CAERNARFON
DENBIGH MOORS
CLWYDIAN RANGE
Capel Garmon
Yr Wyddfa (Snowdon)
ERYRI (Snowdonia)
LLYN PENINSULA
Corwen
LLANGOLLEN
Llandrillo
BALA
PWLLHELI
HARLECH
BERWYN HILLS
Cwm Hirnant
CADIR IDRIS
CORRIS
WELSHPOOL
SHELVE HILL
LONG MYND
MONTGOMERY
Much Wenlock
CHURCH STRETTON
PLYMLYMON
AT
AH
ABERYSTWYTH
Clun Forest
LUDLOW
Mortimer Forest
CENTRAL WALES
RHAYADER
Old Radnor
Abberley
MARLOES
WI
SKOMER ISLAND
Freshwater East
FwW
CARDIGAN
Llangrannog
Tresaith
LLANWRYD WELLS
Garth
BUILTH WELLS
WELSH BOARDERLAND
FISHGUARD
MYNYDD EPYNT
Abereiddi
PRESELI HILLS
FOEL CWMCERWYN
LLANDOVERY
WOOLHOPE
MALVERNS
CARMARTHEN
Drefach
LLANDEILO
MAY HILL
RAMSEY ISLAND
HAVERFORDWEST & Whithybush
USK
HAFREN SUPERGROUP
PRESELI SUPERGROUP
CARDIFF
River sources:
AH - Afon Hafren (River Severn)
AT - Afon Trannon (River Tarannon)
50 km

FIGURE 2

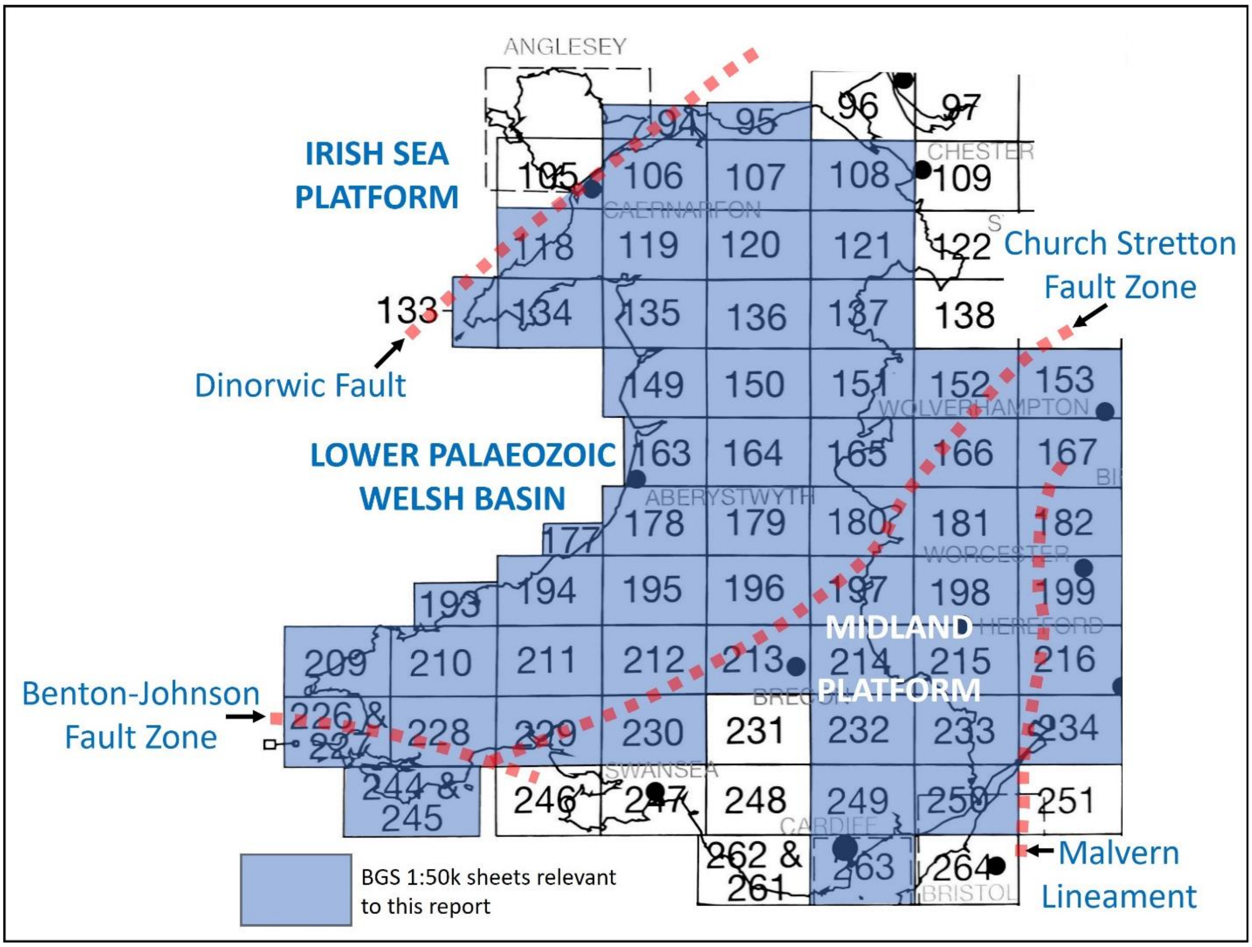



FIGURE 3

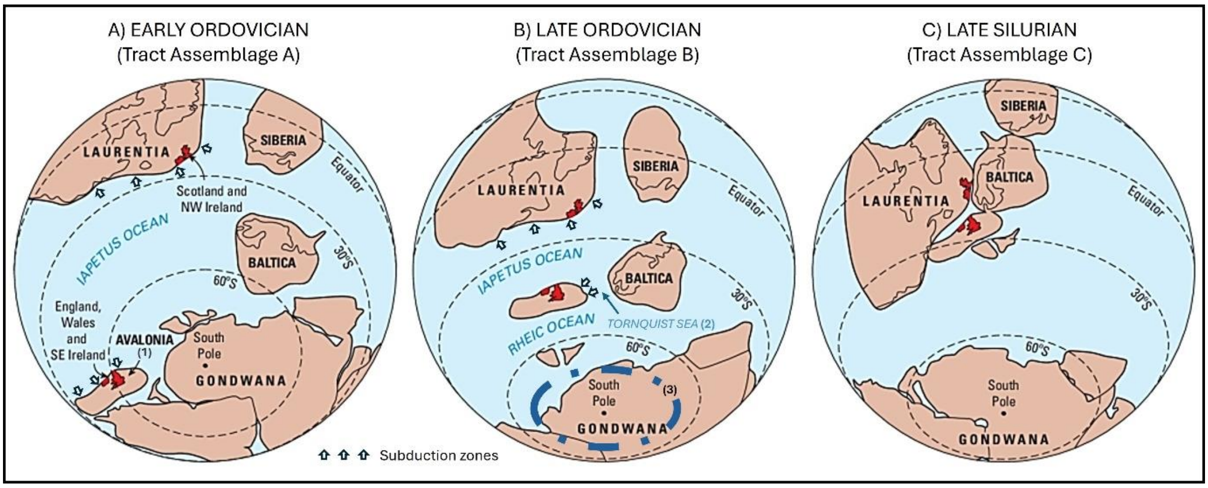


FIGURE 4

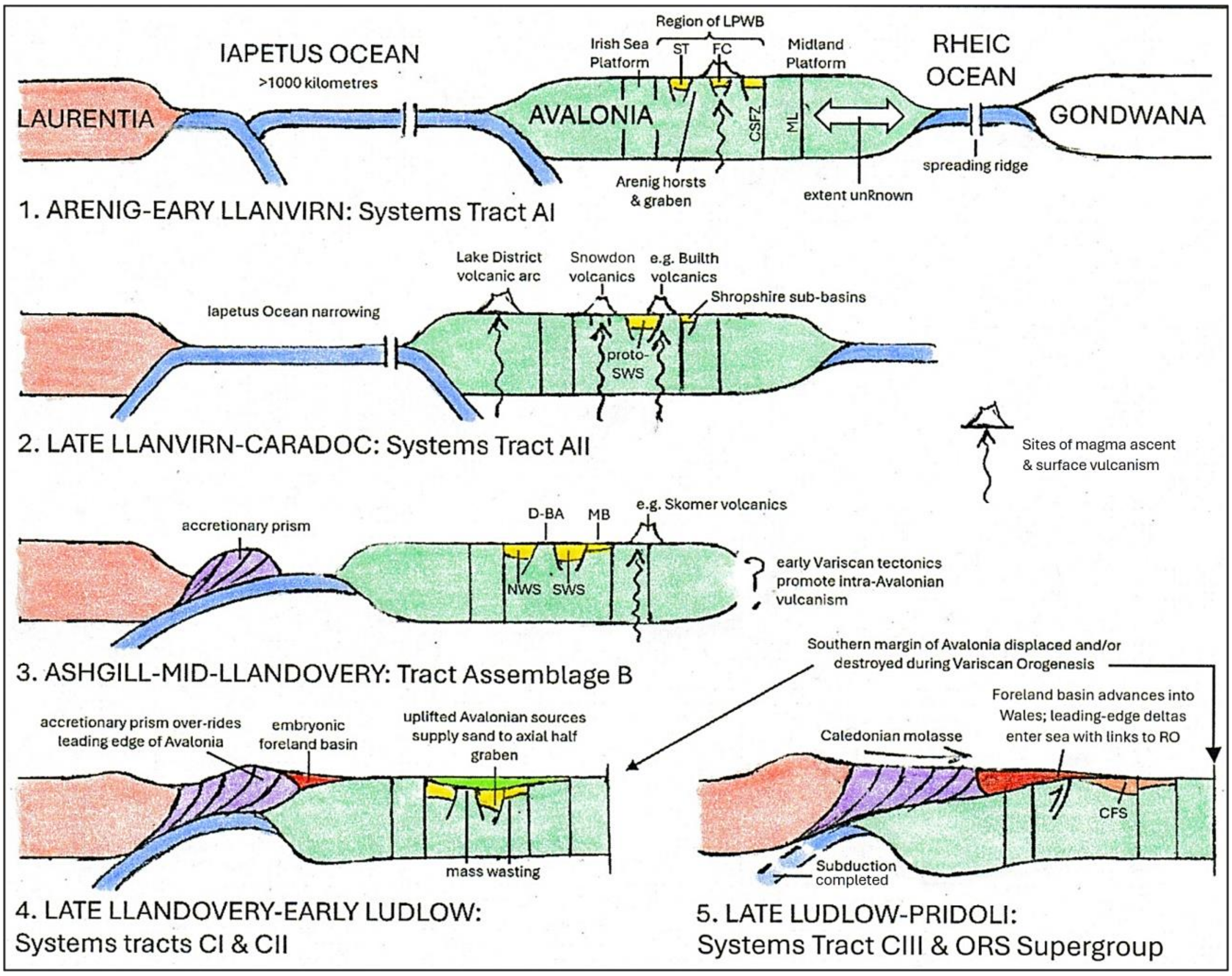



FIGURE 5

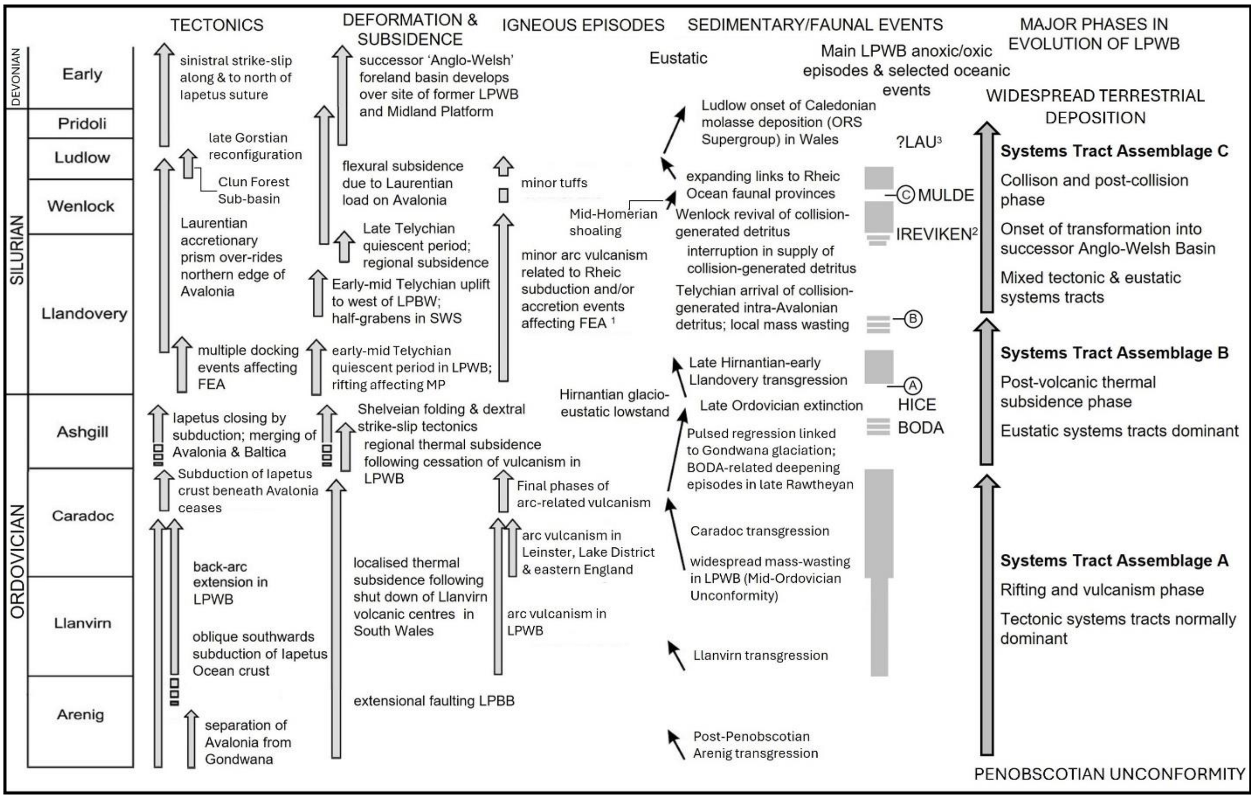


FIGURE 6

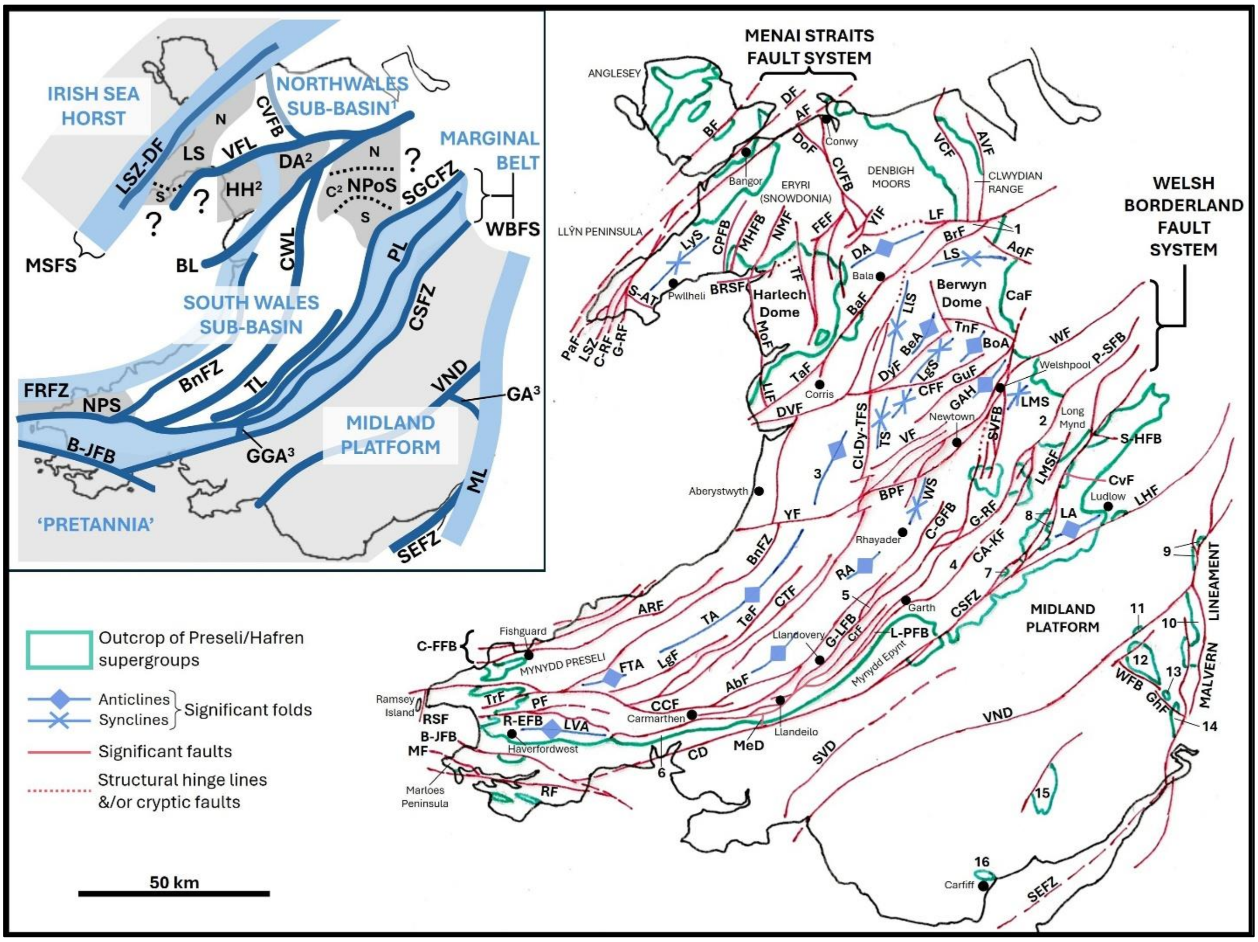



FIGURE 7

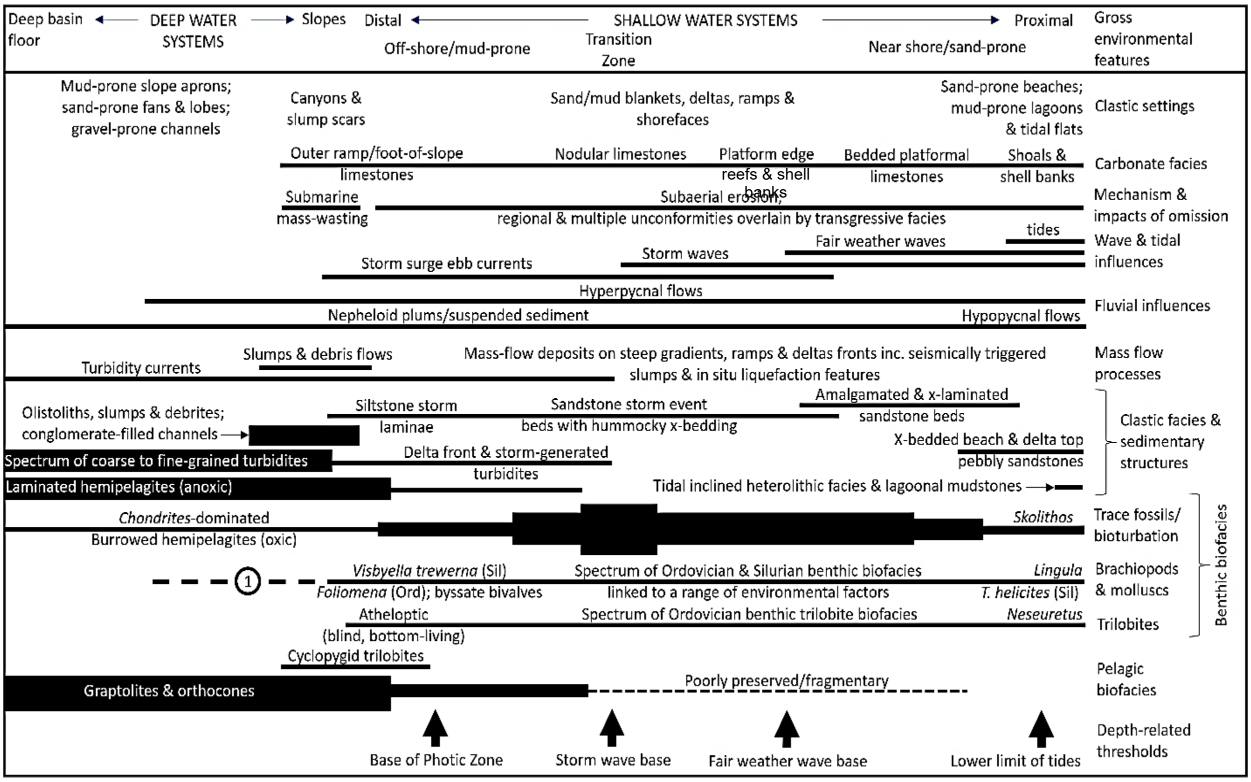
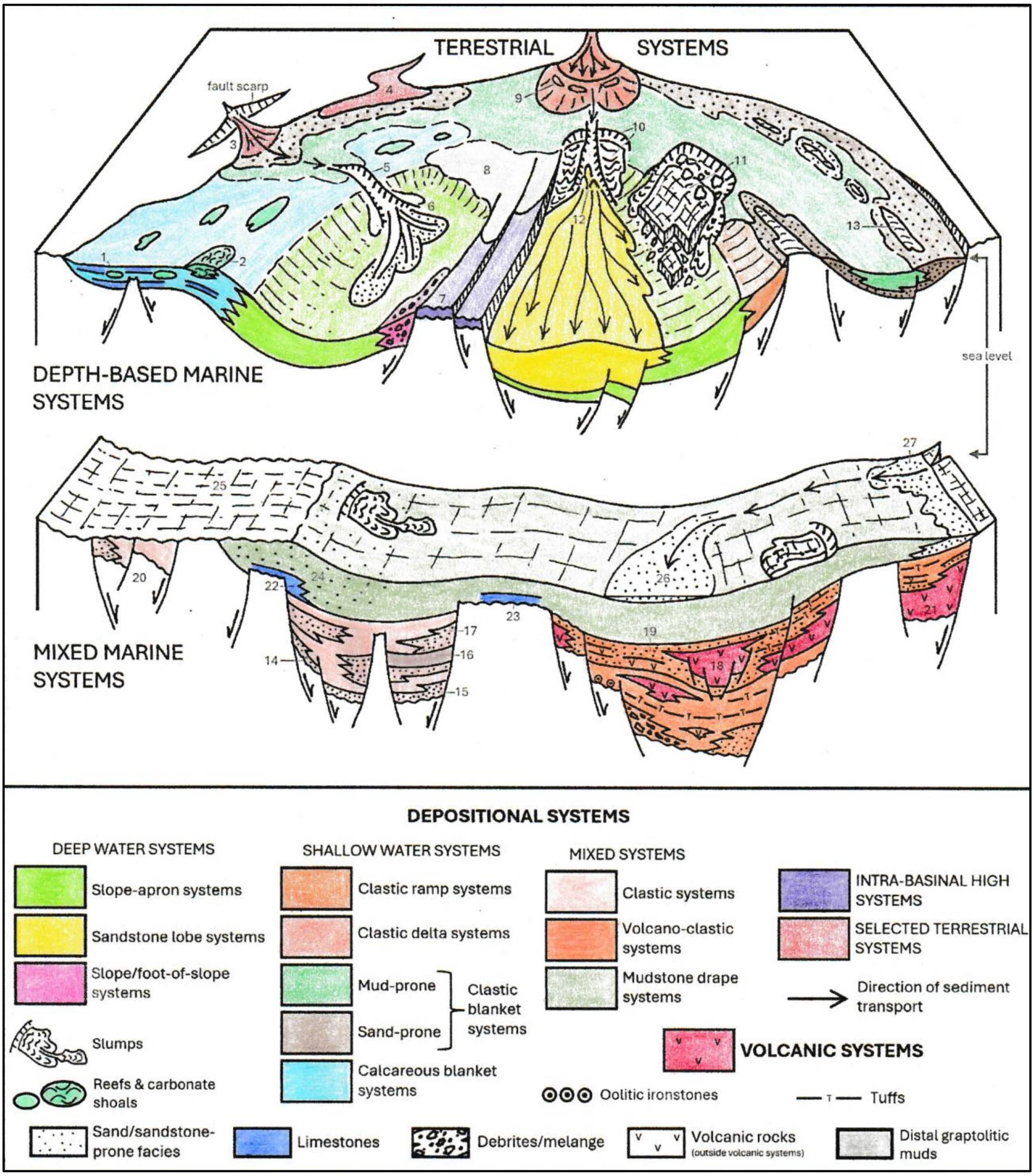
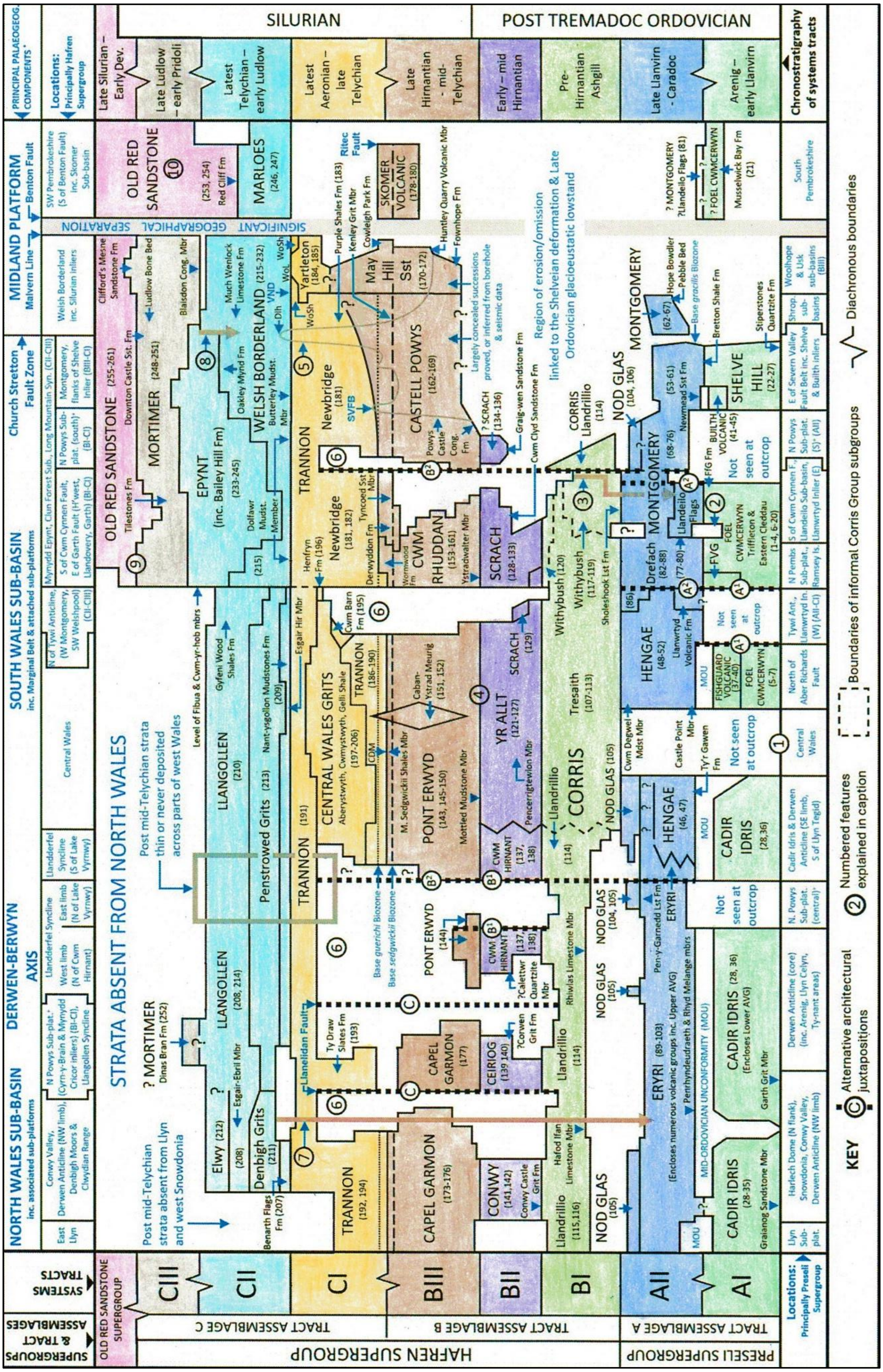


FIGURE 8



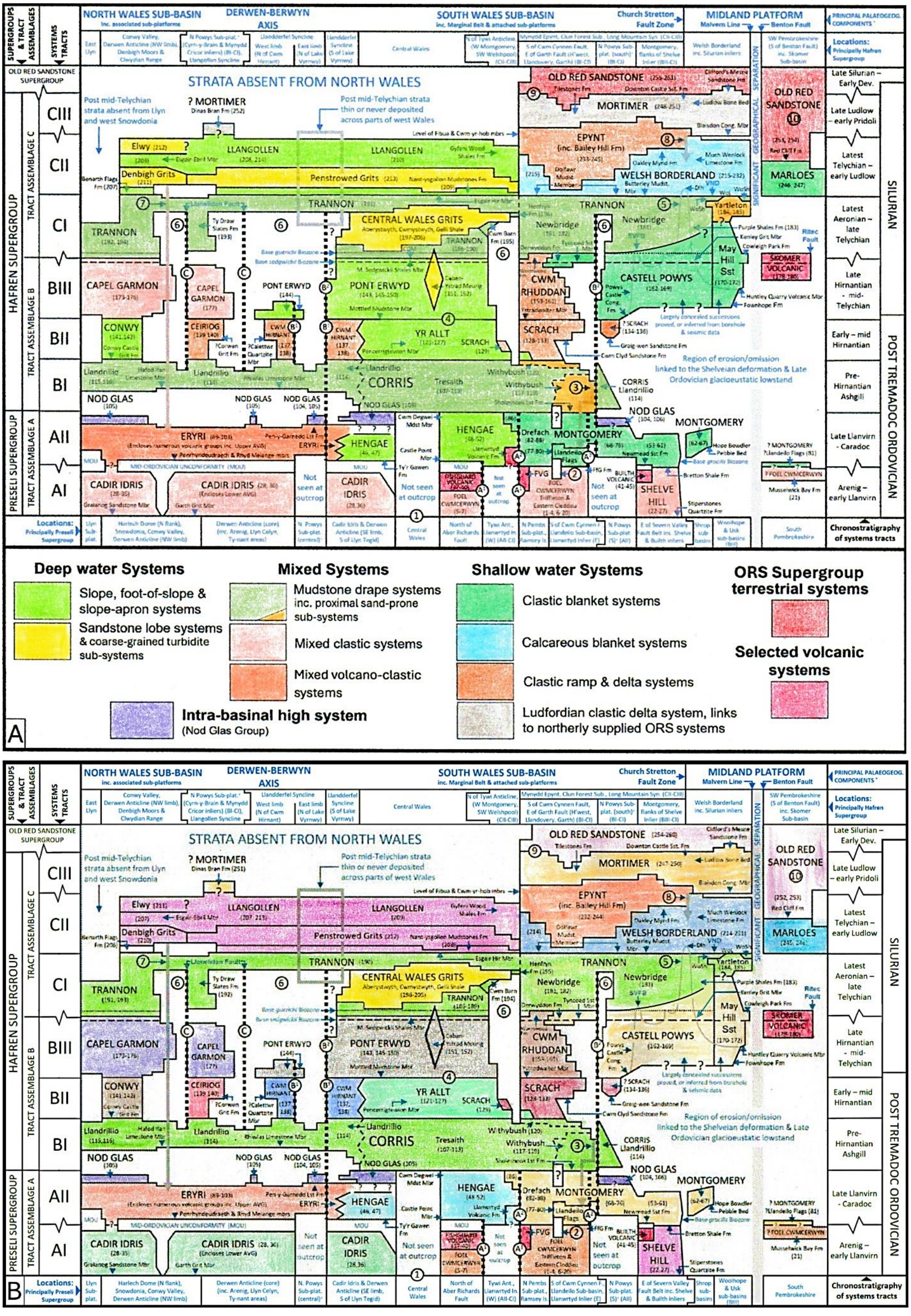
TERESTRIAL SYSTEMS
fault scarp
1
2
3
4
5
6
7
8
9
10
11
12
13
sea level
DEPTH-BASED MARINE SYSTEMS
14
15
16
17
18
19
20
21
22
23
24
25
26
27
MIXED MARINE SYSTEMS
DEPOSITIONAL SYSTEMS
DEEP WATER SYSTEMS
Slope-apron systems
Sandstone lobe systems
Slope/foot-of-slope systems
Slumps
Reefs & carbonate shoals
SHALLOW WATER SYSTEMS
Clastic ramp systems
Clastic delta systems
Mud-prone
Sand-prone
Clastic blanket systems
Calcareous blanket systems
MIXED SYSTEMS
Clastic systems
Volcano-clastic systems
Mudstone drape systems
INTRA-BASINAL HIGH SYSTEMS
SELECTED TERRESTRIAL SYSTEMS
Direction of sediment transport
VOLCANIC SYSTEMS
Oolitic ironstones
Tuffs
Sand/sandstone-prone facies
Limestones
Debrites/melange
Volcanic rocks (outside volcanic systems)
Distal graptolitic muds

FIGURE 9



SILURIAN
POST TREMADOC ORDOVICIAN
NORTH WALES SUB-BASIN
DERWEN-BERWYN AXIS
SOUTH WALES SUB-BASIN
MIDLAND PLATFORM
BENTON PLATFORM
SIGNIFICANT GEOGRAPHICAL SEPARATION
STRATA ABSENT FROM NORTH WALES
HAFREN SUPERGROUP
PRESELI SUPERGROUP
OLD RED SANDSTONE SUPERGROUP
TRACT ASSEMBLAGE A
TRACT ASSEMBLAGE B
TRACT ASSEMBLAGE C
CIII
CII
CI
BIII
BII
BI
AII
AI
OLD RED SANDSTONE
MORTIMER
LLANGOLLEN
EPYNT
WELSH BORDERLAND
MARLOES
TRANNON
CENTRAL WALES GRITS
CAPEL GARMON
PONT ERWYD
CWM RHUDDAN
CASTELL POWYS
YR ALLT
SCRACH
CONWY
CEIRIOG
CORRIS
NOD GLAS
ERYRI
HENGAE
MONTGOMERY
CADIR IDRIS
SHELVE HILL
SKOMER VOLCANIC
Chronostratigraphy of systems tracts
KEY
Alternative architectural juxtapositions
Numbered features explained in caption
Boundaries of informal Corris Group subgroups
Diachronous boundaries

FIGURE 10



NORTH WALES SUB-BASIN
DERWEN-BERWYN AXIS
SOUTH WALES SUB-BASIN
Church Stretton Fault Zone
MIDLAND PLATFORM
OLD RED SANDSTONE SUPERGROUP
STRATA ABSENT FROM NORTH WALES
HAFREN SUPERGROUP
PRESELI SUPERGROUP
TRACT ASSEMBLAGE C
TRACT ASSEMBLAGE B
TRACT ASSEMBLAGE A
SILURIAN
POST TREMADOC ORDOVICIAN
Chronostratigraphy of systems tracts
Deep water Systems
Slope, foot-of-slope & slope-apron systems
Sandstone lobe systems & coarse-grained turbidite sub-systems
Mixed Systems
Mudstone drape systems inc. proximal sand-prone sub-systems
Mixed clastic systems
Mixed volcano-clastic systems
Shallow water Systems
Clastic blanket systems
Calcareous blanket systems
Clastic ramp & delta systems
Ludfordian clastic delta system, links to northerly supplied ORS systems
ORS Supergroup terrestrial systems
Selected volcanic systems
Intra-basinal high system
(Nod Glas Group)
A
B

FIGURE 10 (cont.)

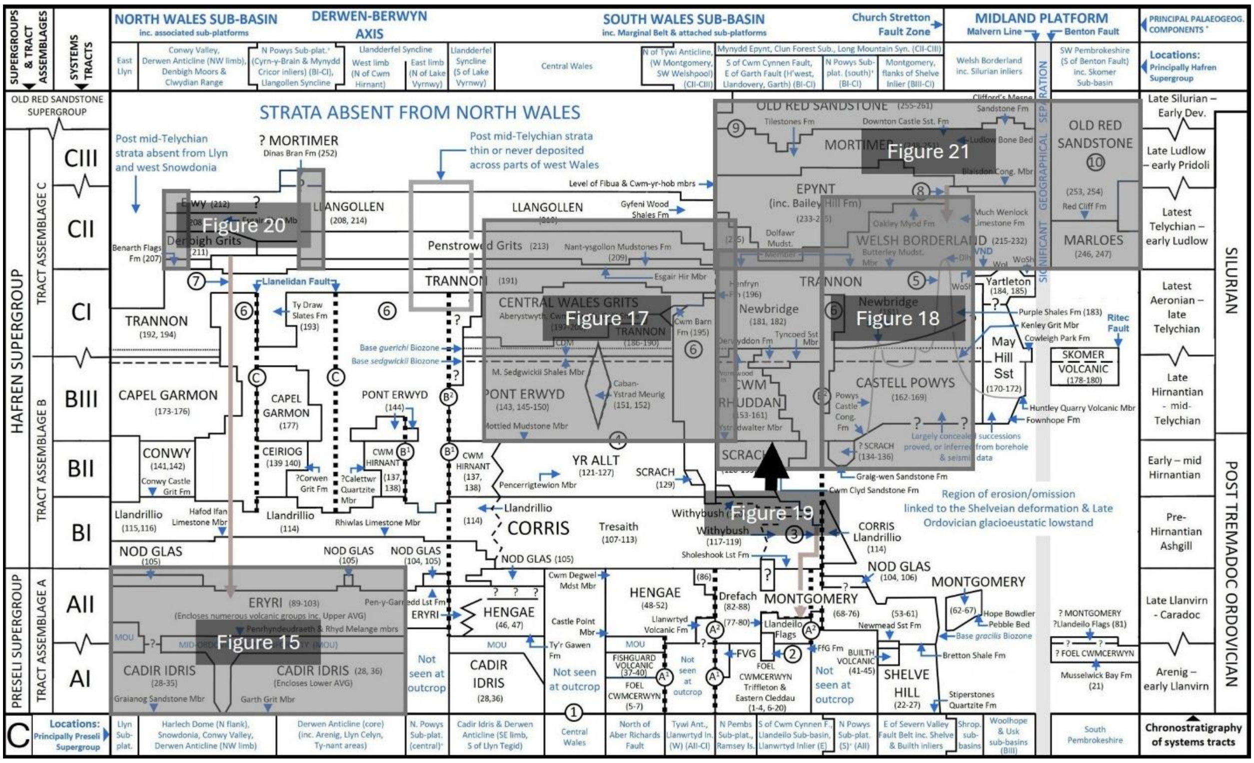


FIGURE 11

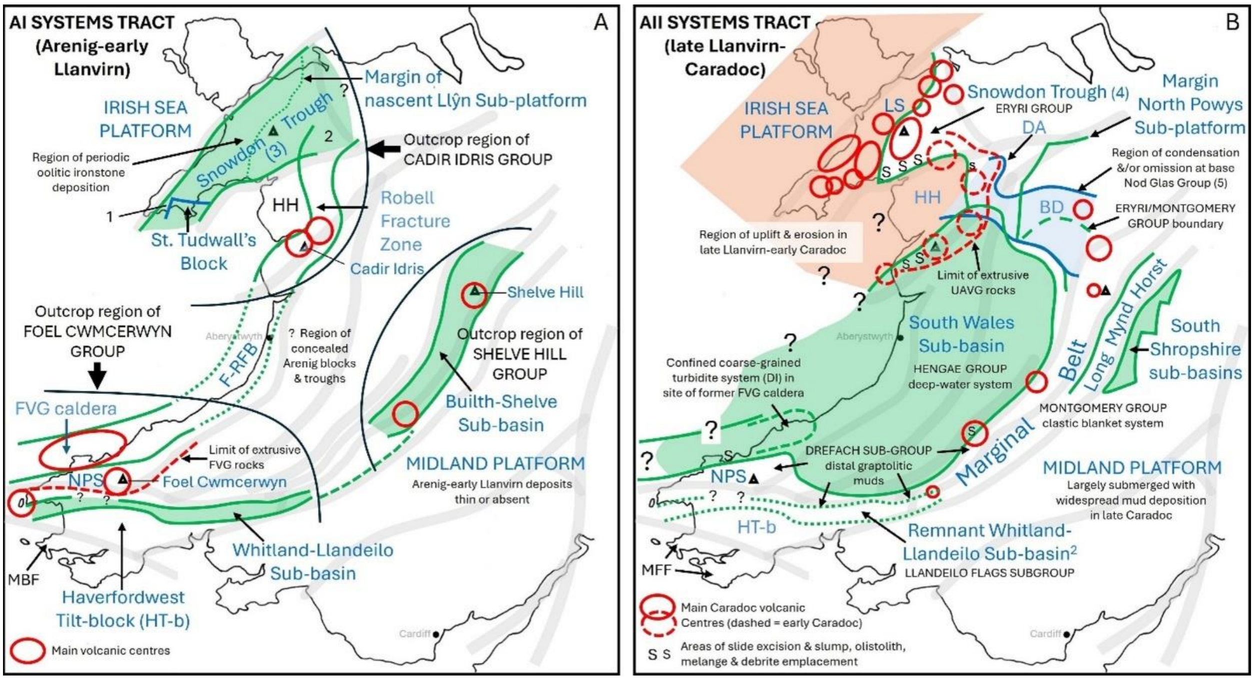



FIGURE 12

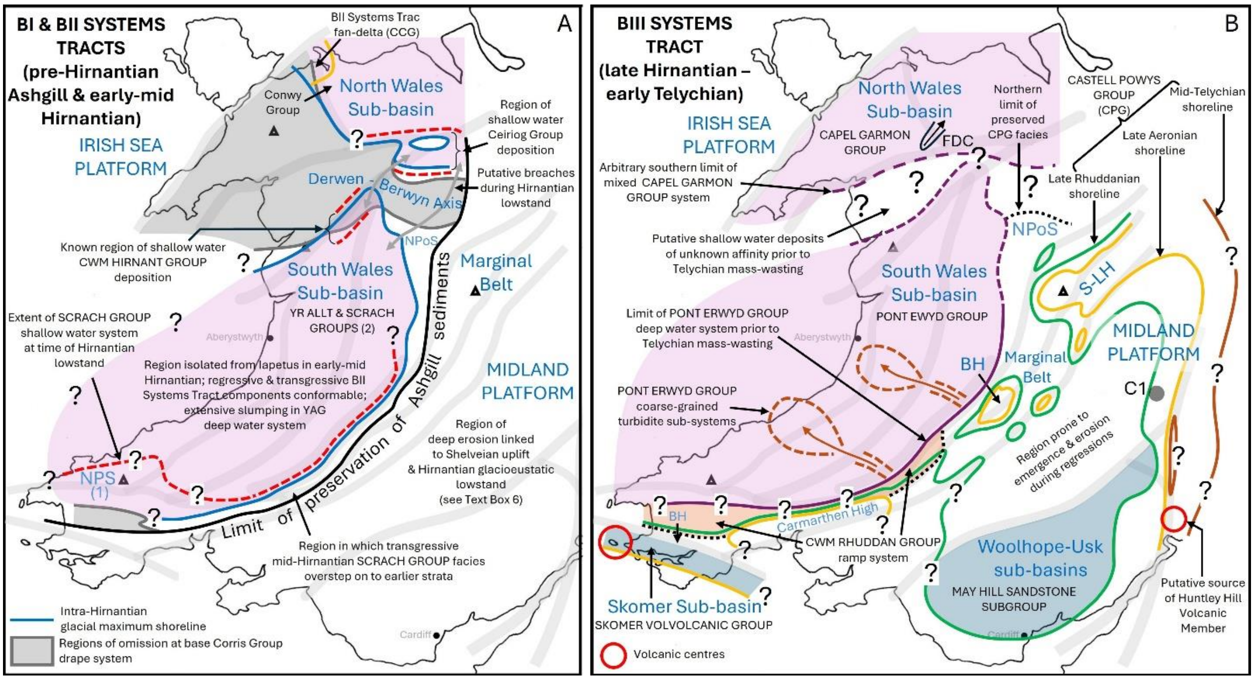


FIGURE 13

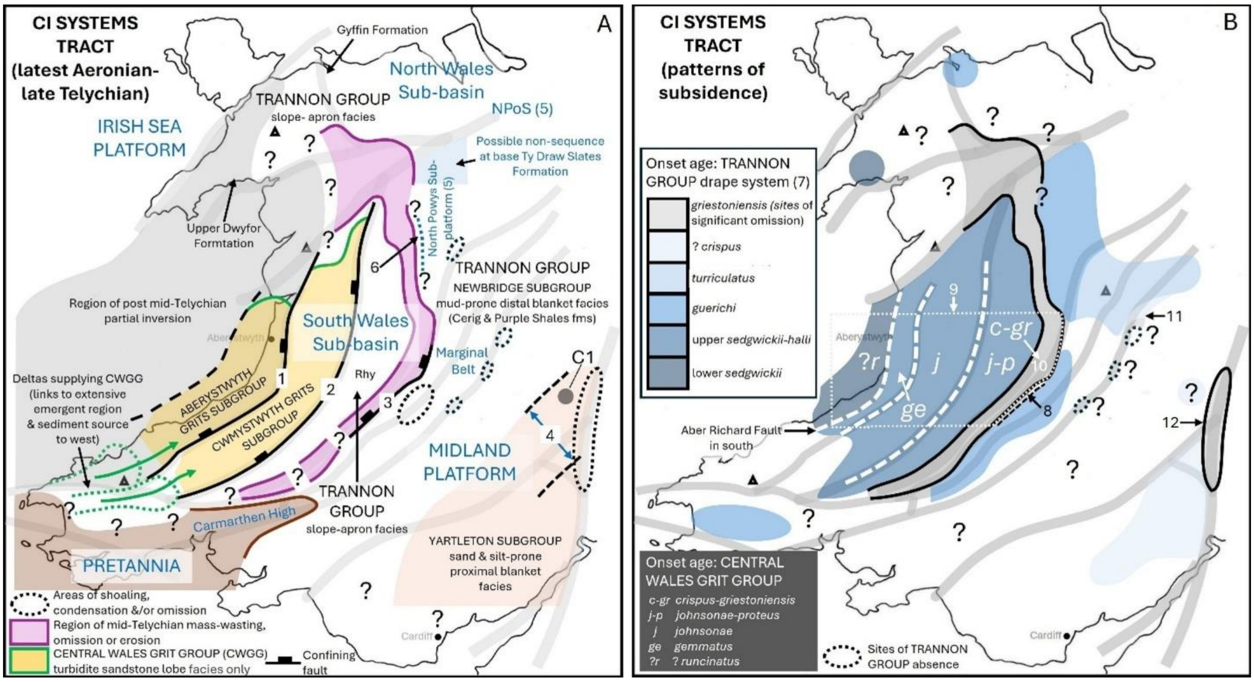



FIGURE 14

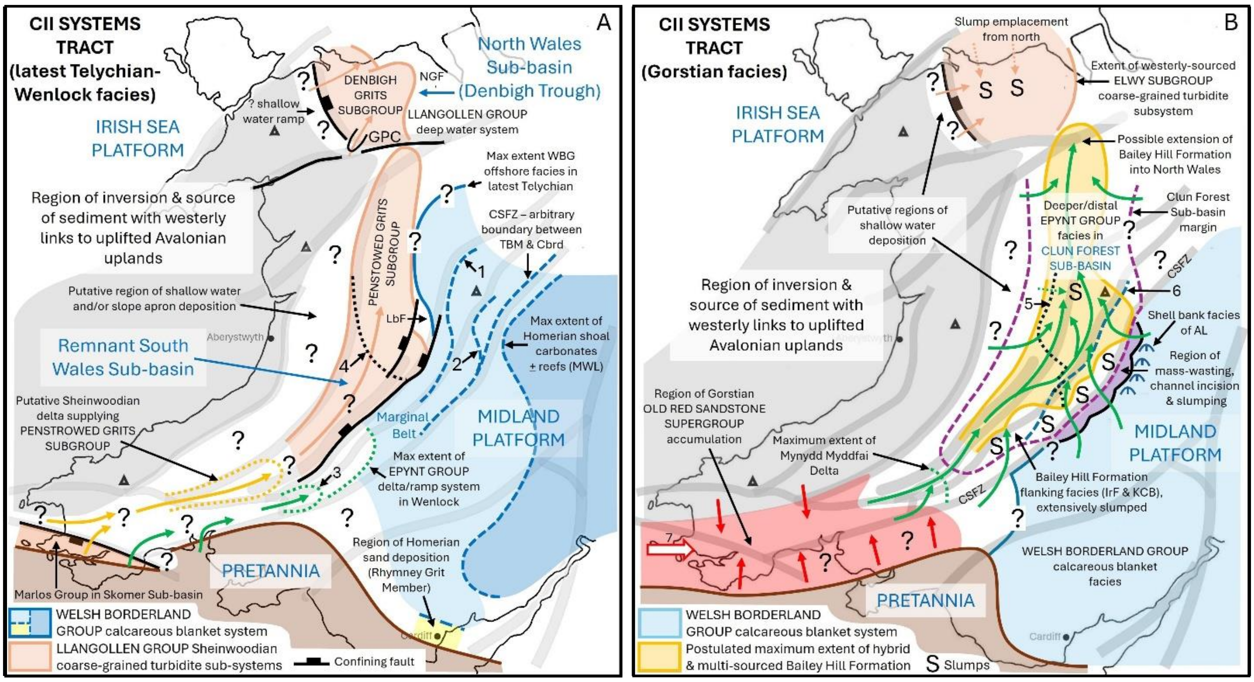
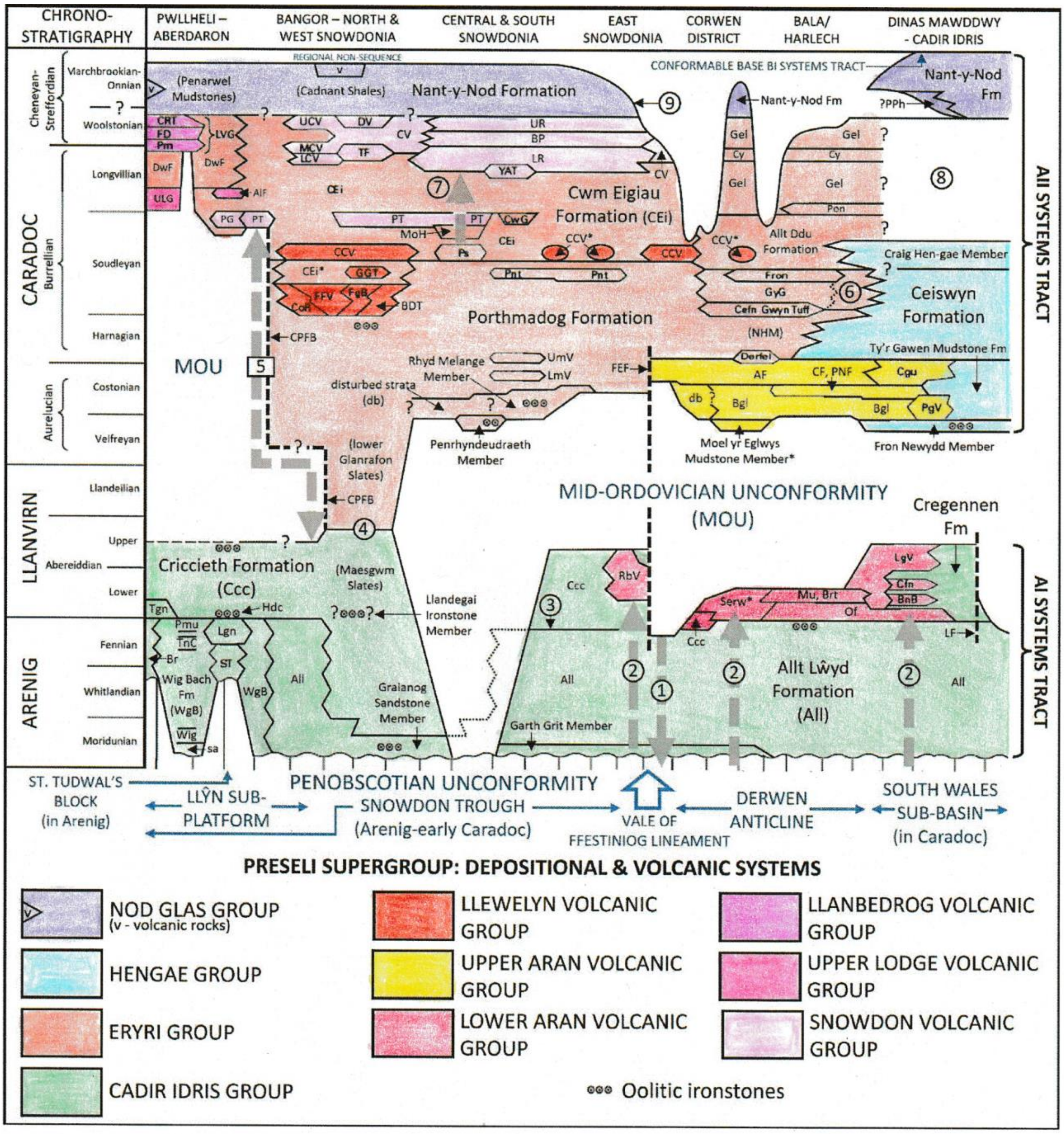


FIGURE 15



CHRONO-STRATIGRAPHY
PWLLHELI – ABERDARON
BANGOR – NORTH & WEST SNOWDONIA
CENTRAL & SOUTH SNOWDONIA
EAST SNOWDONIA
CORWEN DISTRICT
BALA/ HARLECH
DINAS MAWDDWY - CADIR IDRIS
CARADOC
LLANVIRN
ARENIG
Cheneyan-Streffordian
Burrellian
Aurelucian
Marchbrookian-Onnian
Woolstonian
Longvillian
Soudleyan
Harnagian
Costonian
Velfreyan
Llandeilian
Upper
Abereiddian
Lower
Fennian
Whitlandian
Moridunian
REGIONAL NON-SEQUENCE
CONFORMABLE BASE BI SYSTEMS TRACT
(Penarwel Mudstones)
(Cadnant Shales)
Nant-y-Nod Formation
Nant-y-Nod Fm
Cwm Eigiau Formation (CEi)
Porthmadog Formation
Ceiswyn Formation
Craig Hen-gae Member
Ty'r Gawen Mudstone Fm
Allt Ddu Formation
Cefn Gwyn Tuff
Rhyd Melange Member
disturbed strata (db)
Penrhyndeudraeth Member
(lower Glanrafon Slates)
Moel yr Eglwys Mudstone Member*
Fron Newydd Member
MOU
MID-ORDOVICIAN UNCONFORMITY (MOU)
Cregennen Fm
Criccieth Formation (Ccc)
(Maesgwm Slates)
Llandegai Ironstone Member
Wig Bach Fm (WgB)
Graianog Sandstone Member
Garth Grit Member
Allt Lŵyd Formation (All)
AII SYSTEMS TRACT
AI SYSTEMS TRACT
PENOBSCOTIAN UNCONFORMITY
ST. TUDWAL'S BLOCK (in Arenig)
LLŶN SUB-PLATFORM
SNOWDON TROUGH (Arenig-early Caradoc)
VALE OF FFESTINIOG LINEAMENT
DERWEN ANTICLINE
SOUTH WALES SUB-BASIN (in Caradoc)
PRESELI SUPERGROUP: DEPOSITIONAL & VOLCANIC SYSTEMS
NOD GLAS GROUP (v - volcanic rocks)
HENGAE GROUP
ERYRI GROUP
CADIR IDRIS GROUP
LLEWELYN VOLCANIC GROUP
UPPER ARAN VOLCANIC GROUP
LOWER ARAN VOLCANIC GROUP
LLANBEDROG VOLCANIC GROUP
UPPER LODGE VOLCANIC GROUP
SNOWDON VOLCANIC GROUP
Oolitic ironstones

FIGURE 16

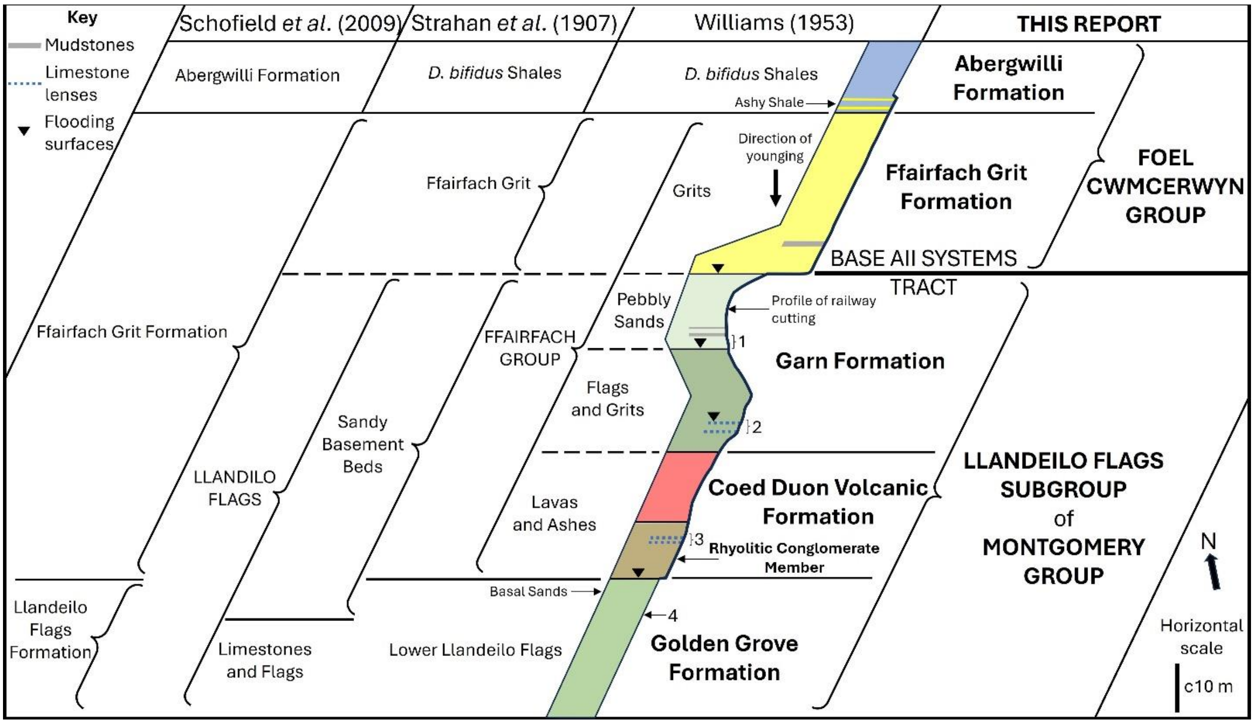



FIGURE 17

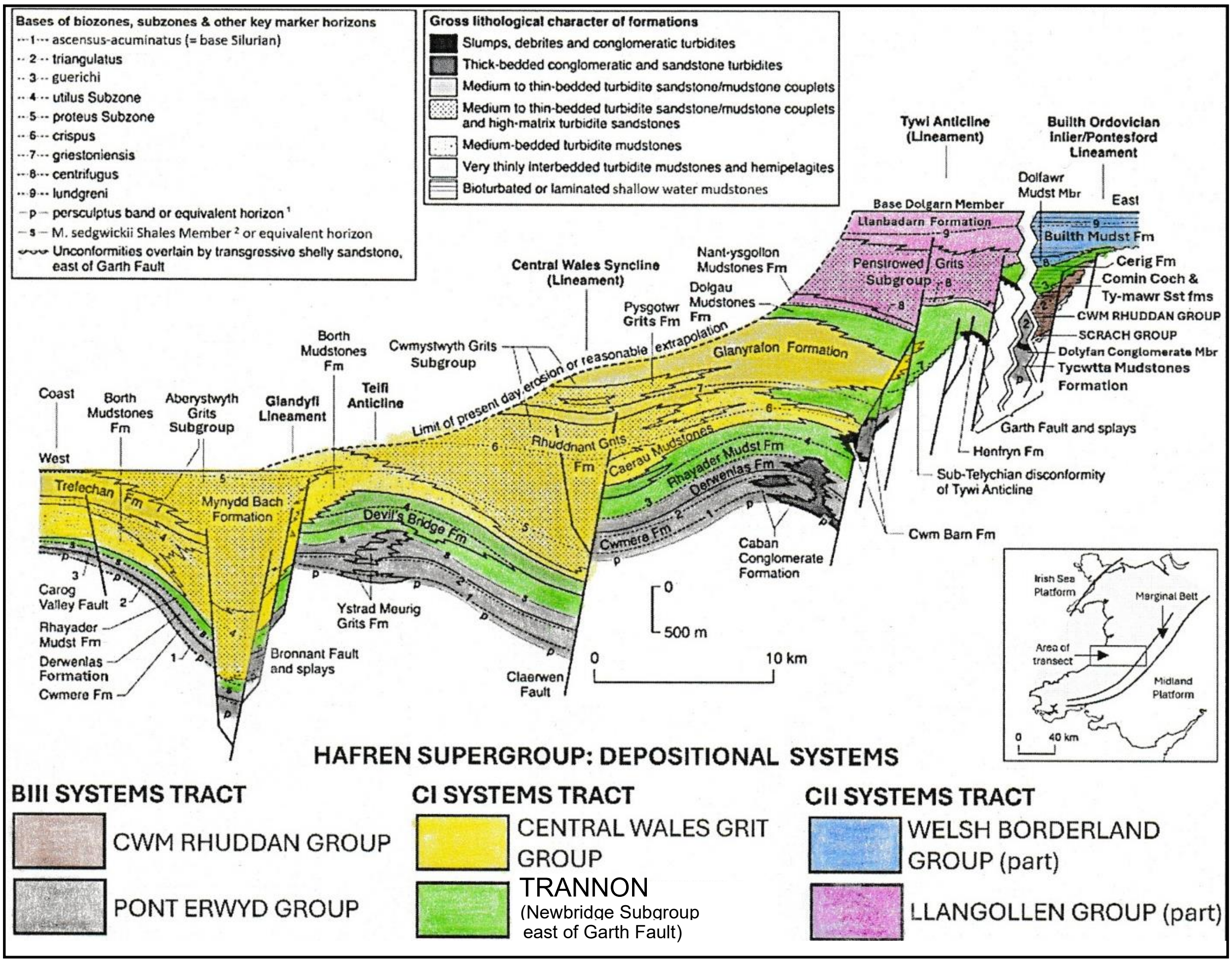


FIGURE 18

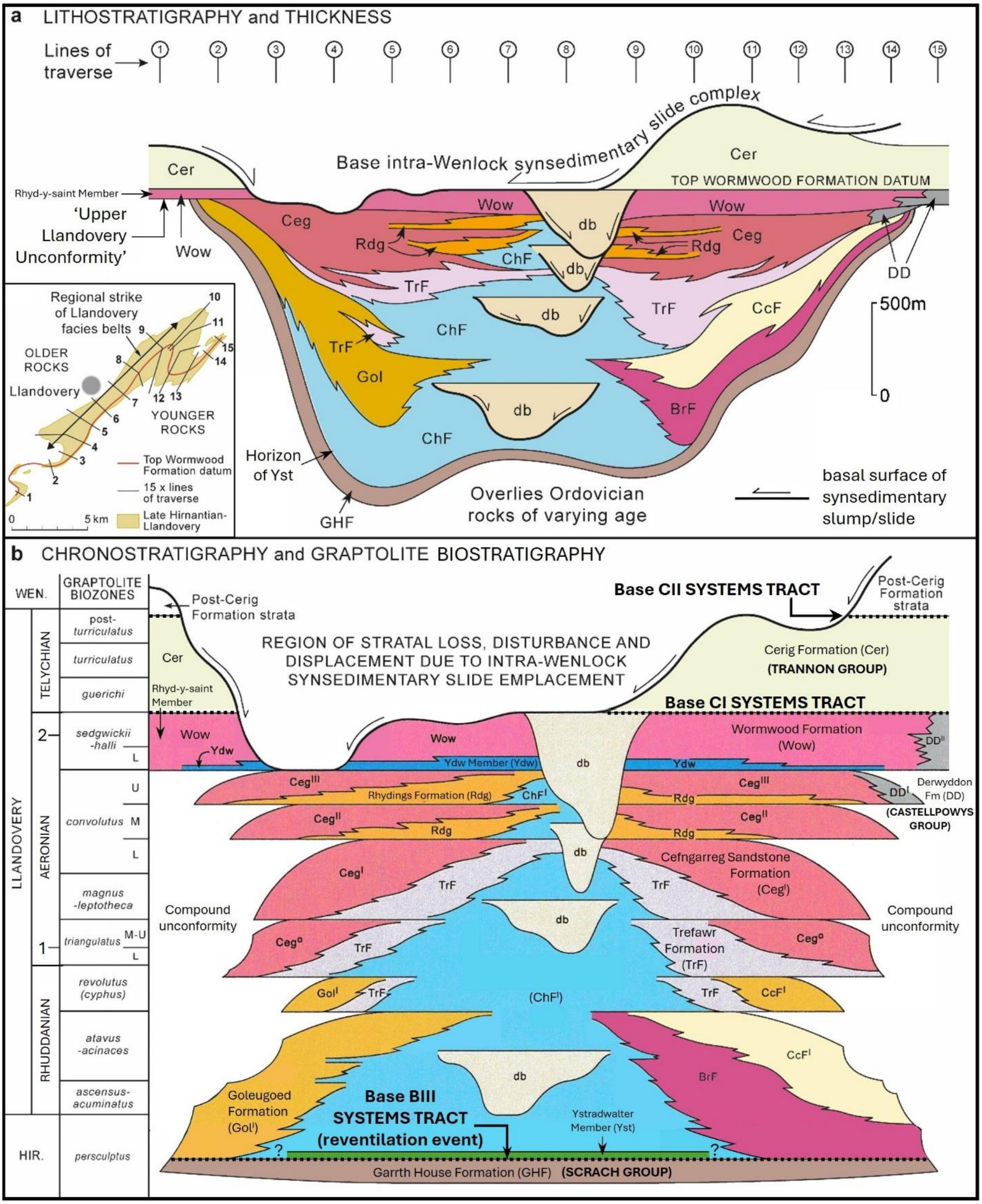

a LITHOSTRATIGRAPHY and THICKNESS
Lines of traverse
Base intra-Wenlock synsedimentary slide complex
TOP WORMWOOD FORMATION DATUM
Rhyd-y-saint Member
'Upper Llandovery Unconformity'
Cer
Wow
Ceg
Rdg
ChF
db
TrF
Gol
BrF
CcF
DD
500m
0
Horizon of Yst
GHF
Overlies Ordovician rocks of varying age
basal surface of synsedimentary slump/slide
Regional strike of Llandovery facies belts
OLDER ROCKS
YOUNGER ROCKS
Llandovery
Top Wormwood Formation datum
15 x lines of traverse
Late Hirnantian-Llandovery
5 km
b CHRONOSTRATIGRAPHY and GRAPTOLITE BIOSTRATIGRAPHY
WEN.
GRAPTOLITE BIOZONES
LLANDOVERY
TELYCHIAN
AERONIAN
RHUDDANIAN
HIR.
post-turriculatus
turriculatus
guerichi
sedgwickii-halli
convolutus
magnus-leptotheca
triangulatus
revolutus (cyphus)
atavus-acinaces
ascensus-acuminatus
persculptus
Post-Cerig Formation strata
REGION OF STRATAL LOSS, DISTURBANCE AND DISPLACEMENT DUE TO INTRA-WENLOCK SYNSEDIMENTARY SLIDE EMPLACEMENT
Base CII SYSTEMS TRACT
Cerig Formation (Cer)
(TRANNON GROUP)
Base CI SYSTEMS TRACT
Wormwood Formation (Wow)
Ydw Member (Ydw)
Rhydings Formation (Rdg)
Derwyddon Fm (DD)
(CASTELLPOWYS GROUP)
Cefngarreg Sandstone Formation (Ceg$^{I}$)
Compound unconformity
Trefawr Formation (TrF)
(ChF$^{I}$)
Goleugoed Formation (Gol$^{I}$)
Base BIII SYSTEMS TRACT (reventilation event)
Ystradwalter Member (Yst)
Garrth House Formation (GHF) (SCRACH GROUP)

FIGURE 19

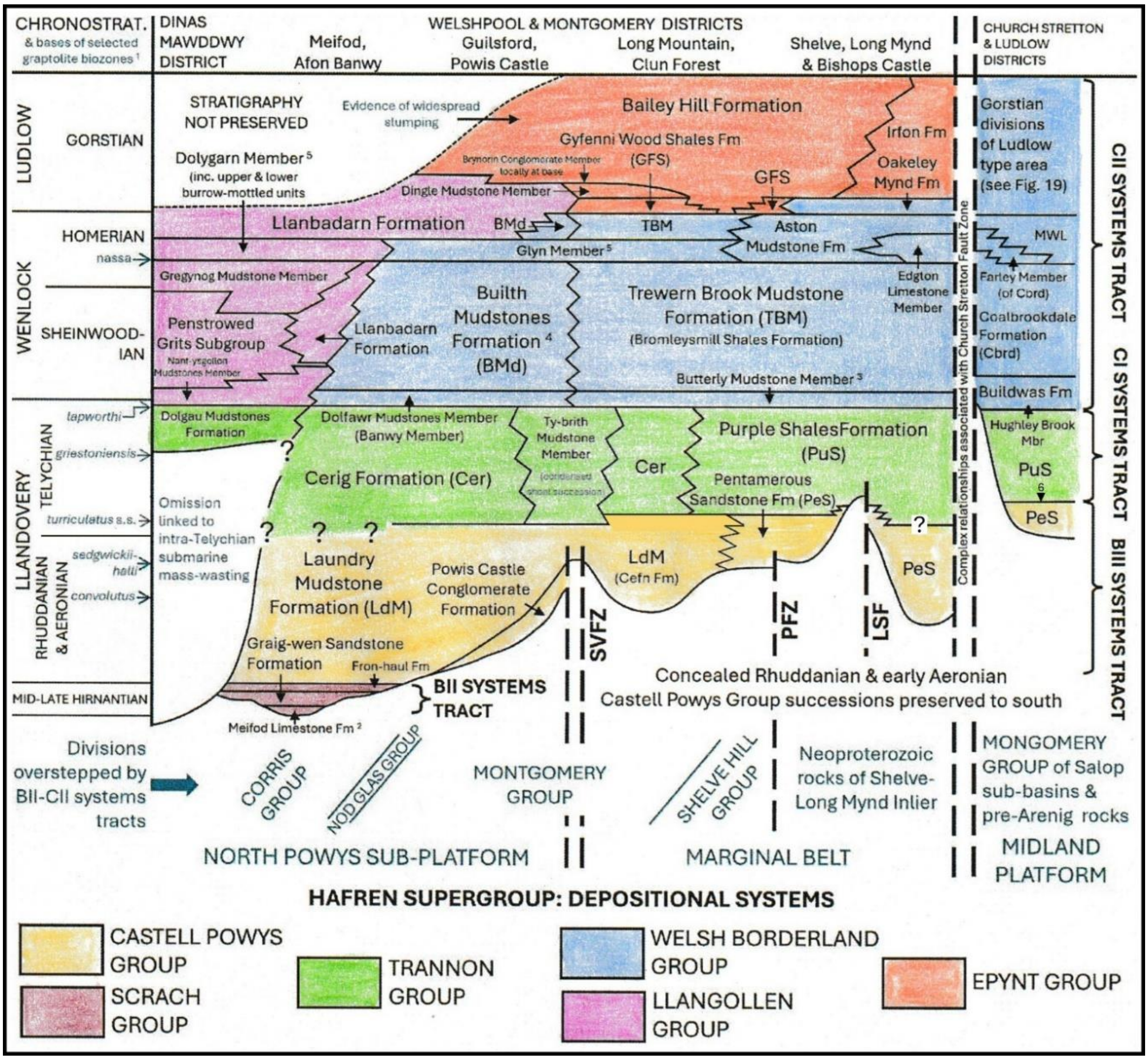



FIGURE 20

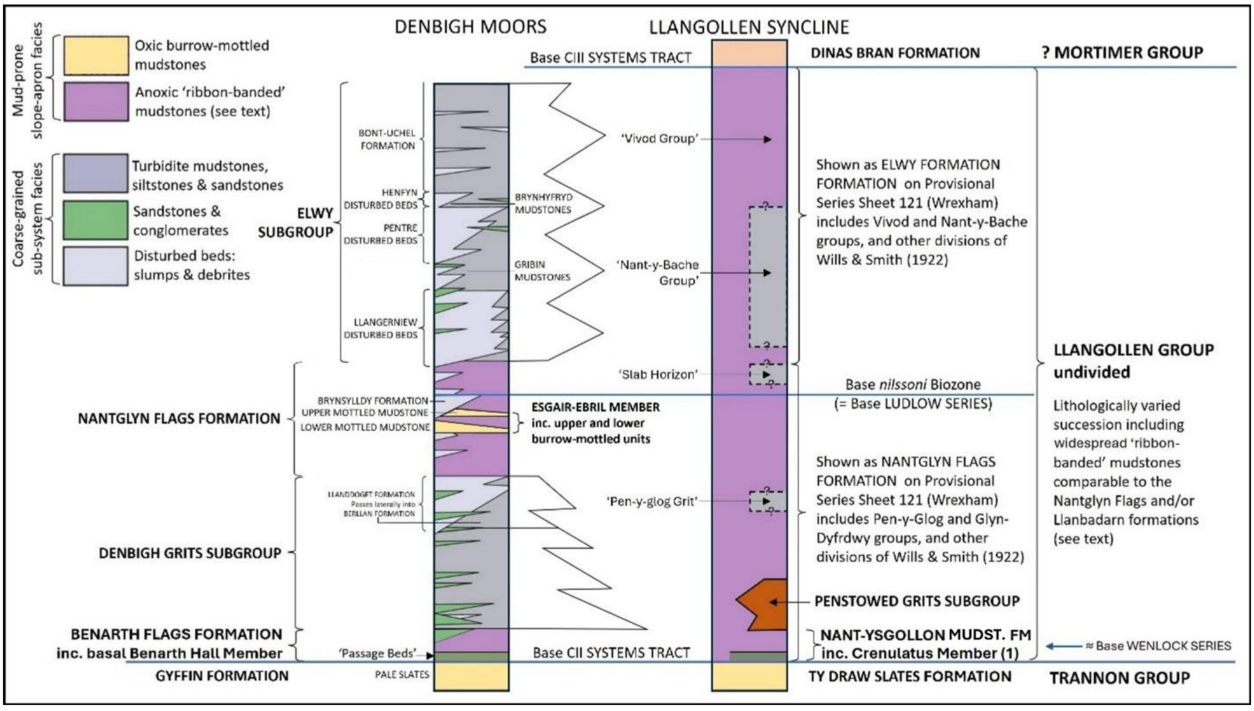


FIGURE 21

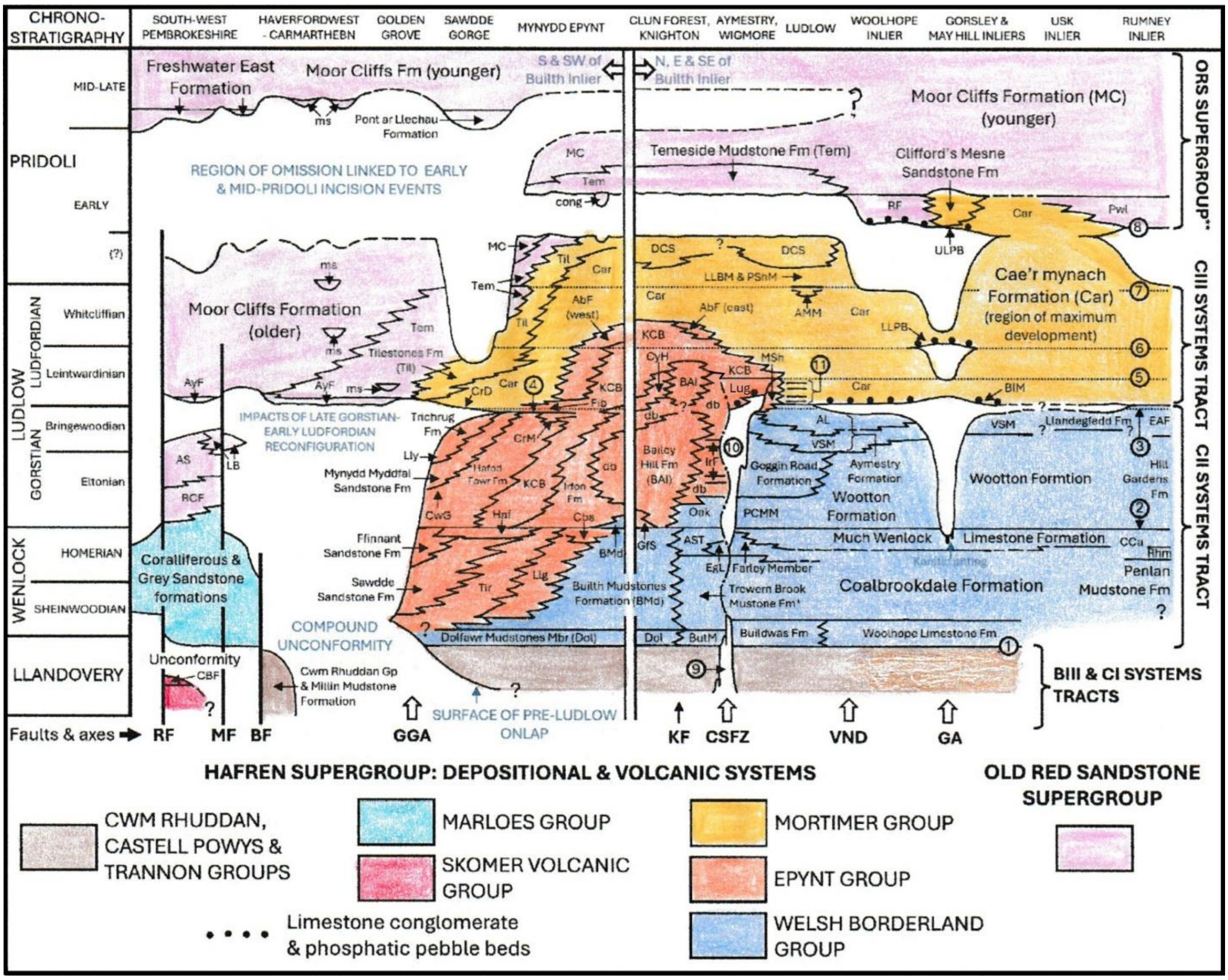
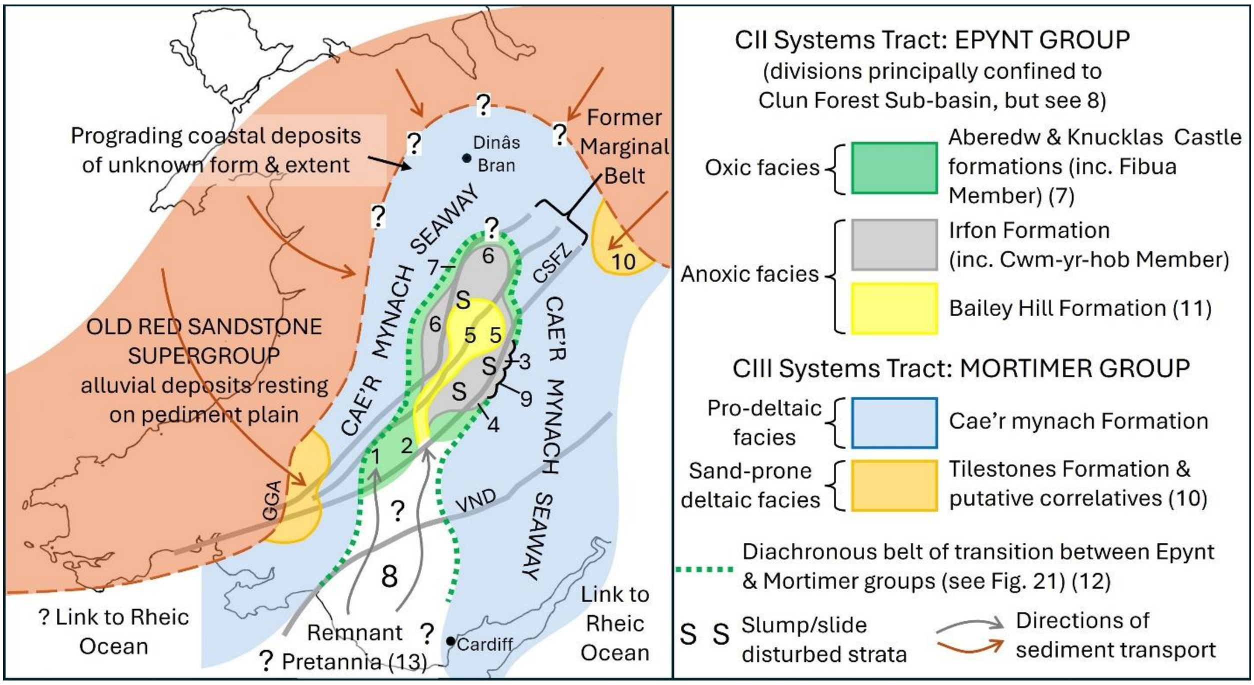



FIGURE 22



## Plates

Plate I. Slumped interbedded mudstones and sandstones, St. Crannog Formation (Yr Allt Group), BII Systems Tract, Llangranog (rucksack is c. 45 cm long) [SN 3105 5431].

Plate 2. Intertwined specimens of the tuning-fork graptolite *Didymograptus murchisoni*, Caerhys Shale Formation (Drefach Subgroup, Montgomery Group), AII Systems Tract, Abereiddi Quarry Abereiddi (scale bar = 1 cm) [SM 7956 3149].

Plate 3. Oxicity indicators in deeper water facies: A) Oxic, burrow-mottled mudstone turbidites and hemipelagites, Nantmel Mudstones Formation (Corris Group), BI Systems Tract, Traeth Penbryn (hammer for scale) [SN 2954 5281]; B) Anoxic, laminated hemipelagites interbedded with structureless turbidite mudstones, Cwmere Formation (Pont Erwyd Group), BIII Systems Tract, Rheidol Gorge (lens cap is 5 cm in diameter) [SN 7534 7981].

Plate 4. Shelly fossils: A) Coquinas of disarticulated, Pentamerus brachiopod valves, Tyncoed Sandstone Member (Comin Coch Formation, Castell Powys Group), BIII Systems Tract, Garth [SN 9580 5173]; B) trilobite Encrinurus from the Trefawr Formation (Cwm Rhuddan Group), BIII Systems Tract, Llandovery (scale bar = 1 cm) [SN 7610 3106].

Plate 5. Nant Ffrancon, northern Snowdonia, viewed from the vicinity of Cwm Idwal [SH 6487 6054], providing a section through rocks of Tract Assemblage A included in the Cadir Idris and lower part of the Eryri groups. Cambrian slate tips are visible in the far distance. Foreground crags are in the Pitts Head Tuff Formation (Snowdon Volcanic Group). Based on Williams (1930, plate XIX), the putative boundary between the pre-Llandeilian Criccieth Formation (Maesgwn Slates) and younger, Llandeilian-Caradoc Porthmadog Formation (lower Glanrafon Slates) is located in crags in the middle distance to the left (see Text Box 3 and Part 4).

Plate 6. Castle Point, Fishguard, as viewed from Penyraber [SM 9587 3738], showing: A) base of the eponymous member of the Penyraber Mudstones Formation (Hengae Group, AII Systems Tract), resting unconformably on extrusive rocks of the Goodwick Volcanic Formation (Fishguard Volcanic Group, AI Systems Tract); B) Aber Richard Fault; and C) mudstone in upper part of the Goodwick Volcanic Formation possibly equivalent to the Cyffredin Shale Member. Note the headland of Dinas Island in the distance.

Plate 7. Abereiddi Quarry and the Blue Lagoon [SM 7955 3141], Abereiddi, exposing the Caerhys Shales Formation with the overlying Castell Limestone Formation forming crags to left of inlet (Drefach Subgroup, Montgomery Group, AII Systems Tract) (swimmers for scale). Crags on the far left are in the Llanrhian Volcanic Formation (Fishguard Volcanic Group, AI Systems Tract). Note, succession is inverted and youngs to the left.

Plate 8. Crags at Uwch-y-coed, near Aberhosan, exposing contact between rusty weathering anoxic mudstones of the Cwmere Formation, lower left, and oxic, feature-forming mudstones of the Derwenlas Formation (Pont Erwyd Group), BIII Systems Tract. Note presence of thin anoxic units in the Derwenlas Formation (note c 1 m-high fence along top of crags for scale) [SN 3000 9502].

Plate 9. Quarry and crags in the Caban Conglomerate Formation (Caban-Ystrad Meurig Sub-group, Pont Erwyd Group), BIII Systems Tract, as viewed from southside of Caban-coch Reservoir [SN 92546 6430], Elan Valley (note car on far side of reservoir for near distance scale; the visible section is over 250 m in height).

Plate 10. Exposures of burrowed sandstones, siltstones and mudstones of the Dinas Bran Formation (?Mortimer Group) beneath the eponymous castle ruins, CIII Systems Tract [SJ 2228 4304].

Plate 11. Red and green slope-apron mudstones, Dolgau Mudstones Formation (Trannon Group), CI Systems Tract, Trannon (hammer for scale) [SN 8955 9565].

Plate 12. CI Systems Tract succession at Cwmtydu [SN 3562 5756], north of the Llangranog, showing thick beds of turbidite sandstones at base (by rucksack) of the Cwmtydu Member (Mynydd Bach Formation, Aberystwyth Subgroup, Central Wales Grits Group) overlying thinly interbedded mudstones and sandstones of the Erwan Fach Formation (Trannon Group).

Plate 13. Interlaminated mudstones, siltstones and fine sandstones of the Esgir Hir Member (Nant-ysgollon Mudstones Formation, Llangollen Group), CII Systems Tract, forestry quarry near Trannon (hammer for scale) [SN 9002 9362].

Plate 14. Thick-bedded turbidite sandstones of the Penstrowed Grits Subgroup (Llangollen Group), CII Systems Tract, roadside quarry, Bwlch-y-sarnau [SO 0364 7503].

Plate 15. Whitcliffian facies of the Cae’r mynach Formation (Mortimer Group) exposed in Whitcliff Quarry [SO 5114 7417], near Ludlow, comprising beds of hummocky cross-bedded sandstone and including the convolute-bedded unit taken to mark the boundary between the former Lower and Upper Whitcliff formations (see Siveter *et al*., 1989).

Plate 16. Base Old Red Sandstone Supergroup, Marloes Sands cliffs [SM 7899 0677], south Pembrokeshire showing transition between the reddish-brown and buff, quasi-marine facies of the Gray Sandstone Formation (Marloes Group) (left) and brick-red terrestrial facies of the Red Cliff Formation (Milford Group) (right). The boundary indicated, located at the base of the lowest, laterally extensive, reddened horizon (see Barclay *et al*., 2016). The pictured succession is thought to span the Wenlock-Ludlow boundary.

PLATE 1

PLATE 2

PLATE 3

PLATE 4


PLATE 5

PLATE 6

PLATE 7

PLATE 8

PLATE 9

PLATE 10

PLATE 11

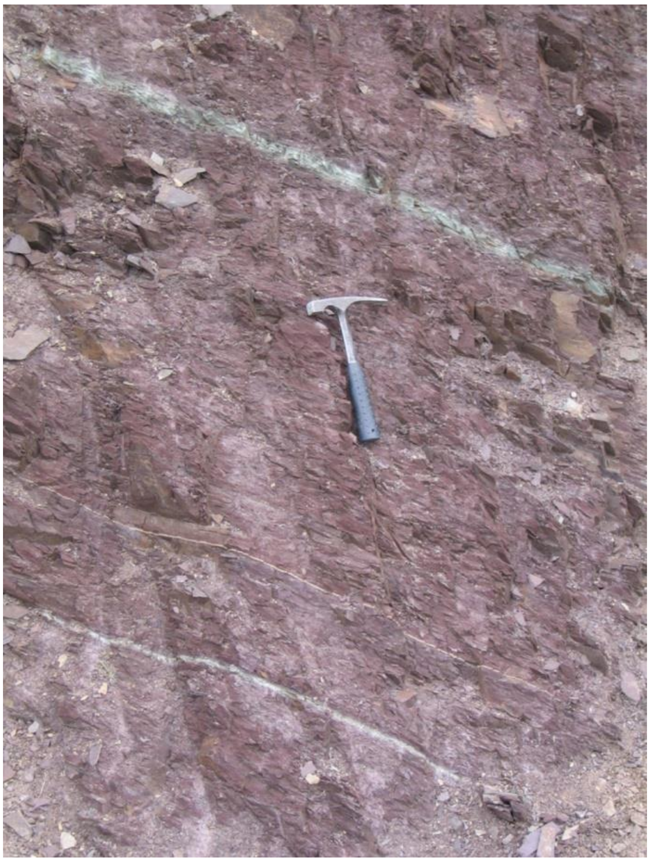


PLATE 12

PLATE 13

PLATE 14

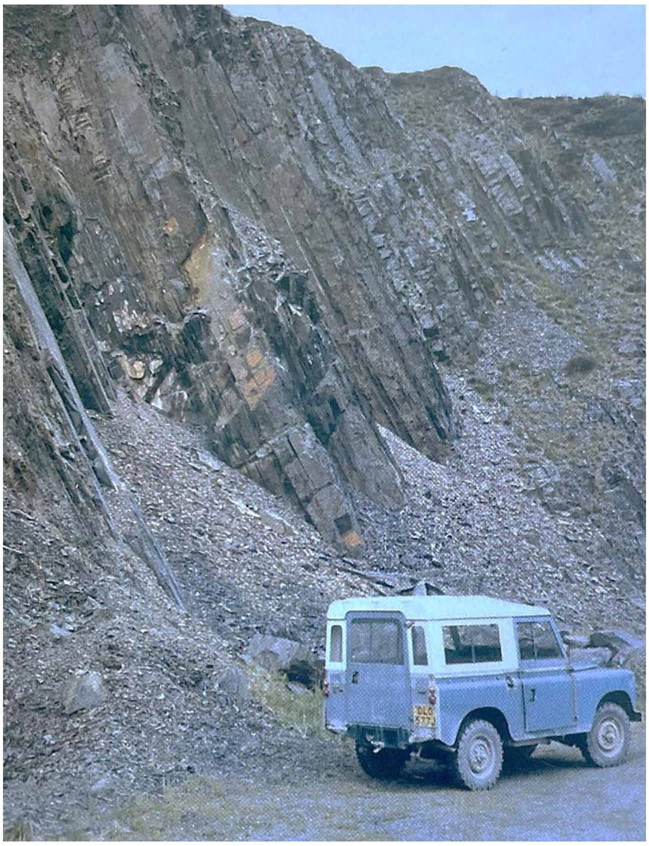


PLATE 15

PLATE 16

## Tables

Table 1. A) Chronostratigraphical and biostratigraphical subdivisions for the Ordovician in the UK showing their relationship to international nomenclature, based principally on Molyneux *et al.* (2023) (see also Gradstein *et al.*, 2020). Note: In older literature the Llanvirn Series excluded rocks that are now assigned to the Llandeilian Stage; prior to erection the Velfreyan Substage, the base of the Caradoc Series was taken at the base of the Costonian, at a level within the gracilis Biozone, with pre-Costonian strata assigned to the former Llandeilo Series; the former Longvillian Stage included levels since assigned to the Woolstonian Substage - see Fortey *et al.* (1995; 2000) and Cocks *et al.* (2010).

Table 1. B) Chronostratigraphical and biostratigraphical subdivision for the Silurian in the UK, based principally on Zalasiewicz *et al.* (2009) (graptolites), Melchin *et al.* (2020) (conodonts) and Davies *et al.* (2016), Mullins and Loydell (2003), Mullins and Aldridge (2004) and Steeman *et al.* (2016) (chitinozoa) (see also Gradstein *et al.*, 2020). 1, In the light of international disagreement re the definition of the base of the Wenlock Series and selection of an acceptable GSSP, Gradstein *et al.* (2020) place the series boundary within the murchisoni Biozone; 2, divisions previously included in either the acuminatus, or a combined ascensus-acuminatus Biozone; 3, formerly the cyphus Biozone; 4, shown in some texts as a combined sedgwickii-halli biozonal interval; 5, see inset for earlier usages and subzonal subdivisions; 6, divisions of the previously undivided crenulata Biozone in the UK; p-d, *praedeubeli-deubeli* Biozone of Fry *et al.* (2017).

Table 2. List of abbreviations used to label structural features on figures 6, 10, 11, 12, 20 and 21.

Table 3. Sedimentary system types and facies used in classifying the Preseli and Hafren supergroup successions of the LPWB and its adjoining region. Notes: 1, excludes most associated intrusive igneous rocks; 2, typically mapped as local facies, members or formations included lithostratigraphically with associated deep or shallow water systems; 3, except in their proximal regions, the gross facies and geometries of clastic ramp, fan delta and delta systems are broadly comparable; 4, intergradational with, and having strong genetic links to contemporary and adjacent volcanic systems; 5, Nod Glas Group is the only intrabasinal high system assigned group status (see text); 6, effects of slope instability (slides, slumps) locally widespread; 7, proximal clastic ramp facies can be contiguous and synonymous with sand-prone facies of clastic blanket systems; 8, currently mapped lithostratigraphical divisions commonly fail to distinguish shallow from deep facies components.

Table 4. Classification of systems tracts and tract assemblages recognised in the LPWB and adjoining area. 1, used as broad descriptive labels that should not be taken to provide precise chronostratigraphical definitions; 2, system tracts with strongly diachronous lower and/or upper boundaries; 3, see text re usage of (?)early Pridoli.

TABLE 1A

| GLOBAL DIVISIONS | | | UK SERIES & STAGES | | CARDOC SUB-STAGES | GRAPTOLITE BIOZONES | CONODONT BIOZONES | CHITINOZOAN BIOZONES |
|---|---|---|---|---|---|---|---|---|
| UPPER ORDOVICIAN | HIRN. | H2 | ASHGILL | Hirnantian | | *persculptus* | *hassi* | *taugourdeaui* |
| | | H1 | | | | *extraordinarius* | *ordovicicus* | |
| | KATIAN | Ka4 | | Rawtheyan | | *anceps* | | *umbilicata* |
| | | | | | | | | *fossensis* |
| | | | | | | | | *rugata* |
| | | Ka3 | | Cautleyan | | *complanatus* | | *'bergstroemi?'* |
| | | | | Pusgillian | | | | |
| | | Ka2 | CARADOC | Streffordian | Onnian | *linearis* | *superbus* | *spinifera* |
| | | | | | | | | *lat.-onn.* |
| | | | | | Actonian | *clingani*: *morrisi* | | *cervicornis*: *actonica* |
| | | Ka1 | | Cheneyan | Marshbrookian | | | |
| | | | | | Woolstonian | *clingani*: *caudatus* | *tvaerensis* | *cervicornis* |
| | SANDBADIAN | Sa2 | | Burrellian | Longvillian | *foliaceus* | | *cervicornis?* |
| | | | | | Soudleyan | | | |
| | | | | | Harnagian | | | *dal.-deunff?* |
| | | Sa1 | | Aurelucian | Costonian | *gracilis* | | *rhenana?* |
| | | | | | Velfreyan | | *anserinus* | |
| MIDDLE ORDOVICIAN | DARRIWILIAN | Dw3 | LLANVIRN | Llandeilian | | *teretiusculus* | | |
| | | | | Abereiddian | | *murchisoni* | *serra* | |
| | | Dw2 | | | | *artus* | *suecicus* | |
| | | | | | | | *pseudoplanus* | |
| | | Dw1 | | Fennian | | *cucullus* | *crassus* | |
| | | | | | | | *variabilis* | |
| | | | | | | | *antivariabilis* | |
| | DAP. | Dp3 | ARENIG | | | *gibberulus* | *parva* | |
| | | Dp2 | | | | | *originalis* | |
| LOWER ORDOVICIAN (part) | | Dp1 | | Whitlandian | | *victoriae* | *navis* | |
| | | | | | | | *triangularis* | |
| | FOLIAN | Fl3 | | | | *simulans* | *evae* | |
| | | Fl2 | | Moridunian | | *jacksoni* | *elegans* | |
| | | Fl1 | | | | *phyllograptoides* | | |

TABLE 1B

| GLOBAL DIVISIONS | | | UK SERIES & STAGES | LUDLOW SUB-STAGES | GRAPTOLITE BIOZONES | CONODONT BIOZONES | CHITINOZOAN BIOZONES |
|---|---|---|---|---|---|---|---|
| SILURIAN | PRIDOLI | Pr2 | **LATE** **MID** | | No younger Graptolite biozones known in UK | *elegans detorus* | *superba* |
| | | Pr1 | **EARLY** | | | *eosteinhornensis* s.l. | *elegans* / *kosovensis* |
| | LUDLOW | Lu3 | **LUDFORDIAN** | Whitcliffian | ? – ? | *crispa* | *barrandei* |
| | | Lu2 | | | *Bohemograptus* | *snajdri* | *phillipi* |
| | | Lu1 | | Leintwardinian | *leintwardinensis* | *siluricus* / *ploeckensis* | *elonganta* |
| | | Go2 | **GORSTIAN** | Bringewoodian | *incipiens* / *scanicus* | *variablis variablis* | ? |
| | | Go1 | | Eltonian | *nilssoni* | *crassa* | |
| | WENLOCK[1] | Ho3 | **HOMERIAN** | | *ludensis* / *p-d* | *ortus obsidata* | *lycoperdoides* |
| | | Ho2 | | | *nassa* | *bohemica longa* | *phachycephala* |
| | | Ho1 | | | *lundgreni* | *sagitta sagitta* | |
| | | Sh3 | **SHEIN-WOODIAN**[1] | | *rigidus-* | *ortus ortus* | *cingulata* |
| | | Sh2 | | | *dubius* | *walliseri* / *rhenana* | |
| | | Sh1 | | | *riccartonensis* / *firmus* / *murchisoni* | *bicornis-procerus* | *margaritana* |
| | ? | | ? | | | | |
| | LLANDOVERY | Te5 | **TELYCHIAN** | | *centrifugus* / *insectus*[5] | *amorphognathoides* | |
| | | Te4 | | | *lapworthi*[5] | | *longicollis-acuminata* |
| | | Te3 | | | *spiralis*[5] / *crenulata*[5] | *celloni* | |
| | | Te2 | | | *griestoniensis* / *sartorius*[4] / *crispus*[4] | *eopannatus* | *doliformis* |
| | | Te1 | | | *turriculatus*[4] / *guerichi*[4] | *staurognathoides* | |
| | | Ae3 | **AERONIAN** | | *halli* / *sedgwickii* | | |
| | | Ae2 | | | *convolutus* / *leptotheca* | *tenuis* | *maennili* |
| | | Ae1 | | | *magnus* / *triangulatus* | *expansa* | |
| | | Rh3 | **RUDDANIAN** | | *revolutus*[3] | *kentuckyensis* | *electa* |
| | | Rh2 | | | *acinaces* / *atavus* | | |
| | | Rh1 | | | *acuminatus*[2] / *ascensus*[2] | | *fragilis-postrobusta* |

| BIOZONES | | SUBZONES |
|---|---|---|
| *crispus* s.l. | *satorius* | |
| | *crispus* | *loydelli* |
| | | *galaensis* |
| *turriculatus* s.l. | *turriculatus* | *carnicus* |
| | | *proteus* |
| | | *johnsonae* |
| | | *utilis* |
| | *guerichi* | *renaudi* |
| | | *gemmatus* |
| | | *runcinatus* |

TABLE 2

| FAULTS AND FOLDS: | |
|---|---|
| AbF, Abergwesyn Fault | LgF, Llanglydwen Fault |
| AF, Aber-Dinlle Fault | LgS, Llangadfan Syncline |
| ARF, Aber Richard Fault | LS, Llangollen Syncline |
| AVF, Allyn Valley Fault | LSZ, Llyn Shear Zone |
| BaF, Bala Fault | LlS, Llandderfel Syncline |
| BF, Berw Fault | LMS, Long Mountain Syncline |
| B-JFB, Benton-Johnson Fault Zone | LMSF, Long Mynd Scarp Fault |
| BnFZ, Bronnant Fault Zone | L-PFB, Llandrindod-Pen-y-waun Fault Belt |
| BoA, Brogan Anticline | LVA, Llandewi Velfrey Anticline |
| BPF, Bryn Posteg Fault | LyS, Llyn Syncline |
| BrF, Bryn Eglwys Fault | MeD, Meusydd Disturbance |
| BRSF, Black Rock Sands Fault | MoF, Mochras Fault |
| C-RF, Cefnamlwch-Rhiw Fault | MHFB, Moel Hebog Fault Belt |
| CCF, Cwm Cynnen Fault | MF, Musselwick Fault |
| CD, Carreg Cennen Disturbance | NMF, Nant Mor Fault |
| CF, Craiglashion Fault | PF, Penfordd Fault |
| Cl-Dy-TFS, Claerwen-Dylife-Tafalog Fault Belt | PaF, Pared Fault |
| C-FFB, Cardigan-Fishguard Fault Belt | P-SFB, Pontesford-Stiperstones Fault Belt |
| C-GFB, Cwmysgawen-Glanalders Fault Belt | RA, Rhiwnant Anticline |
| CM-KF, Cwm Mawr-Knucklas Fault | R-EFB, Roch-Egremount Fault Belt |
| CPFB, Cwm Pennant Fault Belt | RF, Ritec Fault |
| CrF, Crychan Fault | RSF, Ramsey Sound Fault |
| CSFZ, Church Stretton Fault Zone | S-AT, Sarn-Abersoc Thrust |
| CTF, Craig Twrch Fault | SEFZ, Severn Estuary Fault Zone |
| CvF, Craven Arms Fault | S-HFB, Sharpstones-Hill End Fault Belt |
| CVFB, Conwy Valley Fault Belt | StCF, St. Clears Fault Felt |
| CyF, Cynllaeth Fault | SVD, Swansea Valley Disturbance |
| DA, Derwen Anticline | SVFB, Severn Valley Fault Belt |
| DF, Dinorwic Fault | TA, Teifi Anticlinorium |
| DoF, Dolgarrog Fault | TaF, Tal-y-llyn Falt |
| DyF, Dyfnant Fault | TeF, Teifi Pools Fault |
| CFF, Cross Foxes Fault | TF, Trawsfynydd Fault |
| FF, Ffynnon Eidda Fault | TnF, Tanat Fault |
| FTA, Foel Twrch Anticline | TS, Trannon Syncline |
| GAH, Guilsfield Anticlinal Horst | TrF, Trefgarn Fault |
| GhF, Glasshouse Fault | VCF, Vale of Clwyd Fault |
| G-LFB, Garth-Llanwrtyd Fault Belt | VF, Van Fault |
| G-RF, Goytre-Rock Park Fault | VND, Vale of Neath Disturbance |
| GuF, Guilsfield Fault | WF, Wem Fault |
| LEF, Leinthall Earls Fault | WS, Waun Marteg Syncline |
| LF, Llaneilian Fault | YF, Ystwyth Fault |
| LlF, Llanegryn Fault | YIF, Ysbyty Ifan Fault |

| STRUCTURAL INLIERS: | | |
|---|---|---|
| 1 Cyrn y Bain Inlier & Mynydd Cricor Ashgill inliers | 6 Llangynog Inlier | 12 Woolhope Inlier |
| 2 Shelve Ordovician Inlier | 7 Old Radnor & Presteigne inliers | 13 Gorsley Inlier |
| 3 Plynlimon area Ashgill inliers | 8 Pedwardine Inlier | 14 May Hill Inlier |
| 4 Builth-Llandrindod Inlier | 9 Aberleys Inlier | 15 Usk Inlier |
| 5 Llanwrtyd Inlier | 10 Malverns Inlier | 16 Rumney Inlier |
| | 11 Shutnal Inlier | |

TABLE 3

| SYSTEMS | | MAPPED FACIES & SUBSYSTEMS | KEY FEATURES & TERMINOLOGY | MACROFAUNA |
|---|---|---|---|---|
| **Volcanic systems[1]** | | Lavas, pyroclastic deposits (tuffs, agglomerates, etc), volcanoclastic sediments | Acid/basic; submarine ± emergent phases | Shelly benthos in volcanoclastic sediments |
| **Deep water systems** | **Slope-apron systems** | Oxic facies | Thinly interbedded fine-grained turbidites & hemipelagites; slump & creep features; unconfined systems; subordinate coarse-grained turbidites confined to channels & lobes | Burrow-mottling in oxic facies; graptolites in anoxic facies |
| | | Anoxic facies | | |
| | | Coarse-grained subsystems | | |
| | **Sandstone lobe systems** | Lobe facies | Thin to thick-bedded muddy debrites & Bouma & coarse-grained turbidites, oxic & anoxic hemipelagites; confined systems | Burrow-mottling in oxic facies; graptolites in anoxic facies |
| | | Sandy fringing facies | | |
| | | Muddy fringing facies | | |
| | **Slope/Foot-of-slope systems[2]** | Slides, slumps, debrites/melange | Thin & condensed slope successions; Foot-of-slope accumulations of slumps, debrites & inc. olistostromes | Mixed & reworked pelagic &/or benthic faunas |
| **Shallow water systems** | **Clastic ramp systems[3]** | Upper (proximal) ramp facies[5] | Wedge-shaped systems; steep seaward-facing gradients; bioturbated sand & mud-rich facies, locally conglomeratic, storm sheet sandstones; anoxic facies in outer ramp settings; slides & slumps | Shallow/nearshore to deep/offshore shelly & trace fossil benthic communities; oxic distal facies barren, anoxic facies graptolitic |
| | | Mid-ramp facies[6] | | |
| | | Outer (distal) ramp facies[6] | | |
| | **Clastic delta systems[3]** | Delta top (proximal) facies | Wedge-shaped systems; steep seaward facing gradients; uni-directional current indicators in some facies; stacked thick-bedded sandstones, thinly interbedded sheet sandstones & mudstones, weakly to intensely bioturbated; distal facies may be anoxic; slides & slumps | Shallow/nearshore to deep/offshore shelly & trace fossil benthic communities; anoxic facies graptolitic |
| | | Delta front facies[6] | | |
| | | Pro-delta (distal) facies, inc. turbidite facies[6] | | |
| | **Clastic blanket systems** – **Mud-prone blanket systems** | Offshore (distal) facies: transition zone & lower shoreface | Laterally extensive tabular systems; bioturbated mudstones; local storm sheet sandstones | Graptolites &/or blind trilobites in deep/offshore facies, shelly benthic communities in shallower facies |
| | **Clastic blanket systems** – **Sand-prone blanket systems** | Nearshore (proximal) facies: littoral & upper shoreface[7] | Fossiliferous sandstones & sheeted facies; commonly as transgressive successions overlying unconformities | Distinctive, shallow water shelly & trace fossil assemblages |
| | **Calcareous blanket systems** | Offshore facies | Highly bioturbated, calcareous silty mudstones & storm sheet sandstones | Deep/offshore to shallow/nearshore shelly benthic communities inc. reef faunas |
| | | Shoal & reef facies | Highly fossiliferous limestones | |
| **Mixed systems** | **Mixed clastic systems** | Deep & shallower water facies exhibit rapid vertical & lateral transitions[8] | Transitions between deeper & shallower water components typically complex & gradational | Deep & shallow water indicators |
| | **Mixed volcano-clastic systems[4]** | As above, strongly influenced by volcanic topography & sediment shed from active centres | Transitions between deeper & shallower water components typically complex & highly gradational | Deep & shallow water indicators |
| | **Mudstone drape systems** | Mixed systems in which deeper slope apron & shallower clastic ramp & blanket mudstone facies (subsystems; formations) display seamless transitions within laterally extensive successions with a sheet- or drape-like geometry | | Deep & shallow water indicators |
| **Intra-basinal high systems[2,5]** | | Hemipelagic muds, limestones & phosphatised sediments | Oxic & anoxic; local non-sequences due to periodic emergence &/or mass wasting &/or nil deposition; thin & condensed successions | Graptolites in anoxic facies; shelly benthos in oxic facies |
| **Terrestrial systems** | | Dominant system type of the Late Ludlow to Devonian ORS Supergroup, but includes calcrete-bearing fluvial red beds of Gorstian age seen in south-west Wales; | | |

TABLE 4

<table>
<tr><th>TRACT ASSEMBLAGES</th><th>SYSTEMS TRACTS</th><th>CHRONOSTRATIGRAPHICAL RANGES [1]</th><th colspan="2">SUPERGROUPS</th></tr>
<tr><td rowspan="3">C<br>Collision & post-collision</td><td>CIII</td><td>Late Ludlow-(?)early Pridoli[2,3]</td><td rowspan="3">upper</td><td rowspan="6">HAFREN</td></tr>
<tr><td>CII</td><td>Latest Telychian-early Ludlow[2]</td></tr>
<tr><td>CI</td><td>Latest Aeronian-late Telychian[2]</td></tr>
<tr><td rowspan="3">B<br>Post-volcanic thermal subsidence & eustasy (some local rifting)</td><td>BIII</td><td>Late Hirnantian-mid Telychian[2]</td><td rowspan="3">lower</td></tr>
<tr><td>BII</td><td>Early-mid Hirnantian</td></tr>
<tr><td>BI</td><td>Pre-Hirnantian Ashgill</td></tr>
<tr><td rowspan="2">A<br>Rifting & volcanic</td><td>AII</td><td>Late Llanvirn-Caradoc[2]</td><td colspan="2" rowspan="2">PRESELI</td></tr>
<tr><td>AI</td><td>Arenig-early Llanvirn[2]</td></tr>
</table>