GeoScienceWorld
Lithosphere
Volume 2021, Article ID 7866176, 24 pages
https://doi.org/10.2113/2021/7866176

Lithosphere

Research Article

The Silurian Transgression of a Palaeoshoreline: The Area between Old Radnor and Presteigne, Welsh Borderlands

David C. Ray,[1] Emilia Jarochowska ,[2] Helen E. Hughes,[3] Anna L. Claussen,[2] Arthur C. Tingley,[4] John Moseley,[4] and Oskar Bremer[5]

[1]*School of Geography, Earth and Environmental Sciences (GEES), University of Birmingham, UK*
[2]*GeoZentrum Nordbayern, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany*
[3]*School of Biological and Marine Sciences and School of Geography, Earth and Environmental Sciences, University of Plymouth, UK*
[4]*Herefordshire and Worcestershire Earth Heritage Trust, University of Worcester, UK*
[5]*Department of Organismal Biology, Uppsala University, Uppsala, Sweden*

Correspondence should be addressed to Emilia Jarochowska; emilia.jarochowska@fau.de

Received 21 September 2020; Accepted 8 March 2021; Published 10 July 2021

Academic Editor: Jean Borgomano

Quarries between Old Radnor and Presteigne, Welsh Borderlands, expose a Silurian nearshore succession, which onlaps a rocky palaeotopography of the Neoproterozoic basement that had been uplifted along the Church Stretton Fault Zone. The succession documents the Aeronian to Sheinwoodian transgression of an island or islands, with the following sequence of events: deposition of shallow marine sandstones (Folly Sandstone Formation), regional uplift, preservation of a rocky shoreline and associated deposits (Dolyhir Rudite Member), deposition of limestones characterized by a profusion of coralline algae and the abundant remains of reefs (Dolyhir and Nash Scar Limestone Formation), and finally deposition of trilobitic silty mudstones (basal Coalbrookdale Formation). Facies analysis, carbon isotope ($\delta^{13}C_{carb}$) values, sequence stratigraphy, and collections of bryozoans, conodonts, thelodonts, and trilobites have been used here as a means of refining our stratigraphic understanding of this unique succession. The revised stratigraphy demonstrates many similarities with the adjoining Midland Platform and the wider Silurian world. Notable features include the globally recognized early Sheinwoodian carbon isotope excursion and sea-level changes of regional and global extent. As one of the best examples of its kind, the palaeoshoreline and nearshore succession of Old Radnor and Presteigne acts as a depositional model for ancient rocky shores worldwide.

1. Introduction

The area that encompasses the settlements of Old Radnor and Presteigne straddles the border between England and Wales (Herefordshire-Powys border) and is notable for its inclusion in a region for which there is no modern published geological map and accompanying text describing the geology [1]. This is despite the classic geology of the area, which has been important in advancing the development of science through the 19th and early 20th centuries [2]. In particular, there is a rare Silurian succession that documents the flooding of the Neoproterozoic basement, which had been uplifted along the Church Stretton Fault Zone (Figure 1). During Llandovery and Wenlock times, the Church Stretton Fault Zone was one of the strands of the Welsh Borderland Fault System that separated the shallow-water facies of the Midland Platform microcraton from the basinal facies of the Welsh Basin and, by repeated episodes of Devonian (Emsian to Frasnian) movement, deformed the Silurian succession described herein [3, 4].

From the earliest descriptions of the Silurian succession between Old Radnor and Presteigne, it was considered to be one of special interest, with both Roderick Murchison and Charles Lapworth noting the differences exhibited by the Dolyhir and Nash Scar Limestone Formation when compared with the age-equivalent Woolhope Limestone Formation of the wider Midland Platform [5]. These differences are, for the most part, the result of a localized and remarkable

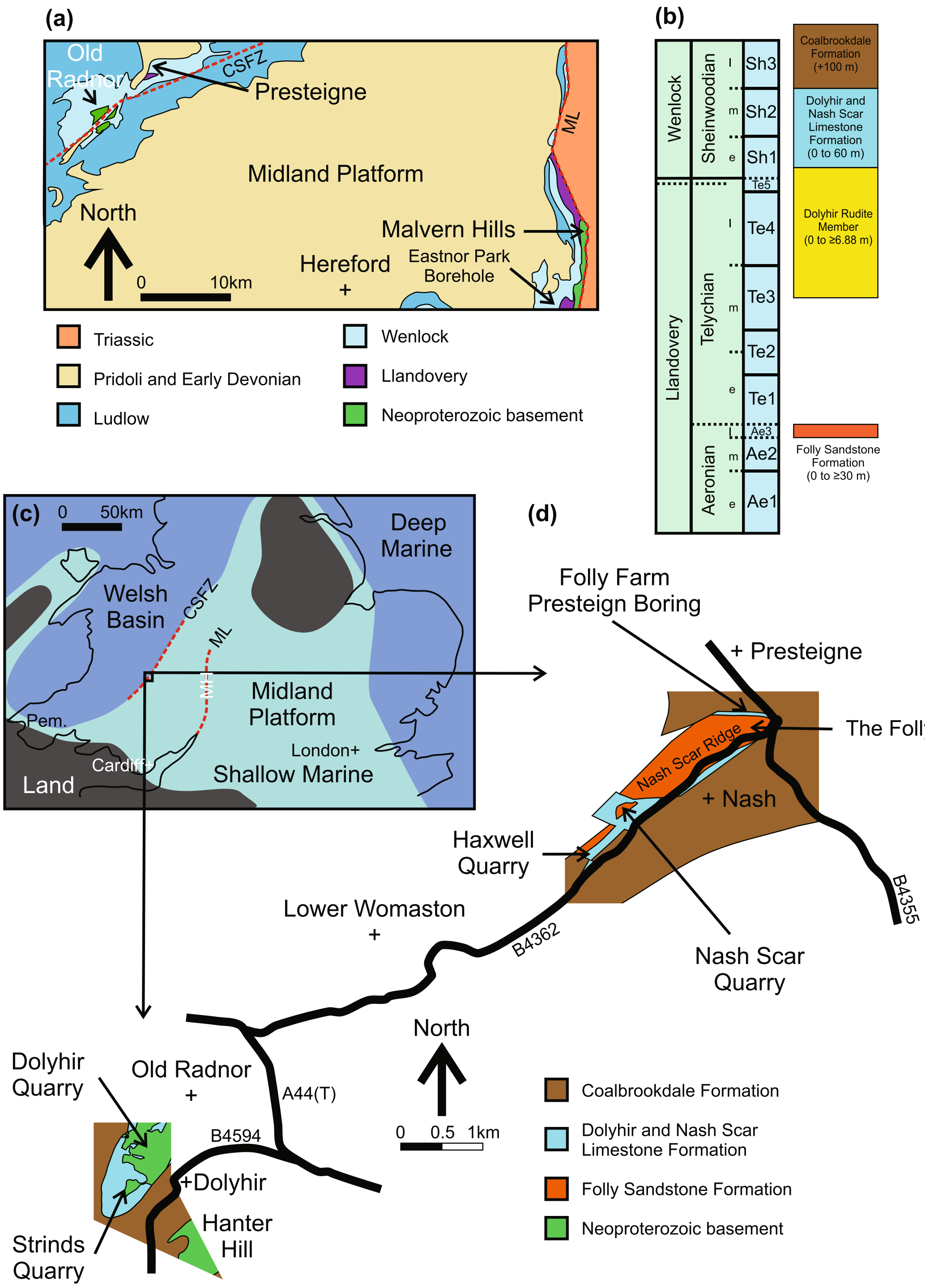


FIGURE 1: Overview of the study area. (a) Simplified geological map showing the area between Old Radnor and Presteigne and the coeval succession of the Malvern Hills. Note that the red dashed lines highlight the approximate trends of the Church Stretton Fault Zone (CSFZ) and Malvern Line (ML). Contains British Geological Survey materials © UKRI (2021). (b) The age and thickness of the succession encountered within the study area, based upon the results of the study herein. Early (e), middle (m), and late (l) subdivisions have been given for the stages, as have the internationally recognized stage slices [19, 20]. (c) Palaeogeographic context of the Old Radnor and Presteigne study area during middle Sheinwoodian times; estimated palaeolatitude of study area 13°S of the equator [31, 94]. CSFZ = Church Stretton Fault Zone; MH = Malvern Hills; ML = Malvern Line; Pem. = Pembrokeshire. (d) The location of the main outcrops investigated. Note that the Dolyhir Rudite Member occurs between the Folly Sandstone and Dolyhir and Nash Scar Limestone formations and between the Neoproterozoic basement and the Dolyhir and Nash Scar Limestone Formation but is of insufficient thickness to illustrate on this map.

profusion of coralline algae, alongside the abundant remains of reefs. Moreover, the study area is notable for the presence of shallow marine sandstone deposits, angular unconformities, and the preservation of a rocky shoreline and associated deposits.

An understanding of the stratigraphy of this Llandovery and Wenlock succession is mostly based on a series of long-standing publications [6–8], with no major published study having been undertaken since that of Garwood and Goodyear [5]. However, the area continued to be of interest with several subsequent studies focusing upon aspects of biostratigraphy (e.g., [9–11]), palaeontology (e.g., [12, 13]), and tectonostratigraphy (e.g., [3]), thereby allowing the succession to be broadly understood in its regional context [14]. To these, a number of unpublished theses also contain much useful information [15, 16], most notably that of Kirk [17].

There are however still gaps in our knowledge of lithostratigraphy, distribution, age, and depositional environments of this succession. For example, there are no detailed sedimentary logs documenting the succession, with the result that the stratigraphic placement of biostratigraphic collections is often cryptic, and an understanding of lateral and vertical facies variability is poor. In addition, biostratigraphic collections have failed to constrain the upper and lower limits of the limestones between Old Radnor and Presteigne (Dolyhir and Nash Scar Limestone Formation) as, although they contain middle Sheinwoodian conodonts, they may range on purely stratigraphic grounds from the upper Aeronian to lower Homerian; based upon age constraint from the under- and overlying formations. The lower age limit of the limestones is based upon the age of the locally developed and underlying Folly Sandstone Formation. However, between the Folly Sandstone Formation and limestones at Presteigne and between the Neoproterozoic basement and limestones at Old Radnor, there is a thin succession of rudite (named here the Dolyhir Rudite Member of the Dolyhir and Nash Scar Limestone Formation) of undetermined age. The upper age limit of the limestone is similarly problematic, with graptolites from the overlying Coalbrookdale Formation being of uncertain stratigraphic placement. More broadly, the current level of stratigraphic understanding has resulted in uncertainty as to whether the succession represents the same depositional system as the wider Midland Platform or an isolated system controlled by local tectonics along the Church Stretton Fault Zone and surrounded by offshore graptolitic silty mudstones.

2. Aims, Objectives, and Analytical Methods

The aims of this study are to better understand the lithostratigraphy, distribution, age, and depositional environments of the Llandovery-Wenlock succession between Old Radnor and Presteigne; the units investigated are the Folly Sandstone Formation, the Dolyhir Rudite Member, the Dolyhir and Nash Scar Limestone Formation, and the basal part of the Coalbrookdale Formation. These aims have been achieved by geological mapping, the logging of sections which are stratigraphically extensive and contain important lithological boundaries, the investigation of borehole records provided by Tarmac (Dolyhir and Strinds quarries) and the British Geological Survey (OpenGeoscience borehole scans), thin-section analysis, carbon isotope ($\delta^{13}C_{carb}$) analysis, and biostratigraphic investigations into bryozoans, conodonts, thelodonts, and trilobites. Note that Ordnance Survey grid references are used for locational information. They consist of two letters followed by six or eight numbers (e.g., SO 3200 6340). Having established a detailed stratigraphic framework, the findings of previous studies have been integrated, and comparisons have been made with successions elsewhere upon the Midland Platform and beyond.

The methods used for the collection of conodonts and thelodonts, alongside conodont counts and $\delta^{13}C_{carb}$ and $\delta^{18}O_{carb}$ values (Tables SM1 and SM2, respectively, and [18]) and a crossplot of $\delta^{13}C_{carb}$ and $\delta^{18}O_{carb}$ values (Figure SM1), are briefly discussed within the supplementary materials. In addition, the identification of suitable lithologies for these analyses, alongside lithological descriptions and bryozoan identifications, has been supported by 59 thin sections created from 21 samples collected from the Dolyhir Rudite Member, Dolyhir and Nash Scar Limestone Formation, and Coalbrookdale Formation.

3. Stratigraphy and Depositional Environment of the Aeronian to Sheinwoodian Succession between Old Radnor and Presteigne

In the following sections, we have combined new research with previous studies to reassess the Folly Sandstone Formation, Dolyhir Rudite Member, and Dolyhir and Nash Scar Limestone Formation, as well as the basal Coalbrookdale Formation. As a means of easily communicating age information, the Aeronian, Telychian, and Sheinwoodian stages have been described and subdivided using internationally recognized stage slices [19, 20] and informally subdivided into early, middle, and late substages (Figure 1).

3.1. Folly Sandstone Formation

3.1.1. Lithostratigraphy and Distribution of the Folly Sandstone Formation. The Folly Sandstone Formation (formerly Corton Grit; [6]) occupies the greater part of a prominent hill (the Nash Scar Ridge), 1.5 km SW of Presteigne (Figure 1). Here, the formation forms the core of an anticline, the limbs of which dip at approximately 40° to 50°, to the NNW and SSE. The Folly Sandstone is known only from the Presteigne area but may be coeval with the nearby Pentamerus Beds of the Pedwardine inlier, approximately 10 km NE [21]. Much of the formation consists of indistinct blocky beds of subarkosic sandstones and grits, with scattered granules and small pebbles of quartz, quartzite, and lithic material (mudrock, sandstone, volcanic, and plutonic clasts) (SO 3200 6340 and SO 3009 6233) [22, 23]. In addition, conglomerates (SO 3060 6272) and thinly bedded fine-grained micaceous sandstones, siltstones, and mudstones are also present (SO 3146 6336). Brachiopods are the most common fossils and are typically preserved as moulds. They occur as scattered

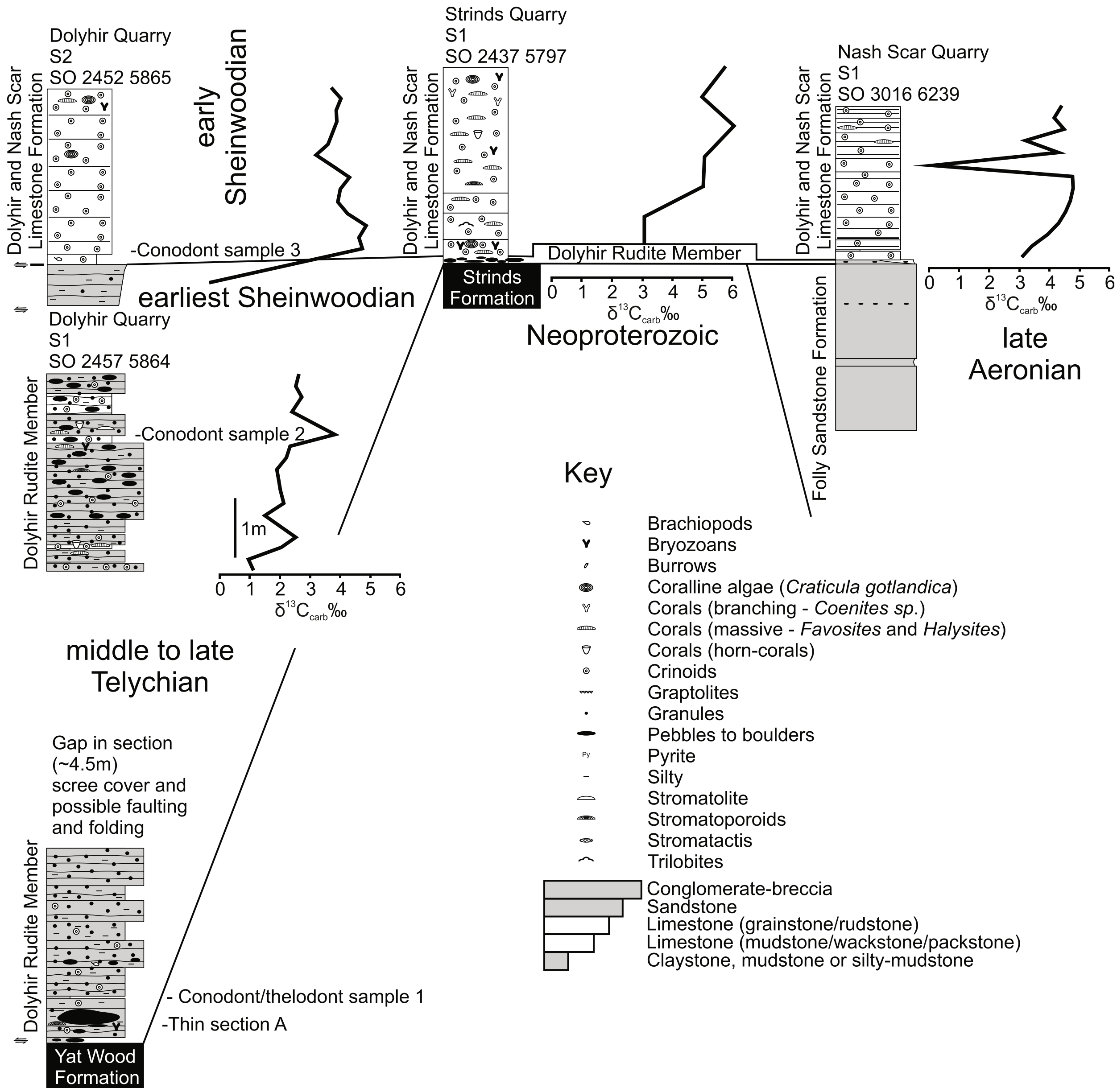


Figure 2: Sedimentary logs from the Old Radnor and Presteigne study area, showing the key sections that contain the Dolyhir Rudite Member of the Dolyhir and Nash Scar Limestone Formation and the immediately under- and overlying successions. $\delta^{13}C_{carb}$ values are given, alongside the location of conodont samples and illustrated thin sections.

individuals or within graded shell beds and fossiliferous lenses. Alongside the brachiopod fauna, crinoids, orthocones (*Dawsonoceras* sp.), tentaculites, calymenid trilobites, and rare solitary rugose corals, as well as colonial tabulate forms (e.g., *Favosites*, [6]), are reported from notably fossiliferous beds (e.g., SO 3175 6342 and SO 3009 6233).

The lower contact of the formation is not exposed but has been recorded at depth (-38 m) near the NE end of the Nash Scar Ridge (SO 3172 6348). Here, within the Folly Farm Presteign Boring, the Folly Sandstone is considered to rest unconformably upon Neoproterozoic (Longmyndian Supergroup) sandstones and conglomerates [6, 24]. Further evidence for the presence of a Neoproterozoic basement comes from substantive Neoproterozoic outcrops to the SW at Old Radnor [25, 26] and to the NE in the Pedwardine inlier [21, 27, 28]. In addition, purplish-red (described as claret-coloured) quartzite pebbles within the Folly Sandstone are considered to have been derived from Longmyndian conglomerates [6]. Accordingly, it seems likely that the Nash Scar Ridge contains a Neoproterozoic core, which may locally crop out upon its wooded slopes.

The upper unconformable contact of the formation is with a locally developed rudite (Dolyhir Rudite Member) or the limestones of the Dolyhir and Nash Scar Limestone Formation. At Nash Scar Quarry (Figures 1 and 2), and immediately SW in the valley of Haxwell, the transition is abrupt, with a minor angular discordance locally developed between the formations [7, 17, 26]. On the northern side of the Nash

Scar Ridge, near the Folly (SO 3152 6347), the angular discordance is more clearly developed and is locally incised by a channel [17, 29]. Here, the Folly Sandstone is overlain by the Dolyhir Rudite, above which is the Dolyhir and Nash Scar Limestone Formation.

The thickness of the Folly Sandstone has been given as in excess of 30 m [29]. However, the unconformable nature of the lower and upper boundaries means that the thickness may be highly variable. For example, within the Folly Farm Presteign Boring, the thickness could be as little as 12.3 m (based on thicknesses corrected for 55 degrees of dip) [6]. Similarly, extensive exposures of the Folly Sandstone, such as the large excavation near Corton House (SO 3200 6340), do not contain the entire formation and provide access to no more than 10 m of the succession.

3.1.2. Age of the Folly Sandstone Formation. A late Aeronian to early Telychian age has been suggested for the Folly Sandstone [14, 29]. However, based upon brachiopod assemblages of *Eocoelia*, *Pentamerus*, and *Stricklandia*, including the rare *Aenigmastricklandia* of Ziegler [11], an exclusively Aeronian age seems more likely. No brachiopods diagnostic of the Telychian have been reported from the Folly Sandstone [30]. Following Cocks et al. [14], we restrict the base of the Folly Sandstone to the upper Aeronian and more broadly consider the formation to be wholly of late Aeronian age (stage slice Ae3), thereby indicating age synchronicity with the Cowleigh Park Formation of the Malvern Hills, some 55 km to the east [14].

3.1.3. Depositional Environment of the Folly Sandstone Formation. The Folly Sandstone Formation was deposited during the Aeronian transgression of a previously subaerially exposed shelf-margin. Regionally, this transgression resulted in the rapid spread of marine conditions to the Malvern Line in the east and the Shelve-Longmynd Peninsula to the north [31]. Transgression within the Folly Sandstone is indicated by the transition from an *Eocoelia* to *Pentamerus* brachiopod community within the upper part of the succession [29]. In addition, the occurrence of a *Lingula* community cannot be ruled out from the Folly Sandstone, as the shallowest part of the succession likely occurs within its unexposed base. In detail, the variety of different lithologies that constitute the Folly Sandstone imply variable water depths and energy levels. These differences likely reflect short-term transgressive-regressive cycles, which are widely evident from the upper Aeronian [32], as well as local bathymetric differences generated during the transgression of the palaeoshoreline. Water depths likely varied between the littoral and sublittoral zones, but the scarcity of large outcrops precludes a detailed assessment of short-term cyclicity.

3.2. Dolyhir Rudite Member of the Dolyhir and Nash Scar Limestone Formation

3.2.1. Lithostratigraphy and Distribution of the Dolyhir Rudite Member. A rudite unit occurs sporadically at the base of the Dolyhir and Nash Scar Limestone Formation [5], named herein the Dolyhir Rudite Member of the Dolyhir and Nash Scar Limestone Formation (Figures 2–5). Across the study area, the rudite is highly variable in composition and thickness and is most extensively developed in Dolyhir Quarry. Here, it consists of very angular to rounded clasts, ranging in size from small grains to boulders 40 cm in diameter (Figure 4(a)). The rudite can be both clast- and matrix-supported. The lithology of the clasts is highly variable and is, in part, dependent upon the makeup of the underlying Neoproterozoic (Yat Wood and Strinds formations) and Folly Sandstone Formation. Sandstone, mudstone, vein quartz, and quartzite are the most common lithologies of the basement-derived clasts, which also include dolerite from dykes that cut the Neoproterozoic at Old Radnor [10, 33] (Figure 5(a)). Limestone clasts, some of which consist of corals and bryozoans in a lime-mud matrix, are also a component of the rudite. Lithological and faunal similarities with limestone beds and the surrounding limestone matrix indicate that these are intraformational. The limestone beds typically consist of crinoidal grainstones and rudstones. The matrix of the rudite is highly variable and ranges from clay to a sandy-grit and lime-mud to coarse crinoid ossicles embedded in secondary calcite (Figure 5(a)). Throughout the succession, crinoid ossicles are the most common fossil component but are associated with fragmentary brachiopods, bryozoans, and tabulate corals (halysitid), as well as solitary rugose corals, stromatolites, and stromatoporoids with borings. In addition, discrete horizons of corals (*Favosites*) up to 15 cm in diameter occur across the study area (e.g., SO 2457 5864 and SO 2417 5817) (Figure 4(b)). Many of these corals are in life position [5] and occur alongside pebbles within both the clastic- and limestone-rich horizons.

Outcrop and borehole records indicate rapid lateral changes in thickness and lithology within the rudite and suggest that it is infilling a preexisting topography of several meters of relief. The lower contact of the rudite is an angular unconformity across the study area, and this is most apparent at Old Radnor (Figure 4(a)) where the Neoproterozoic dips steeply beneath the gently dipping rudite. Similarly, on the northern side of the Nash Scar Ridge (SO 3152 6347), the Folly Sandstone is truncated, locally incised by a small channel (0.5 m wide by 0.04 m deep) and onlapped by the rudite. Here, such an arrangement has been used to suggest a relief on the unconformity surface of 1.5 m and 1.2 m, over a distance of 2.5 m and 6 m, respectively [17, 29]. Based upon the most extensive succession investigated (Dolyhir Quarry, Section 1 (S1); approximates to Quarry K of Garwood and Goodyear [5]) (Figures 2–4(a)), a maximum directly measurable thickness of 6.88 m has been documented, with a possible further 4.5 m obscured by scree. Faulting and folding are likely to affect the obscured part of the succession, thereby complicating thickness estimates. In terms of lithological variability, the lower part of this succession has a mostly noncalcareous matrix (clay to a sandy-grit) with occasional limestone beds, while the upper part contains more frequent limestone beds and has a calcareous matrix. The upper boundary of the rudite can be seen in a section immediately to the west (Dolyhir Quarry, S2). Here, the contact between the silty sandstones of the rudite and the massive overlying Dolyhir and Nash Scar Limestone appears sharp and possibly unconformable, but the very limited exposure of the contact

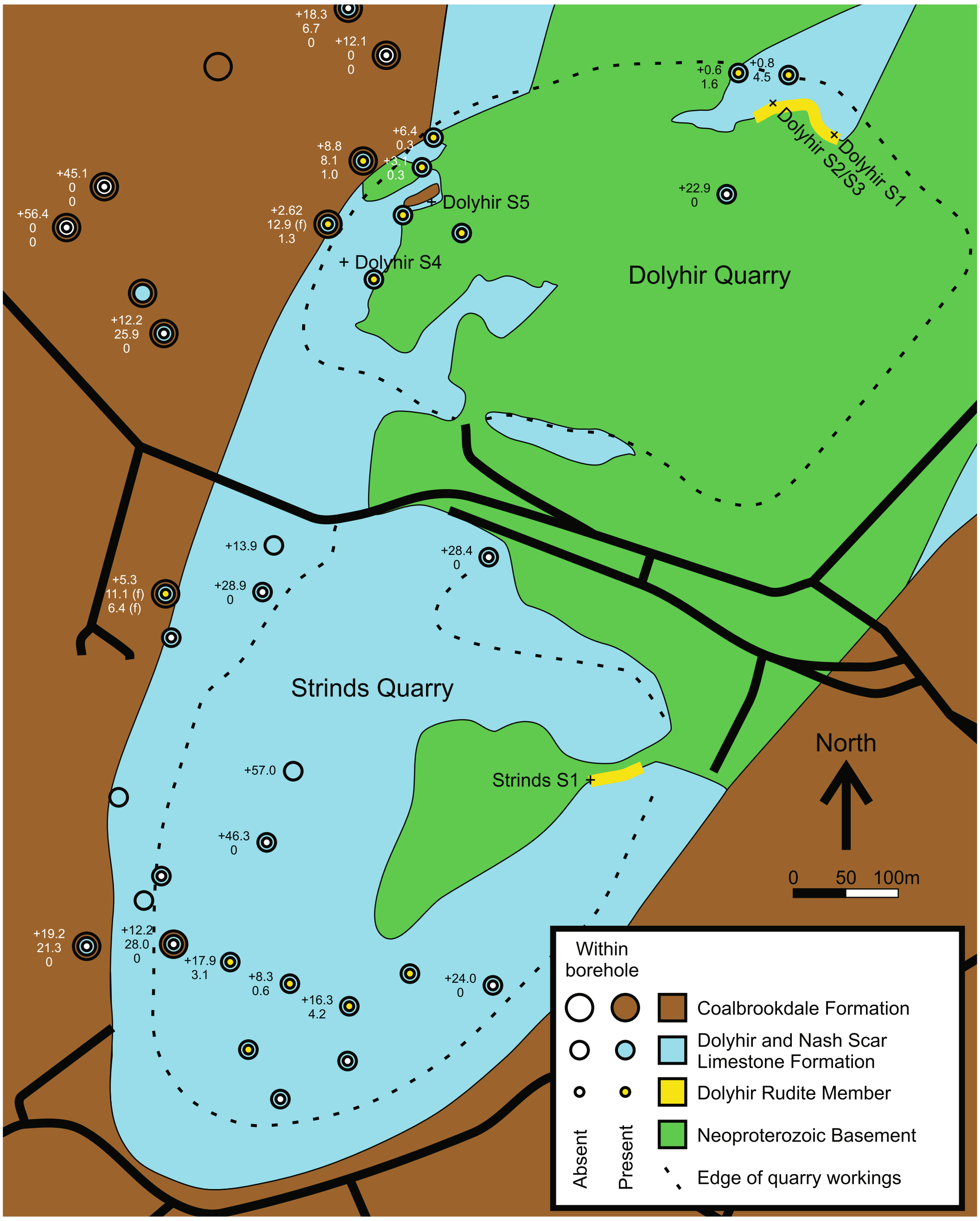
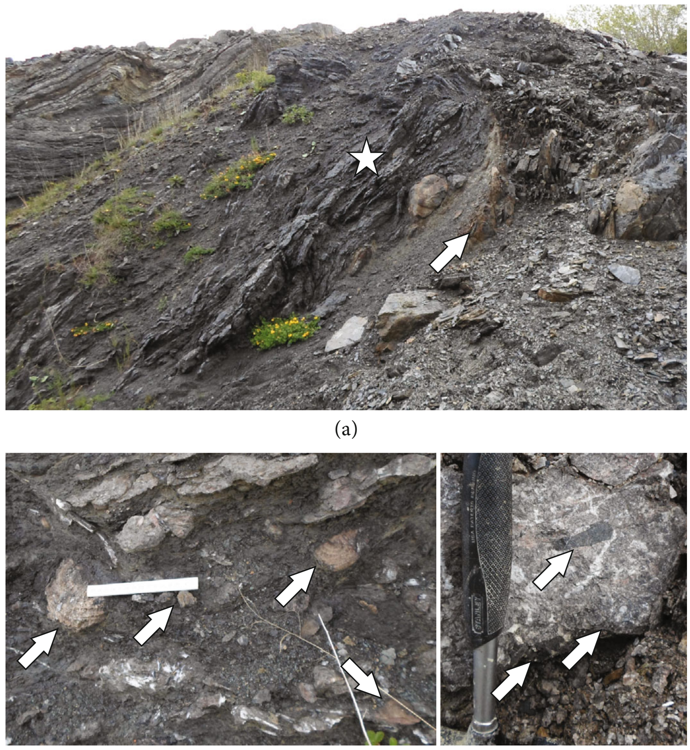


Figure 3: A simplified geological map of the Strinds and Dolyhir quarries, showing the location of key sections (Strinds S1; Dolyhir S1 to S4) and the distribution of the Neoproterozoic basement rocks (Strinds and Yat Wood formations), the Dolyhir Rudite Member, the Dolyhir and Nash Scar Limestone Formation, and the Coalbrookdale Formation. Borehole locations and lithostratigraphic units encountered, alongside a selection of representative thicknesses, are shown. Thickness values (m) are given to the left of the borehole with the youngest unit at the top (f = faulting within the borehole records). The thicknesses have not been corrected for the typically gentle dip of the Silurian succession (not reported in borehole records). Note that the Dolyhir Rudite Member occurs between the basement and the Dolyhir and Nash Scar Limestone Formation but is only located here within borehole records and at well-exposed sections. The map was modified from those given in Garwood and Goodyear [5], Woodcock [3], and Brewer et al. [33].

means that tectonic movement at this boundary cannot be excluded.

Away from the northern end of Dolyhir Quarry, the rudite is typically thinner, being <2.0 m across much of Old Radnor [5, 33] and <0.4 m at the Nash Scar Ridge [17]. Among these thinner rudite successions, the lithology is typically less variable and the transition with the overlying Dolyhir and Nash Scar Limestone appears conformable. On the northern side of the Nash Scar Ridge, at least 0.4 m of green clays and lenticular pebble beds within a limestone matrix are developed [17] and likely correspond to Davis's [7] account of a few feet of shale developed between the Folly



(a)

(b) (c)

Figure 4: The Dolyhir Rudite Member. (a) View of the unconformable contact (arrow) between the Neoproterozoic Yat Wood Formation (below and right) and the Dolyhir Rudite Member (above and left), at Dolyhir Quarry (Section 1 (S1)) looking northwest. Note the boulder (40 cm in diameter) near the contact; the star symbol identifies the location of Conodont/Thelodont Sample 1. The folded beds in the background are all part of the rudite. (b) Horizon containing abundant corals (arrows) within a clastic-rich (middle) part of the Dolyhir Rudite Member, at Dolyhir Quarry (S1). Scale bar 15 cm. (c) Clasts of the Neoproterozoic Strinds Formation (arrows) forming a pebble bed at the base of the rudite and floating in a limestone matrix above, at Strinds Quarry (S1).

Sandstone and Dolyhir and Nash Scar Limestone formations. At the nearby Nash Scar Quarry (S1), a thin (8 cm) clay-rich sandstone containing quartz pebbles is overlain by a 0.35 m thick interval of crinoidal grainstone and rudstone beds separated by rubbly clay-rich partings, above which is the massively bedded Dolyhir and Nash Scar Limestone Formation. Lastly, at Strinds Quarry, Old Radnor, the rudite consists of pebbles in a matrix of crinoidal rudstone, with abundant tabulate corals (*Favosites*) both within and above the rudite. The clasts are self-supporting near the contact with the Neoproterozoic, above which the pebbles float within the limestone matrix (Figure 4(c)). The thickness of the rudite ranges from 0.1 m (SO 2437 5797) to 1.5 m (SO 2417 5817, Quarry D of Garwood and Goodyear [5]) over a distance of approximately 280 m and is gradational with the overlying Dolyhir and Nash Scar Limestone. It is of note that this limestone-rich variety of rudite with scattered clasts would have a wireline signature that is similar to that of the Dolyhir and Nash Scar Limestone and may therefore account for the apparent absence of the rudite in the numerous wireline-based borehole records (Figure 3).

3.2.2. Age of the Dolyhir Rudite Member. The age of the Dolyhir Rudite can be loosely constrained by age diagnostic fossils within the underlying Folly Sandstone and overlying Dolyhir and Nash Scar Limestone (i.e., late Aeronian to early Sheinwoodian herein). In addition, comparisons with nearby successions that are associated with major bounding structural lineaments (i.e., Malvern Line and Church Stretton Fault Zone), and of a similar age, can provide further refinement. For example, within the Malvern Hills [14, 29, 34, 35], the Neoproterozoic basement and upper Aeronian sandstones (Cowleigh Park Formation) are overstepped, in a palaeoshoreline setting, by the middle to upper Telychian Wyche Formation, which is in turn overlain by the lower Sheinwoodian Woolhope Limestone Formation. Similarly, within the Pedwardine inlier [21], the middle to upper Telychian Letton Formation oversteps the Shineton Shale Formation (Tremadocian) and *Pentamerus* Beds (upper Aeronian to lower Telychian). In these examples, a middle to late Telychian conglomeratic sandstone depositional package (rudite equivalent) oversteps the pre-Silurian basement, as well as a late Aeronian to early Telychian depositional package (Folly Sandstone equivalent). In addition, there is the possibility of a stratigraphic gap within the lower Telychian. This stratigraphic gap likely correlates with an episode of tectonic uplift and subaerial exposure within Pembrokeshire (approximately 150 km to the SW of the study area) and a rerouting of sediment influx to the Welsh Basin resulting in the deposition of thick turbidite successions (e.g., the Devil's Bridge Formation) [36, 37]. This tectonic event may be the cause of the angular unconformity between the Folly Sandstone

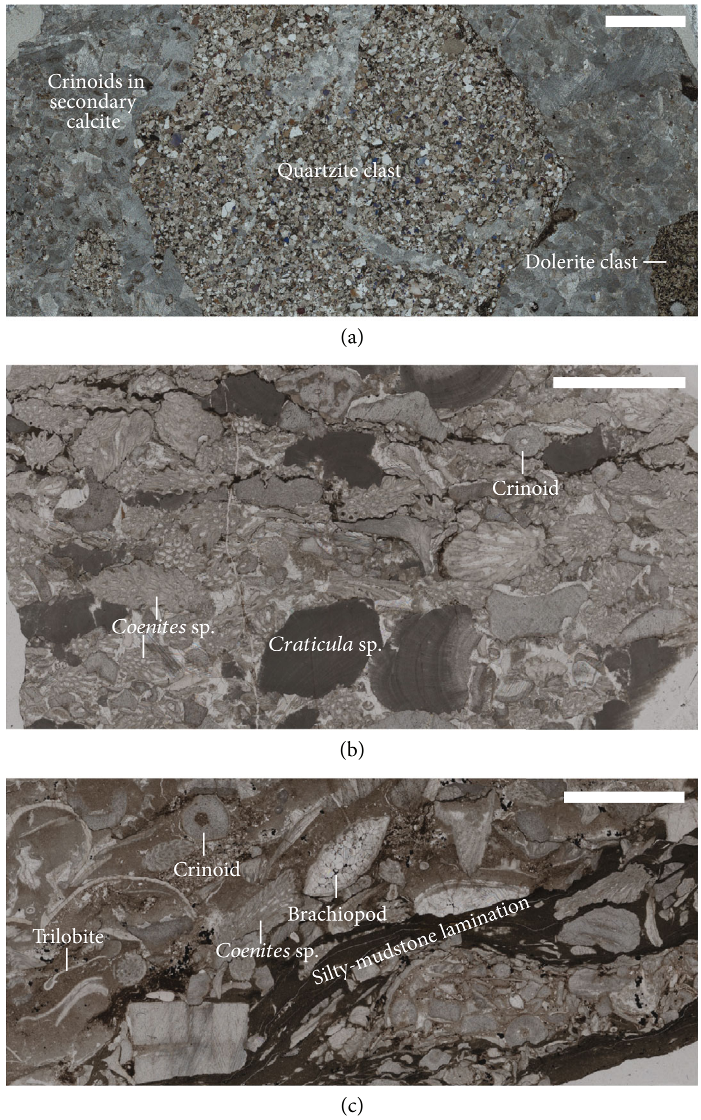


FIGURE 5: Typical lithologies encountered at Dolyhir Quarry. Scale bar is 5 mm. (a) Basal Dolyhir Rudite Member showing quartzite and dolerite clasts within a matrix of crinoids in secondary calcite (XPL). (b) The Dolyhir and Nash Scar Limestone Formation composed of reef-derived allochthonous bioclasts, notably the coral *Coenites* sp., as well as irregular to subspherical masses of the algae *Craticula gotlandica*. (c) Silty mudstones within the Dolyhir and Nash Scar Limestone Formation containing a distinctive fauna of brachiopods, crinoids, corals, and trilobites. See Figures 2 and 7 for the location of the thin sections.

and the rudite and was possibly linked to the initial docking of eastern Avalonia with Laurentia. As a means of comparing the rudite with this regionally defined age model, brachiopod, bryozoan, conodont, and thelodont occurrences and $\delta^{13}C_{carb}$ trends have been investigated.

(1) Brachiopod Records from the Dolyhir Rudite Member. Poorly preserved fragments of the brachiopods *Costistricklandia lirata* (*Stricklandia lirata*), *Bellimurina wisgoriensis* (*Leptaena wisgoriensis*), and *Atrypa reticularis* are reported from the rudite, beneath the Dolyhir and Nash Scar Limestone Formation ([10]; a precise location is not given). Both *C. lirata* and *B. wisgoriensis* are age diagnostic and are reported from the middle to upper Telychian Wyche Formation of the Malvern and Abberley Hills [14, 38, 39]. In addition, *C. lirata* is common within the Telychian Haugh Wood Formation of the Woolhope inlier [40]. Outside of Avalonia, *B. wisgoriensis* occurs within the Telychian and Sheinwoodian of Gotland, Sweden [39]. Based upon brachiopod occurrences, the rudite appears age equivalent to surrounding clastic deposits (Wyche Formation and Haugh Wood Formation), which are of a middle to late Telychian age [14].

(2) Bryozoan Records from the Dolyhir Rudite Member. The majority of bryozoans encountered within the rudite and the overlying limestones can be considered long-ranging and of little stratigraphic use. However, *Cuneatopora lindstroemi*, collected from the upper part of the rudite at the northern end of Dolyhir Quarry (S1; Conodont Sample 2),

is notable for its cooccurrence within the Lower Visby and Upper Visby, and Högklint formations of Gotland (Sweden), thereby indicating a late Telychian to middle Sheinwoodian age [41].

(3) Conodont Records from the Dolyhir Rudite Member. Conodonts within the rudite are poorly preserved and fragmentary, thereby hindering identification. Conodonts were collected from the thickest development of the rudite at the northern end of Dolyhir Quarry (S1). Collections have been made at 0.78 m from the base (Conodont Sample 1) and within the upper half of the succession (Conodont Sample 2) (Figures 2 and 6(b)–6(l)). Conodont Sample 1 contains *Distomodus* sp., *Icriodella* sp., and *Panderodus greenlandensis*. The presence of *Pa. greenlandensis* can be taken to indicate an age no younger than Datum 2 of the Ireviken Event (Lower *Ps. bicornis* Conodont Zone). However, while considerably less common, *Pa. greenlandensis* is reported from strata as young as Homerian upon the Midland Platform [42] and Ludfordian of Australia and Gotland [43]. Conodont Sample 2 contains *Aulacognathus*? sp., *Distomodus* sp., *Dapsilodus* sp., *Oulodus* sp., *Panderodus equicostatus*, *Panderodus* sp., *Pseudooneotodus bicornis*, *Pterospathodus* sp., and *Wurmiella excavata*. Based upon the uncertain identification of a broken element of *Aulacognathus*, the fauna may be assigned to the *Pt. eopennatus* Conodont Superzone [19]. More broadly, *Aulacognathus* is regionally indicative of the middle to upper Telychian [44], with *Aulacognathus kuehni* reported from the Wyche Formation of Gullet Quarry, Malvern ([34], p. 83). The presence of *Pterospathodus* sp. indicates a fauna not younger than the Lower *K. ranuliformis* Conodont Zone (lower Sheinwoodian; [19, 45, 46]). Thus, conodont occurrences suggest a dominantly Telychian age, but overall, a middle Telychian to early Sheinwoodian age is possible.

(4) Thelodont Records from the Dolyhir Rudite Member. Conodont Sample 1 (Dolyhir Quarry, S1), collected 0.78 m from the base of the rudite, yielded slightly abraded thelodont scales that are identifiable as *Loganellia scotica* (Figure 6(a)), described in the supplementary materials (Figure SM2). *L. scotica* is known to be restricted to the Telychian, and the *Loganellia scotica* Vertebrate Chron is considered to be of late Telychian age [47]. Within the Telychian of the Welsh Borders, *L. scotica* is reported from the upper part of the Purple Shales and occurs within the conglomeratic limestones near the base of the Wyche Formation of the Malvern Hills [47–49]. In addition, *L. scotica* has previously been reported from the Aeronian of the Welsh Borders [48], but these specimens were later referred to as the new taxon *L. aldridgei* [50]. Based upon conodont cooccurrences, the limestones from the base of the Wyche Formation are considered to correspond to a position in the middle Telychian *Pterospathodus eopennatus* n. ssp. 2 Conodont Zone [51]. The presence of *L. scotica* within the base of the Wyche Formation and the base of the Dolyhir Rudite offers the possibility of age synchronicity and constrains these successions to the *Loganellia scotica* Vertebrate Chron, which, in the Welsh Borders, corresponds to the middle to late Telychian.

(5) $\delta^{13}C_{carb}$ Records from the Dolyhir Rudite Member. $\delta^{13}C_{carb}$ data have been obtained from carbonate-rich beds within the upper half of the thickly developed rudite at the northern end of Dolyhir Quarry (S1 and S2) and within the thinner rudite successions that are transitional with the overlying Dolyhir and Nash Scar Limestone at Strinds Quarry (S1) and Nash Scar Quarry (S1) (Figure 2). At Dolyhir Quarry (S1) over a 3.45 m interval, 16 samples reveal a progressive rise in values that range from 1.0‰ to 3.8‰. Two additional samples are recorded from the uppermost beds of the rudite at Dolyhir Quarry (S2) and reveal notably lower values (-0.3‰ and 1.5‰). Accordingly, a minor positive excursion is present within the most thickly developed rudite, and based upon a probable middle Telychian to early Sheinwoodian age of the succession, the carbon isotope excursion (CIE) may reflect the middle to late Telychian Sommerodde or Manitowoc CIE, as described from Bornholm and the Michigan Basin, respectively [52, 53], rather than the earlier Telychian Valgu CIE [19]. Alternatively, a minor positive shift in $\delta^{13}C_{carb}$ values is also reported from the basal 6 m of the nearby Woolhope Limestone Formation and prior to the start of the early Sheinwoodian CIE ([54], Figure 3) (Figure 10). This excursion approximates the Telychian-Sheinwoodian boundary within the Eastnor Park Borehole and occurs between 44 m and 50 m.

Within the thinner rudites at Strinds Quarry and Nash Scar Quarry, $\delta^{13}C_{carb}$ values consistently rise from around 3‰ in the rudite to near 5‰ within the basal few meters of the overlying Dolyhir and Nash Scar Limestone. Based upon the probable Sheinwoodian age of the Dolyhir and Nash Scar Limestone (see below sections), this marked rise in isotopic values is reflective of the early Sheinwoodian CIE [54] (Ireviken CIE of [55]) and indicates that the thinly developed rudites are age synchronous across the study area and occur either immediately prior to or during the onset of the early Sheinwoodian CIE (i.e., early Sheinwoodian). Similarly, a marked rise in values is seen across the rudite-Dolyhir and Nash Scar Limestone boundary at Dolyhir Quarry (S2) and may suggest the same boundary age; however, in tandem shifts of $\delta^{13}C_{carb}$ and $\delta^{18}O_{carb}$ values are suggestive of a diagenesis- or lithology-related signal. To evaluate the effects of diagenetic alteration on isotopic values in this study, the relationship between $\delta^{13}C_{carb}$ and $\delta^{18}O_{carb}$ values was investigated (Table SM2 and Figure SM1) (see [56]). Dolyhir Quarry (S1), which exposes the thickest succession of the rudite, showed a significant relationship between isotopic values (slope 0.21487, $p = 0.000667$, and $n = 16$), suggesting a diagenetic overprint. In the remaining sections, no relationship could be detected, precluding a substantial diagenetic overprint.

(6) Likely Age of the Dolyhir Rudite Member. Based upon regional stratigraphic comparisons; brachiopod, bryozoan, conodont, and thelodont occurrences; and carbon isotopic trends, it seems most likely that the rudite within the most extensive succession at the northern end of Dolyhir Quarry has a maximum age range of middle Telychian to early Sheinwoodian (stage slices Te3 to Sh1). In particular, it is

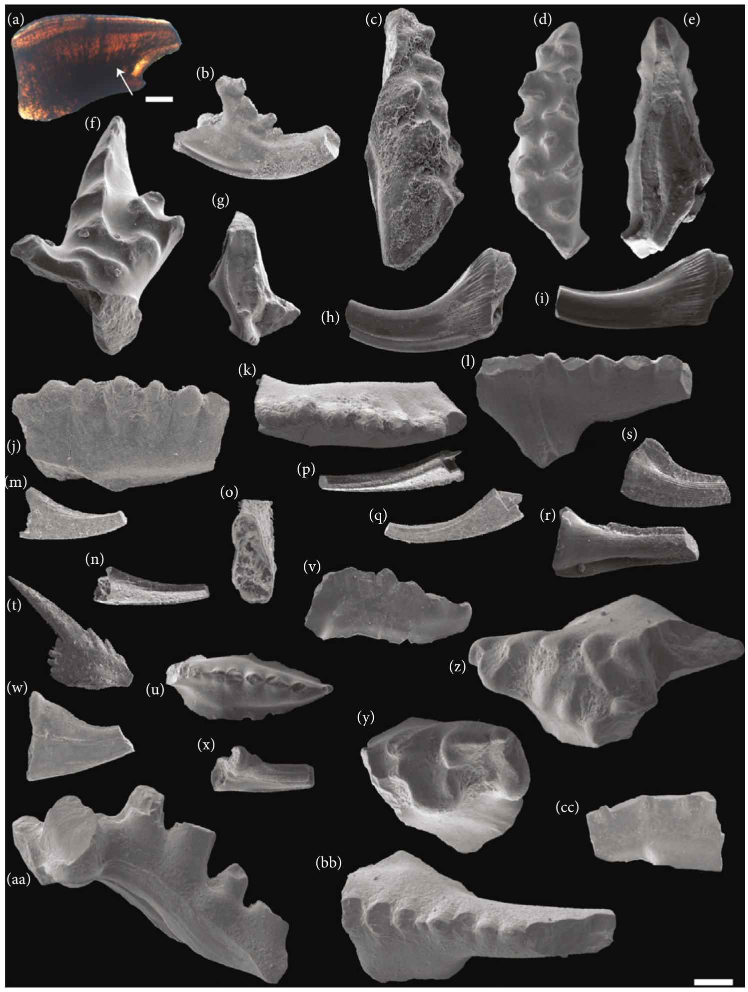


Figure 6: Vertebrate fossils and collection codes from the Dolyhir Rudite Member (Conodont Samples 1 and 2) and the Dolyhir and Nash Scar Limestone Formation (Conodont Samples 3-7), Dolyhir Quarry (S1-2, 4-5). Conodont Sample 1: (a) *Loganellia scotica*, microscope image of a trunk in lateral view, with the anterior facing left, scale submerged in aniseed oil (arrow indicates pulp cavity), PMU 36862, immediately associated scale bar 100 μm. (b) *Distomodus* sp., EJ-17-1-001. (c) *Icriodella*? sp., EJ-17-1-002. (d) Unidentified: *Icriognathus*? sp. or *Pedavis vindemus*, EJ-17-1-003. (e) Unidentified: *Icriognathus*? sp. or *Pedavis vindemus*, EJ-17-1-004. (f, g) *Icriodella* sp., EJ-17-1-005. (h, i) *Panderodus greenlandensis*, tortiform element, EJ-17-1-006. Conodont Sample 2: (j, k) *Aulacognathus*? sp., EJ-17-33-001. (l) *Pterospathodus* sp., EJ-17-33-002. Conodont Sample 3: (m–o) *Walliserodus* sp. n. AA [69], EJ-17-38-001. (p, q) *Walliserodus* sp., EJ-17-38-002. (r, s) *Decoriconus fragilis*, EJ-17-38-003. (t) *Pterospathodus* sp., sinistral curved element, EJ-17-38-004. Conodont Sample 5: (aa, bb) *Kockelella ranuliformis*, WDQ-001. Conodont Sample 6: (u, v) *Oz. sagitta rhenana*, EJ-17-61-001. Conodont Sample 7: (w, x) *Panderodus panderi*?, EJ-17-60-001. (y, z) *Icriodella* sp., EJ-17-60-002. (cc) *Oz. paraconfluens*?, EJ-17-60-003. Scale bar in the lower right corner refers to all conodont photos and equals 100 μm, except for (g–i, u, v) where it is 200 μm and (o) where it is 50 μm. Collection codes starting with PMU = housed in the Palaeontological Collections, Museum of Evolution, Uppsala University, Uppsala, Sweden; EJ and WDQ = housed in the collections of GeoZentrum Nordbayern, Erlangen, Germany.

associated with the *Loganellia scotica* Vertebrate Zone [47] and shares a number of important brachiopod, conodont, and thelodont cooccurrences with the middle to upper Telychian Wyche Formation at Gullet Quarry, Malvern Hills. $\delta^{13}C_{carb}$ records indicate the presence of a minor positive excursion within the rudite, while values from the more geographically extensive uppermost part of the rudite are suggestive of an interval either immediately prior to or during the onset of the early Sheinwoodian CIE. This excursion is fully expressed in the overlying Dolyhir and Nash Scar Limestone. In accordance with the upper age limit of the associated conodonts, the uppermost part of the rudite is of probable early Sheinwoodian age (stage slice Sh1).

3.2.3. Depositional Environment of the Dolyhir Rudite Member. The Dolyhir Rudite closely resembles the Telychian conglomeratic limestone (basal Wyche Formation), which is developed at Gullet Quarry, Malvern Hills [34, 35], and is approximately age synchronous. In particular, the Gullet Quarry conglomeratic limestone rests upon a Neoproterozoic basement (Malvern Complex) and, like the rudite, is poorly sorted, has a highly variable clast composition, angularity, and size, and has an extremely variable matrix (clays to sands and shelly limestones). There are also shelly limestones and abundant *Favosites* corals present. At Gullet Quarry, these features are considered indicative of deposition in front of a retreating rocky shoreline [35], and this same nearshore depositional environment seems likely for the Dolyhir Rudite.

Across the Old Radnor and Presteigne study area, rapid lateral changes in thickness and lithology within the rudite suggest that it has been deposited over a preexisting topography. The most extensive (≥6.88 m) rudite deposit occurs at the northern end of Dolyhir Quarry and begins with a clastic-dominated succession containing subangular to subrounded boulders up to 40 cm in diameter near its base. The angularity and size of the clasts, together with their lithological affinity with the underlying Neoproterozoic (Yat Wood and Strinds formations and dolerite dykes), suggest that these deposits have not undergone significant transport or reworking and may represent the local collapse of overhangs at the bases of sea cliffs. However, the presence of an associated marine fauna (e.g., stromatoporoids, conodonts, brachiopods, and bryozoans) indicates a shallow subtidal, rather than intertidal, setting. Higher in the succession, the rudite typically contains granules and pebbles of a range of angularities and locally derived compositions. These clasts along with in situ corals and the increasing abundance of limestone (beds and matrix) argue for a progressive deepening. The replacement of clastic sediments with limestones continues upward through the succession and culminates with the regionally synchronous replacement of the rudite by the Dolyhir and Nash Scar Limestone. Away from the northern end of Dolyhir Quarry, the rudite is typically much thinner (<2.0 m) and younger (early Sheinwoodian), suggesting that much of the study area was emergent prior to an early Sheinwoodian transgression. Accordingly, a middle to upper Telychian shoreline probably occurred in the area of Dolyhir Quarry.

A notable feature of the transition into the Dolyhir and Nash Scar Limestone is the presence of basement-derived clasts that float within a crinoidal grainstone/rudstone matrix (Figure 4(c)). A similar matrix-supported conglomerate (the Sutton Stone) has been described from an Early Jurassic rocky shoreline [57, 58] and is considered to represent a high-energy storm-dominated shoreface setting [58]. A similar setting is envisaged here, with the occurrence of in situ *Favosites* corals resulting from the rising sea level and increasingly episodic storm sedimentation. In addition, the presence of clasts indicates a nearby subaerially exposed source area, which was presumably much reduced in area by Dolyhir and Nash Scar Limestone times.

3.3. Dolyhir and Nash Scar Limestone Formation

3.3.1. Lithostratigraphy and Distribution of the Dolyhir and Nash Scar Limestone Formation. The Dolyhir and Nash Scar Limestone Formation is restricted to the Old Radnor and Presteigne study areas but is considered approximately age synchronous with other Sheinwoodian limestones across the Midland Platform (Woolhope Limestone, Buildwas, and Barr Limestone formations) [14]. The most extensive exposures of the Dolyhir and Nash Scar Limestone occur at Strinds (SO 241 579), Dolyhir (SO 243 585), and Nash Scar (SO 302 623) quarries, with lesser exposures scattered along the Nash Scar Ridge (old quarry workings within the valley of Haxwell (SO 2967 6183) and the Folly) (Figures 3, 7, and 8). In addition, British Geological Survey borehole records indicate the subsurface continuation of limestone between the Old Radnor and Presteigne areas (Lower Womaston Borehole; SO 2684 6058). The isolated and discontinuous outcropping of the Dolyhir and Nash Scar Limestone Formation has resulted in multiple names for this lithostratigraphic unit: the Nash Limestone [7], the Woolhope Limestone [5], the Nash Scar Limestone, and the Dolyhir Limestone [59]. Here, we use the formally introduced Dolyhir and Nash Scar Limestone Formation [60], with the addition of the Dolyhir Rudite Member which occupies the basal few meters of the formation (see Section 3.2). It should be noted that the Nash Scar Limestone and the Dolyhir Limestone are often classified as separate lithostratigraphic units, depending on the location (Presteigne or Old Radnor areas, respectively), but the limestones of both areas are lithologically very similar and are described together herein. In particular, they are mostly composed of branching tabulate corals (mainly *Coenites* sp., described as a rock forming "bryozoan" by [5]) (Figures 5(b) and 8(e)) and crinoids, with abundant coralline algae (*Craticula gotlandica* = *Solenopora gracilis* of [5]; see [61]) (Figures 5(b) and 8(c)). Furthermore, the base of the formation comprises the Dolyhir Rudite Member and the top is overlain by the Coalbrookdale Formation. The limestone is typically white to blue-grey, highly crystalline, and poorly to massively bedded (Figure 8(a)), making intraformational division and correlation difficult. The lithological variability is most apparent in the Old Radnor area and consists of an addition of distinctive *Favosites* coral beds that are transitional with the underlying Dolyhir Rudite and silty mudstone intervals with distinctive brachiopod and trilobite faunas (*Stropheodonta* Band and Included Shale Band of [5]). The *Orthoceras* Bed of Garwood and Goodyear [5] has not been encountered in this study but occurs within the upper part of the succession, above the upper Bryozoan Bed. In addition, the "conspicuous" developments of *Coenites* sp., termed the lower and upper Bryozoan Beds by Garwood and Goodyear [5], are insufficiently described to be identifiable with certainty. However, the lower development is reported as associated with the *Stropheodonta* Band and the Included Shale Band (i.e., near the base of the succession), and the upper development occurs high in the succession and is associated with abundant remains of *Favosites* and *Halysites* corals [5]. This upper development may correspond to a 0.55 m thick bed with conspicuous *Coenites* sp. that overlies an interval with abundant corals (Dolyhir Quarry, S4) (Figures 7 and 8(e)).

Thin sections from Strinds and Dolyhir quarries reveal that much of the succession consists of rudstone, composed of reef-derived allochthonous bioclasts (Figure 5(b)). The fauna is mainly composed of tabulate corals (mainly *Coenites* sp.) and crinoids (see list of fossils in [5]). Algae, bryozoans,

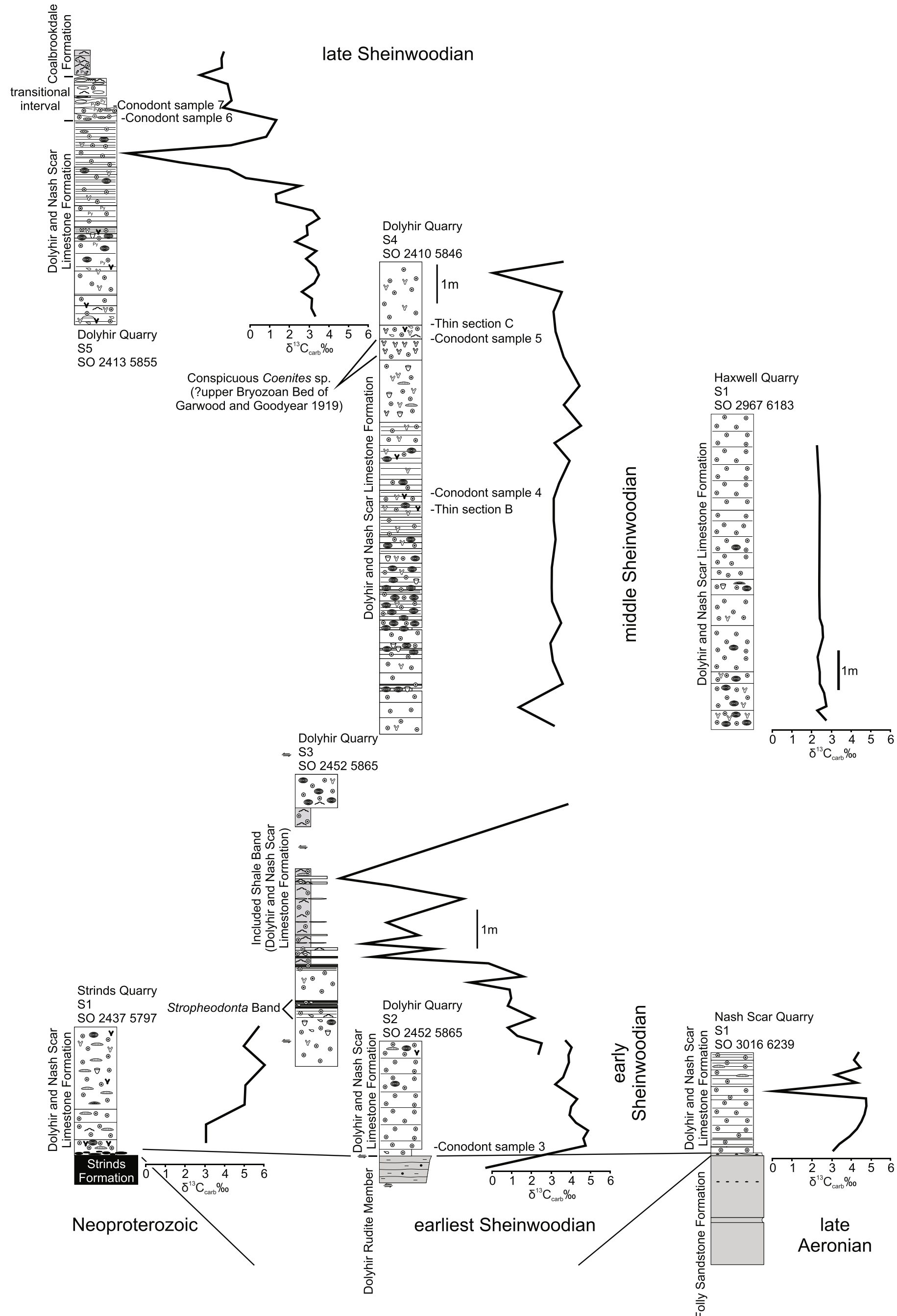


Figure 7: Sedimentary logs from the Old Radnor and Presteigne study area, showing the key sections that contain the Dolyhir and Nash Scar Limestone Formation and the immediately under- and overlying successions. $\delta^{13}C_{carb}$ values are given, alongside the location of conodont samples and illustrated thin sections.

brachiopods, ostracods, and trilobites are also present. The alga *Craticula gotlandica* forms irregular to subspherical bioclasts, which can easily be observed in hand specimens and range from 0.5 cm to 40 cm in length (Figure 8(c)). In the freshly quarried sections, they are of deep purple colour, but upon weathered surfaces, they form conspicuous white porcelaneous masses [12, 15]. These bioclasts are not contained in every limestone layer and have a higher abundance in the middle and upper parts of the succession. Lithoclasts are also present and can be identified by a coating of the fossils by sediment or by broken and reworked already-lithified *Rothpletzella* and *Allonema* mats in a microsparitic and sparitic matrix. The matrix is composed of microsparite and sparite but owing to the fitted fabric contributes a relatively small proportion of the limestone. This lithology dominates much of the succession and is likely reflective of the two chemical analyses from the Dolyhir and Nash Scar Limestone that have been used to characterize the succession as consisting of a very high calcium carbonate content (99% $CaCO_3$; [5]) with a negligible clastic component ([34], pp.

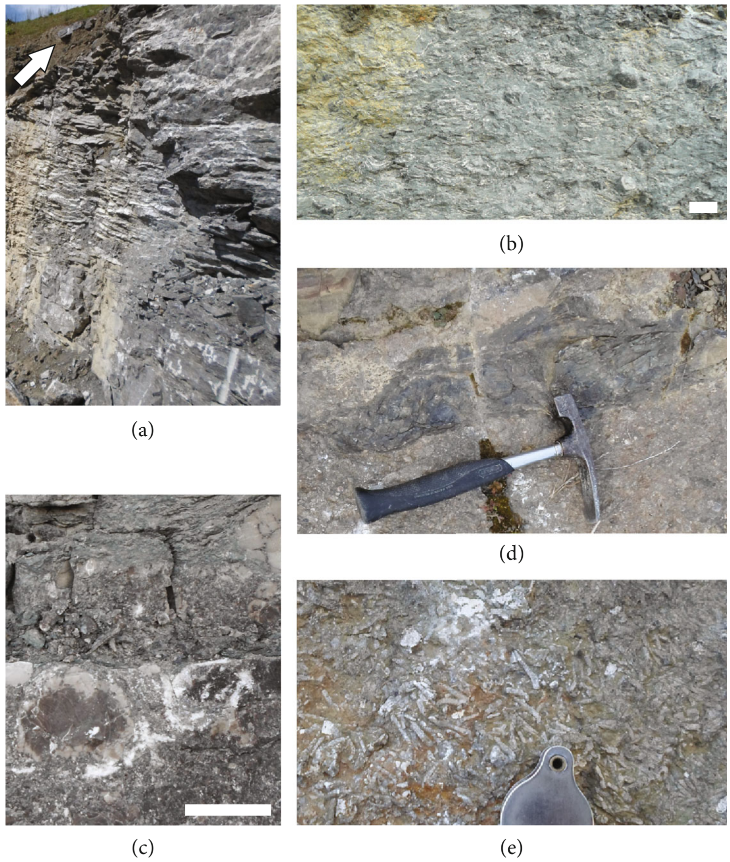


Figure 8: The Dolyhir and Nash Scar Limestone Formation and its upper contact with the Coalbrookdale Formation. (a) Upper half (c. 10 m) of the Dolyhir and Nash Scar Limestone between Dolyhir Quarry sections (S4 and S5). The transition into the silty mudstones of the Coalbrookdale Formation can be seen at the very top of the section (arrow). (b) Tectonized trilobite accumulations (white shelly material) dominated by the illaenid trilobite *Bumastus*? *phrix* (scale bar 1 cm). Basal Coalbrookdale Formation, Dolyhir Quarry (S5). (c) Circular masses of the coralline algae (*Craticula gotlandica*), associated with silty mudstone laminations and rudstone (scale bar 5 cm), Dolyhir Quarry (S4). (d) The transition between the Dolyhir and Nash Scar Limestone and Coalbrookdale formations, showing a scoured starvation surface at the top of the Dolyhir and Nash Scar Limestone and an infilling pocket of trilobitic silty mudstone, Dolyhir Quarry (S5). (e) A conspicuous development of the coral *Coenites* sp. (possibly from the upper Bryozoan Bed of Garwood and Goodyear [5]), Dolyhir Quarry (S4).

256–259; [62]). However, within the rudstones, the matrix is occasionally brownish siltstone or marl. Moreover, brown and green silty mudstone laminations are developed intermittently throughout the Dolyhir Quarry succession (Figures 5(c) and 8(c)). These laminations are the result of primary deposition and contain a distinctive assemblage of fewer but more intact fossils. The faunas (brachiopods, bryozoans, crinoids, corals, trilobites, and algal and cyanobacterial bioclasts), while sometimes broken, are mostly complete and include fragile taxa such as fenestrate bryozoans (*Unitrypa* sp.), suggesting limited transport or in situ deposition. Pyrite crystals occur within the silty matrix and on the fossil rims.

Silty mudstones also form more substantive intervals within parts of the succession. These comprise wayboards of shale in the valley of Haxwell and near Corton House [7, 8] and the Included Shale Band at Old Radnor [5]. As with the silty laminations described from Dolyhir Quarry, these intervals contain a different assemblage to that of the limestones. The Included Shale Band and associated fossils have been described in detail [5] and examined in Dolyhir Quarry (S3; Figure 7). Here, the Included Shale Band occurs c. 4.9 m above the base of the Dolyhir and Nash Scar Limestone and 0.9 m above a 0.45 m thick succession of rubbly limestones and silty mudstones which is rich in brachiopods (*Atrypa* sp., *Leptaena* sp., and *Megastrophia* sp.), crinoids, and algal bioclasts, as well as occasional trilobites and solitary rugose corals. This interval corresponds to the *Stropheodonta* Band. The Included Shale Band is c. 3 m to 4 m thick and consists of silty mudstone beds (12 cm to 60 cm thick) separated by thinner (2 cm to 7 cm) limestone beds consisting of grainstone, rudstone, or micrite, as well as subspherical micritic concretions. The fauna comprises accumulations of crinoid stems, brachiopods (*Atrypa* sp., *Leptaena* sp.), gastropods (*Platyceras prototypum*), small solitary rugose corals (*Streptelasma* sp.), and an abundance of trilobites dominated by *Bumastus*? *phrix* (*Illaenus* (*Bumastus*) *barriensis* of [5, 63]) with *Tapinocalymene volsoriforma* [64] present also.

Accurate thickness estimates for the Dolyhir and Nash Scar Limestone have been hampered by difficulties in intraformational correlation and faulting. Garwood and Goodyear [5] estimated a thickness of 24 m from a measured succession at Old Radnor, a value that corresponds well with our estimate of 28 m, based upon closely spaced sections in Dolyhir Quarry (S2-S5; Figure 7). However, borehole and structural analysis at Dolyhir Quarry indicates that the limestone varies in thickness from 0 m to 46 m [33], while within Strinds Quarry, the limestone may be as much as 60 m thick [17]. Borehole records examined herein, from both the Dolyhir and Strinds quarries, identify a similar amount of variability (Figure 3). Notably, within Dolyhir Quarry, the limestone shows a thinning and eventual disappearance beyond the NW limit of the quarry, across a distance of approximately 100 m. In Strinds Quarry, incomplete borings through the limestone indicate a possible maximum thickness of 57 m and a thinning of the limestone to the west. The Dolyhir and Nash Scar Limestone is also absent on the NW flank of Hanter Hill, approximately 1.5 km to the SE of Dolyhir Quarry [26]. Here (SO 2490 5736), discontinuous outcrops reveal the Neoproterozoic Stanner Hanter Igneous Complex [25] unconformably overlain by mudstones, sandstones, and conglomerates containing a Wenlock age fauna that passed, without evidence of intervening limestones, into the Coalbrookdale Formation [17]. The faunal and lithological characteristics of the basal shelly mudstones of the Coalbrookdale Formation at Hanter Hill initially led Kirk [17] to consider them contemporaneous with the Coalbrookdale beds above the Dolyhir and Nash Scar Limestone at Old Radnor. However, a subsequent publication [10] attributed the mudstones, sandstones, and conglomerates to the Upper Llandovery and considered the shelly mudstones to be contemporaneous with the Dolyhir and Nash Scar Limestone but without explanation. Variations in limestone thickness are also documented at Nash Scar Quarry with at least 30 m [7] and possibly as much as 60 m [17, 65] present. However, on the NE side of the Nash Scar Ridge, there is a notable thinning of the limestone. Davis [7] described 2.4 m of highly crystalline limestone separated from the underlying Folly Sandstone by 0.6 m of shale. Similarly, within the nearby Folly Farm Presteign Boring, the Folly Sandstone is overlain by 0.8 m of shale, 3.5 m of Dolyhir and Nash Scar Limestone, and 3.2 m of Coalbrookdale Formation ([6]; thicknesses corrected for 55 degrees of dip).

The upper contact between the Dolyhir and Nash Scar Limestone and the Coalbrookdale Formation is commonly tectonized and has previously only been investigated in detail along the Nash Scar Ridge (see Section 3.2 for details of the lower contact). Near the NE end of the Nash Scar Ridge, the upper contact has been encountered in small disused quarries and within the Folly Farm Presteign Boring [6, 7]. Here, the uppermost Dolyhir and Nash Scar Limestone (0.3 m) is somewhat nodular and concretionary, weakly tectonized, and overlain by at least 3.0 m of olive-green silty mudstone, containing flattened nodules of micritic limestone (basal Coalbrookdale Formation). The Coalbrookdale Formation here contains abundant trilobites, most notably *Bumastus*? *phrix*, alongside brachiopods, corals, graptolites, and orthocones [7]. On the southern side of the Nash Scar Ridge, the entrance to Nash Scar Quarry (SO 303 623) exposed the contact on a steeply dipping bedding plane of Dolyhir and Nash Scar Limestone, which is encrusted by many crinoid holdfasts. The immediately overlying Coalbrookdale Formation contains crinoid cup plates and abundant columnals, alongside other shelly detritus [59].

At Old Radnor, an upper contact has only previously been inferred from downfaulted blocks and isolated patches of Coalbrookdale Formation within the main mass of the Dolyhir and Nash Scar Limestone inlier [5]. However, ongoing workings at Strinds and Dolyhir quarries have exposed the top of the Dolyhir and Nash Scar Limestone as an irregular limestone surface overlain by brownish-grey mudstones containing septarian nodules mineralized by calcite, quartz, and occasionally barite [66]. At Dolyhir Quarry (S5), the transition between the formations has been investigated. The uppermost Dolyhir and Nash Scar Limestone consists of a rudstone, with lenses of grainstone and laminations of silty mudstone. Stromatactis-like lenses filled with calcite are common, as are pyrite crystals. Stratigraphically above are rubbly to nodular carbonate mudstones, occasional grainstones, and calcareous silty mudstones, which contain abundant trilobites, crinoids, and occasional graptolites. The base of the Coalbrookdale Formation is placed immediately above the highest continuous nodular horizon, as is the case across the Midland Platform. The basal Coalbrookdale Formation (0.65 m) consists of silty mudstones containing accumulations dominated by the trilobite *Bumastus*? *phrix* (Figure 8(b)). Crinoid stems, brachiopods, and simple pyritized burrows are also present. In addition, within the overlying scree are limestone beds and micritic subspherical nodules that are likely derived from the Coalbrookdale Formation. The transition between the formations includes local concentrations of trilobites containing distinctive assemblages that include *Bumastus*? *phrix*, *Odontopleura ovata*, *Decoroproetus*, *Cyphoproetus*, *Planiscutellum*, *Cheirurus*, and *Tapinocalymene*. The vertical and lateral extent of these local concentrations cannot be traced and demonstrates that they reflect multiple sediment fills of irregular hardground surfaces (Figure 8(d)). In addition, some concentrations are associated with Neptunian dykes, which pipe trilobitic silty mudstones, as much as 5 m, into the underlying Dolyhir and Nash Scar Limestone.

3.3.2. Age of the Dolyhir and Nash Scar Limestone Formation. The age of the Dolyhir and Nash Scar Limestone Formation has previously been loosely constrained to the Sheinwoodian using a mixture of biostratigraphy (brachiopods, conodonts, graptolites, and trilobites) and regional stratigraphic considerations [14, 59, 65]. However, owing to a scarcity of age diagnostic fossils within the formation, and the frequently faulted nature of the lower and upper contacts, the age limits of the formations have proven difficult to establish in detail ([34], pp. 256–259; [67]). Based upon the upper age limit of the conformable Dolyhir Rudite, herein, the age of the base of the limestone can be constrained to the lower Sheinwoodian, whereas the upper contact and intervening limestone require further investigation.

(1) Conodont Records from the Dolyhir and Nash Scar Limestone Formation. Conodonts previously reported from the Dolyhir and Nash Scar Limestone are mostly long-ranging (e.g., *Wurmiella excavata*, *Dapsilodus obliquicostatus*, and *Decoriconus fragilis*), with the exception of *Ozarkodina sagitta rhenana*, the presence of which restricts at least part of the limestone to the eponymous biozone and the middle Sheinwoodian ([9, 34], pp. 256–259, [68]).

As a means of further refining the age constraint, new conodont collections have been made within Dolyhir Quarry at the base (Conodont Sample 3), middle (Conodont Samples 4 and 5), and top of the Dolyhir and Nash Scar Limestone (Conodont Samples 6 and 7) (Figures 6(m)–(cc) and 7). In spite of the mostly poorly preserved and fragmentary nature of the conodonts collected, the following biostratigraphic determinations can be made. Conodonts from the base of the Dolyhir and Nash Scar Limestone (Conodont Sample 3) consist of *Decoriconus fragilis*, *Panderodus equicostatus*, *Pterospathodus* sp., and *Walliserodus* sp. n. AA Männik in [69]. Of these, only *Pterospathodus* sp. is considered age diagnostic [46] and constrains the base of the succession to not younger than the Lower *K. ranuliformis* Conodont Biozone (lower Sheinwoodian [19, 45, 55]). Conodonts from the middle of the succession (Conodont Samples 4 and 5) consist of *Kockelella ranuliformis*, *Pseudooneotodus bicornis*, and *Wurmiella excavata*?, with *K. ranuliformis* indicative of an age from the late Telychian to middle Sheinwoodian [55]. The top of the succession contains *Ozarkodina sagitta rhenana* (Conodont Sample 6), as well as *Dapsilodus* sp., *Decoriconus fragilis*, *Icriodella* sp., *Ozarkodina paraconfluens*?, *Panderodus equicostatus*, and *Panderodus panderi*? (Conodont Sample 7). These samples are stratigraphically 20 cm apart and coincide with hardground development at the transition into the overlying Coalbrookdale Formation. *Ozarkodina sagitta rhenana*, *Ozarkodina paraconfluens*?, and *Panderodus panderi* are of biostratigraphic significance and are all reported from the middle Sheinwoodian ([55], Figure 3, [70]). *Panderodus panderi*? has been reported as temporarily absent from the interval ranging from the Upper *Pterospathodus procerus* Conodont Biozone up to the Lower *Kockelella walliseri* Conodont Biozone in Gotland [70]. Based on superposition, its finding above Conodont Sample 6 indicates that the occurrence is not older than the *Oz. sagitta rhenana* Conodont Biozone, but the presence of *Oz. paraconfluens*? indicates that it cannot be younger than the biozone. Although *Pa. panderi* was absent in this biozone in Gotland, its reappearance in the upper Sheinwoodian indicates that it was present globally and the occurrence in the uppermost part of the Dolyhir and Nash Scar Limestone does not preclude assigning this interval to the *Oz. sagitta rhenana* Conodont Biozone.

(2) Chitinozoan and Trilobite Records from the Dolyhir and Nash Scar Limestone Formation. Chitinozoans and trilobites support the Wenlock age attributions derived from conodonts. In particular, the chitinozoan *Cingulochitina cingulata* ([16], pp. 38-42) occurs within both the Dolyhir and Nash Scar Limestone and the overlying Coalbrookdale Formation and is indicative of a middle Sheinwoodian to Homerian age [71–73]. Similarly, the trilobites *Bumastus*? *phrix* and *Tapinocalymene* are only reported from Wenlock strata [63, 64, 74] but are stratigraphically less diagnostic as they are of limited geographical distribution within the Welsh Borderlands. As the first occurrence of *C. cingulata* is reported from near the base of the Dolyhir and Nash Scar Limestone [16], and the stratigraphically lowest of the forementioned trilobite occurrences are reported from the Included Shale Band (c. 4.9 m to 8.9 m above the base of the Dolyhir and Nash Scar Limestone), it may be concluded that the vast majority of the Dolyhir and Nash Scar Limestone is of Wenlock age.

(3) Graptolite and Brachiopod Records from the Dolyhir and Nash Scar Limestone and Coalbrookdale Formations. Graptolites have played an important role in determining the age of the basal Coalbrookdale Formation (e.g., [65]) but have typically been collected from downfaulted blocks with ambiguous relationships with the upper contact of the limestones [5]. During this study, graptolites were encountered within the uppermost Dolyhir and Nash Scar Limestone (Dolyhir Quarry, S5; Figure 7); these specimens were poorly preserved but represent *Monograptus flemingii*, *Pristiograptus dubius*?, and *Monoclimacis* sp. and indicate a stratigraphical level within the *riccartonensis* to *lundgreni* Graptolite Zones (D. Loydell 2020, pers. comm., November). Based upon more extensive graptolite collections from Old Radnor, the oldest beds of the Coalbrookdale Formation are associated with *Cyrtograptus symmetricus* (*C. rigidus*) [10, 17] and the middle to upper Sheinwoodian *Cyrtograptus rigidus* Graptolite Zone [75] (the *Cyrtograptus rigidus-Monograptus belophorus* Graptolite Zone of [19]). At Nash Scar Quarry (SO 3045 6245), a graptolite fauna definitely referable to the lower Homerian *Cyrtograptus lundgreni* Graptolite Zone is reported from immediately above the Dolyhir and Nash Scar Limestone but apparently in association with a faulted contact ([65], Figure 2). In addition, at the same location, the brachiopod *Resserella sabrinae sawddensis* has been documented and is considered indicative of the *C. rigidus* Graptolite Zone to the lower *C. lundgreni* Graptolite Zone [59, 76].

(4) $\delta^{13}C_{carb}$ Records from the Dolyhir and Nash Scar Limestone Formation. $\delta^{13}C_{carb}$ values are particularly age diagnostic within the Sheinwoodian, owing to the presence of the globally identifiable early Sheinwoodian CIE [54, 55]. However, the Dolyhir and Nash Scar Limestone contains features that are less than ideal for the preservation of a primary $\delta^{13}C_{carb}$ signal (i.e., crystalline limestones, which are locally tectonized and subject to secondary mineralization). Significant covariation of $\delta^{13}C_{carb}$ and $\delta^{18}O_{carb}$ was observed within the Dolyhir and Nash Scar Limestone in Dolyhir Quarry Sections 3 and 4 (evaluated in Table SM2 and Figure SM1), and as such, analysis of these results is approached with caution. Within the study area, the onset of the early Sheinwoodian CIE is marked by a rise in values from around 3‰ in the uppermost Dolyhir Rudite to near 5‰ within the basal few meters of the overlying limestones (Figures 2 and 7), with the highest value recorded at Strinds Quarry (S1) (6.0‰ at

2.3 m). A $\delta^{13}C_{carb}$ record for a near-complete succession through the Dolyhir and Nash Scar Limestone has been achieved at Dolyhir Quarry (S2 to S5), with additional records from the base and middle of the formation recorded at Nash Scar Quarry (S1) and Haxwell Quarry (S1), respectively (Figure 7). Following the initial peak in isotopic values, the lower third of the Dolyhir and Nash Scar Limestone shows a progressive reduction in values, falling consistently below 2‰ by the base of the *Stropheodonta* Band. Above the *Stropheodonta* Band, there is a marked drop into negative values at the transition with the Included Shale Band. Within the Included Shale Band, $\delta^{13}C_{carb}$ values range from -0.1‰ to -7.6‰. This section (Dolyhir Quarry S3) exhibited the strongest negative covariation between the $\delta^{13}C_{carb}$ and $\delta^{18}O_{carb}$ values (Figure SM1; regression slope -0.6376, $p = 0.00683$), indicating that it is currently impossible to discern whether the negative $\delta^{13}C_{carb}$ excursion observed around the Included Shale Band represents original seawater values or diagenetic alteration. The negative trend may reflect the intraexcursion negative shift in values that is widely reported from part of the *Monograptus riccartonensis* Graptolite Zone (*K. ranuliformis* Conodont Superbiozone) [55] and the Woolhope Limestone and Buildwas formations of the Midland Platform [54]. However, the severity of the negative shift in values is unusual when compared with the wider Midland Platform and may have been enhanced by diagenetic alteration within an interval that is commonly heavily tectonized over much of Old Radnor [5]. Above the Included Shale Band, and throughout the majority of the remaining Dolyhir and Nash Scar Limestone, values fluctuate around 3.3‰, with an upper peak in values (4.5‰) achieved c. 9 m from the top of the formation. At Haxwell Quarry, the middle of the Dolyhir and Nash Scar Limestone is associated with values that fluctuate around 2.5‰, and based upon the lack of isotopic variability, this section appears equivalent to the lower half of Dolyhir Quarry Section 4 (S4) (Figure 7). The upper Dolyhir and Nash Scar Limestone and the basal Coalbrookdale Formation are associated with a decrease in values that begins 3.6 m below the top of the Dolyhir and Nash Scar Limestone and culminates in values between -2.5‰ and -1.3‰ within the lowermost Coalbrookdale Formation. Within this broad episode of falling values, there is an additional pronounced negative excursion (-0.2‰ to -6.0‰) over five samples and 0.8 m, which begins 2.6 m below the top of the Dolyhir and Nash Scar Limestone. The broader fall in values, close to the transition between the Dolyhir and Nash Scar Limestone and the Coalbrookdale Formation, corresponds to the end of the early Sheinwoodian CIE, as is the case across the Midland Platform [54]. Based upon global comparisons [19], the end of the early Sheinwoodian CIE is considered to occur within the lower part of the *Cyrtograptus rigidus-Monograptus belophorus* Graptolite Zone (Lower *K. walliseri* Conodont Zone) and is therefore in agreement with the proposed age of the uppermost Dolyhir and Nash Scar Limestone (*O. sagitta rhenana* Conodont Zone) and the oldest part of the Coalbrookdale Formation (*Cyrtograptus rigidus* Graptolite Zone).

(5) Likely Age of the Dolyhir and Nash Scar Limestone Formation. Based upon the occurrence of biostratigraphically useful taxa, $\delta^{13}C_{carb}$ trends, and regional stratigraphic comparisons, the Dolyhir and Nash Scar Limestone Formation is coeval across the study area and of early to middle Sheinwoodian age (stage slices Sh1 and Sh2). Notably, chitinozoan and trilobite occurrences restrict the majority of the limestones to the Wenlock, while conodont and graptolite occurrences further restrict the succession to the Sheinwoodian. Based upon these biostratigraphic age constraints, it is apparent that the broad rises and falls in $\delta^{13}C_{carb}$ values recorded within the limestones reflect the well-known early Sheinwoodian CIE [19, 54]. We therefore consider that the Dolyhir and Nash Scar Limestone is approximately age synchronous with other limestones that are developed across the Midland Platform during the Sheinwoodian.

3.3.3. Depositional Environment of the Dolyhir and Nash Scar Limestone Formation. The Dolyhir and Nash Scar Limestone Formation has been typically interpreted as reflecting deposition in a very shallow-water turbulent environment. Furthermore, the somewhat offshore position of the limestones, near the outer margin of the Midland Platform, and lack of clastic sediment have been used to argue for deposition upon a locally developed bathymetric high ([5, 34], pp. 256–259).

The majority of the Dolyhir and Nash Scar Limestone succession consists of rudstone, composed of reef-derived allochthonous bioclasts, and is indicative of an area in close proximity to substantial reef development. The limited transportation of bioclasts is well illustrated by the alga *Craticula gotlandica*, which is one of the most obvious constituents of the limestone and locally makes up nearly 50% of the bulk of the limestone. The irregular to subspherical form of these bioclasts (Figures 5(b) and 8(c)) suggests that the algae did not form as mobile rhodoliths but instead grew as a stabilized frame builder in a biostromal setting, with periodic storm events resulting in the breakage and transportation of the skeletons [12]. However, while the algal bioclasts and the associated constituents of the rudite (mainly the coral *Coenites* sp. and crinoids) are clearly transported, their large and varied grain size suggests only localized transport.

Silty mudstones are a negligible component of much of the succession but where present are accompanied by a distinctive assemblage of fewer but more intact fossils, suggesting limited transport or in situ deposition within a somewhat deeper-water setting (Figure 5(c)). Such an arrangement mirrors that of the Sheinwoodian limestone successions of the rest of the Midland Platform, where the most prominent silty mudstone bands correspond to widely traceable flooding surfaces [54]. The similarity with the limestone and silty mudstone packages of the wider platform is also evident in the timing of some sea-level rises. Most notably, the Included Shale Band is associated with a negative shift in $\delta^{13}C_{carb}$ values within the middle of the early Sheinwoodian CIE, as is the case in a prominent silty mudstone flooding surface within the Woolhope Limestone and Buildwas formations (fs2 of [54]). Similarly, the termination of limestone development and the onset of Coalbrookdale Formation deposition are approximately synchronous with the end of the early Sheinwoodian CIE, both within the study area and across the wider platform. As regards the onset of limestone development, this is approximately synchronous with the start of the early Sheinwoodian CIE within the Dolyhir and Nash Scar Limestone, a position several meters above the base of the Woolhope Limestone and Buildwas formations, the onset of deposition of which approximates to the base of the Sheinwoodian. However, a prominent silty mudstone flooding surface (fs1 of [54]) does approximately coincide with the start of the early Sheinwoodian CIE within the Woolhope Limestone and Buildwas formations and may represent the same sea-level rise that is responsible for the onset of Dolyhir and Nash Scar Limestone deposition.

Based upon the association of silty mudstones with sea-level rises and the apparent synchronicity of sea-level changes, it seems most likely that the Dolyhir and Nash Scar Limestone was connected to the same broad sedimentary system as the wider Midland Platform and subjected to a similar subsidence rate. However, the Dolyhir and Nash Scar Limestone clearly occupied a shallower and more turbulent depositional setting than the majority of the platform. Accordingly, the poorly to massively bedded rudstones of the Dolyhir and Nash Scar Limestone reflect storm deposition and subsequent winnowing in a shallow subtidal setting approximating to the normal wave base. This setting seems to have dominated the majority of the succession at Nash Scar, while the presence of more substantial silty mudstone intervals within the Old Radnor area (i.e., *Stropheodonta* Band and Included Shale Band) indicates that it may have represented a slightly deeper-water or lower-energy setting.

A further notable feature of the Dolyhir and Nash Scar Limestone is its variability in thickness (0 m to 60 m). As with the underlying Dolyhir Rudite Member, this variation suggests that deposition took place over a preexisting topography. The most compelling evidence for this topography comes from the Old Radnor area. Within Dolyhir and Strinds quarries, the limestone varies from ≥57 m to absent over several hundred meters of distance, with the silty mudstones of the Coalbrookdale Formation resting upon the Neoproterozoic basement to the immediate NW of Dolyhir Quarry. Similarly, at Hanter Hill, approximately 1.5 km to the SE of Dolyhir Quarry, the basement is unconformably overlain by a transitional succession of mudstones, sandstones, and conglomerates that are in turn overlain by the Coalbrookdale Formation [17]. Given the short distances between locations where limestone essentially rests on the basement and where Coalbrookdale shales rest on the basement, it seems unlikely that the total loss of limestone could have resulted from a rapid facies transition into a deeper-water shale-dominated setting. Furthermore, Kirk [17] noted an absence of Longmyndian pebbles (e.g., Strinds and Yat Wood formations) within the transitional succession at Hanter Hill. As with the absence of the limestones, this may be best explained by the elevation and subaerial exposure of the Neoproterozoic dolerites of the Hanter Hill area during the deposition of the Dolyhir and Nash Scar Limestone. Accordingly, the limestones around Old Radnor appear to have been deposited around the reefal margin of a series of islands that protruded from the open sea at the edge of the Midland Platform.

Along the Nash Scar Ridge, a marked thinning of the Dolyhir and Nash Scar Limestone is also reported (60 m to 3.5 m) and takes place over c. 1.5 km. According to Garwood and Goodyear [5], this represents the transition into a deeper-water open sea setting. Here, the thinner, mixed limestones and silty mudstones of the Woolhope Limestone Formation were deposited. Based upon our observations at Old Radnor, it seems equally likely that the thinning of the limestone could represent deposition upon the rising margins of a bathymetric high. Unfortunately, the unusually thin succession of the Dolyhir and Nash Scar Limestone is no longer exposed; however, if Garwood and Goodyear [5] are correct in their interpretation, it does demonstrate the connection of the Dolyhir and Nash Scar Limestone with the wider carbonate platform.

The final phase of the depositional history of the Dolyhir and Nash Scar Limestone relates to the transition into the Coalbrookdale Formation. Based upon the available age constraint (biostratigraphy and the end of the early Sheinwoodian CIE), there was a near-synchronous and platform-wide termination of Sheinwoodian limestones [54]. The termination of limestone development appears to be linked to a major transgression that was sufficient not only to drown the carbonate platform but also to overstep the landmass developed around Old Radnor. Here, the coarse-grained clastics of the transitional deposits at Hanter Hill reflect a locally developed transgressive lag [17]. Notably, the Coalbrookdale Formation within the nearby Gore road cut (SO 2596 5912), which is considered rather higher than the basal beds of the formation [17], contains beds of fine sandstones [26], thereby suggesting the continued presence of local bathymetric highs and possibly a landmass during deposition of higher beds of the Coalbrookdale Formation. Lastly, the top of the Dolyhir and Nash Scar Limestone is also reflective of a major transgression, with hardgrounds developed in association with sediment starvation and winnowing, as evidenced by in situ crinoid holdfasts and isolated pockets of trilobitic sediments. However, based upon biostratigraphic and carbon isotopic grounds, we cannot find evidence for the significant stratigraphic gap, which has previously been inferred between the top of the limestones and the base of the Coalbrookdale Formation (e.g., [26, 62, 67]).

4. Local, Regional, and Global Synthesis

4.1. Depositional History. The area that encompasses Old Radnor and Presteigne contains a unique Silurian succession that documents the progressive transgression of the Neoproterozoic basement, which had been uplifted along the Church Stretton Fault Zone (Figure 9). Notably, the upper Aeronian Folly Sandstone documents an initial and limited encroachment of marine conditions, being restricted to the Presteigne area, while the regionally extensive upper Sheinwoodian Coalbrookdale Formation documents the complete submergence of the area. The rate of transgression was not uniform and was notably interrupted by a phase of uplift, tilting, and exposure during early Telychian times.

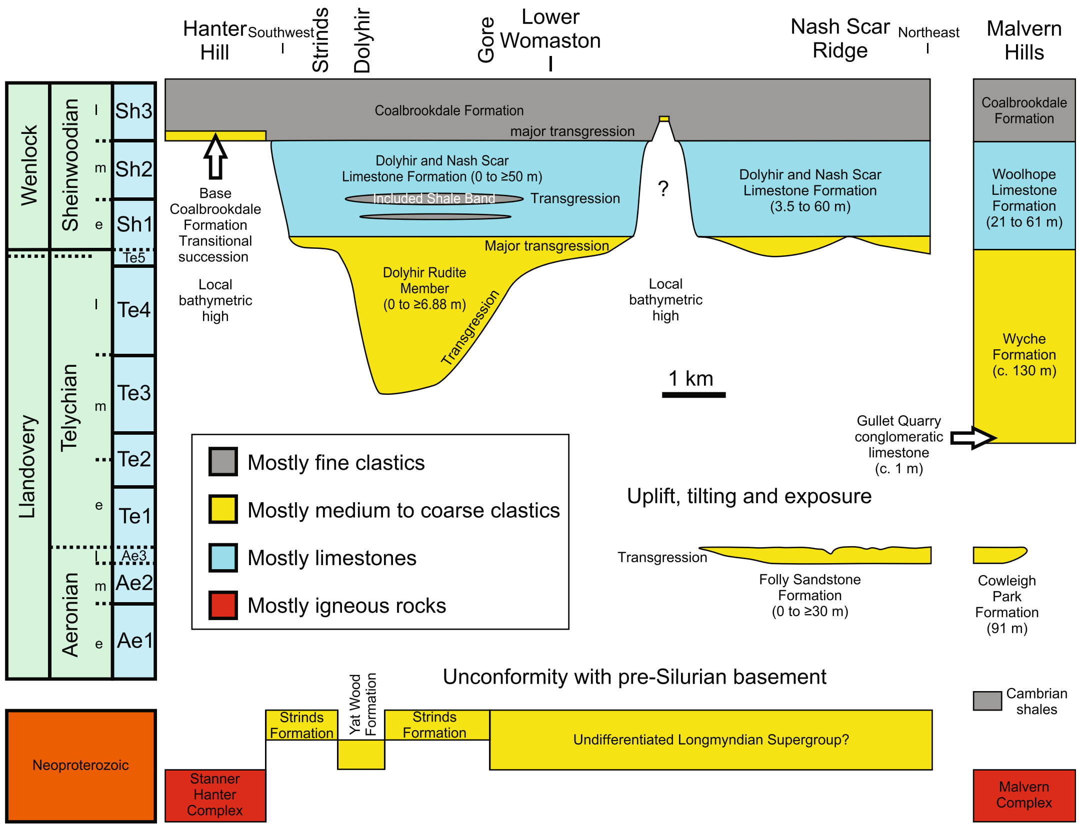


FIGURE 9: A schematic chronostratigraphic representation of the succession from Hanter Hill (SO 249 574) to the southwest edge of Strinds Quarry (SO 239 576) to the northeast end of the Nash Scar Ridge (SO 320 634). A generalized succession is given for the Malvern Hills approximately 55 km to the east of the study area (SO 761 381). Early (e), middle (m), and late (l) subdivisions have been given for the stages, as have the internationally recognized stage slices [19, 20].

This tectonic event is most clearly evidenced by the angular unconformity that is developed between the Folly Sandstone and the Dolyhir Rudite Member. After uplift, the return of marine conditions was initially restricted to Old Radnor and specifically Dolyhir Quarry, where the Dolyhir Rudite is the oldest and of middle to late Telychian age. Transgression within the Dolyhir Rudite is documented by increasingly calcareous and fossiliferous beds. Within the upper part of the succession, the rate of transgression appears to increase, resulting in the expansion of the marine conditions and the rudite across large parts of the study area. A further impact of the expansion of marine conditions was a reduction in clastic sedimentation and the replacement of the rudite by the Dolyhir and Nash Scar Limestone Formation. This event occurred within the early Sheinwoodian.

The allochthonous coral-algal rudstones of the Dolyhir and Nash Scar Limestone Formation show rapid lateral thickness variations and localized absences, indicating that they were deposited against a considerable topography and in close proximity to an area of significant reef development. Furthermore, the limestones of the Old Radnor area appear to have occupied a slightly deeper marine setting when compared to those at Nash Scar, owing to the presence of offshore silty mudstone intervals rich in brachiopods and trilobites (i.e., *Stropheodonta* Band and Included Shale Band).

The late Sheinwoodian was marked by a major transgression, which terminated the deposition of the Dolyhir and Nash Scar Limestone Formation and replaced it with the offshore graptolitic silty mudstones of the Coalbrookdale Formation. The transition from limestones to silty mudstones takes place over a few meters and is associated with multiple hardground surfaces, Neptunian dykes, and an abundance of trilobites. In addition, much of the remaining land appears to have been submerged during this event, resulting in the localized deposition of the Coalbrookdale Formation onto the Neoproterozoic basement, locally with a transgressive lag deposit of coarse-grained clastics at the base of the formation.

4.2. Regional and Global Comparisons. The depositional history outlined above is age constrained by previous biostratigraphic studies and new discoveries described herein. Together, these age refinements allow for a more detailed understanding of the relationship between this succession and that of the wider Midland Platform and beyond. What follows is a summary of the similarities between the Old Radnor and Presteigne area and the wider Midland Platform, with particular reference to the succession within the Malvern Hills, an area that also demonstrates the Silurian transgression of an uplifted area of the Neoproterozoic basement (Figure 9).

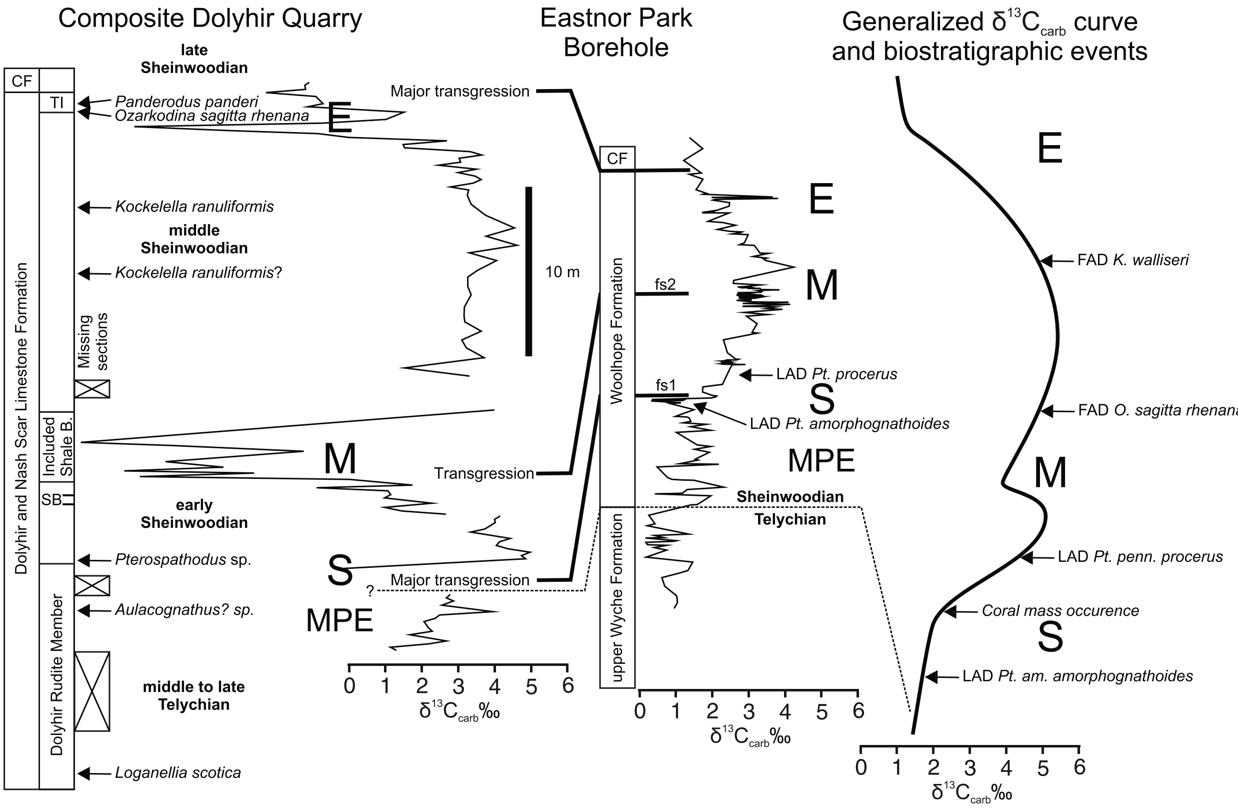


Figure 10: A summary of the lithostratigraphy, biostratigraphy, $\delta^{13}C_{carb}$ trends, and transgressions established at Dolyhir Quarry, showing correlations to the Eastnor Park Borehole (near the Malvern Hills) (modified from [54]) and a generalized (global) $\delta^{13}C_{carb}$ curve with biostratigraphic events (modified from [19]). Conodont abbreviations: *Pt.=Pterospathodus*; *am.=amorphognathoides*; *penn.=pennatus*; *O.=Ozarkodina*; *K.=Kockelella*. Other abbreviations: SB=*Stropheodonta* Band; TI=transitional interval; CF=Coalbrookdale Formation; fs=flooding surface; MPE=minor positive carbon isotope excursion (not necessarily the same event); S=start of the early Sheinwoodian carbon isotope excursion (ESCIE); M=middle ESCIE negative shift; E=end of the ESCIE.

The deposition of the Folly Sandstone Formation in late Aeronian times appears approximately age synchronous with the conglomerates, sandstones, and siltstones of the Cowleigh Park Formation of the Malvern Hills and is lithologically similar. Regionally, both the Folly Sandstone and Cowleigh Park formations reflect deposition against topographic highs developed along the Church Stretton Fault Zone and Malvern Line, respectively. Between these shorelines was a subdued area of the flooded shelf, which was further bounded by the landmass of Pretannia in the south and the Shelve-Longmynd Peninsula to the north [31]. This late Aeronian transgression of the margins of the Midland Platform is widely documented beyond the study area and likely reflects a eustatic event [32]. Both the Folly Sandstone and Cowleigh Park formations are unconformably overlain by younger Telychian sediments, suggesting the regional exposure of much of the intervening shelf. The Aeronian-Telychian unconformity is associated with uplift and has been linked to a pulse of regional tectonism [36, 37].

The middle to late Telychian is notable as the acme of the global Silurian sea level [77–79], and this is regionally reflected by the widespread transgression of the Midland Platform beyond the Malvern Line to the east and the submergence of the Shelve-Longmynd Peninsula in the north [29, 31, 80]. Previously, the Old Radnor and Presteigne area has been interpreted as wholly emergent at this time (e.g., [31]). However, within the Dolyhir Rudite Member of Dolyhir Quarry, Old Radnor, are brachiopod, conodont, and thelodont occurrences that mirror those reported from the middle to upper Telychian Wyche Formation and its conglomeratic limestone base (Malvern Hills). Most notable is the thelodont *L. scotica*, the presence of which restricts at least the lower part of the rudite to the eponymous biozone and the middle to upper Telychian. Based upon such cooccurrences, the Wyche Formation and the base of the Dolyhir Rudite appear age synchronous. However, while the Dolyhir Rudite reflects a depositional setting akin to the basal few meters of the Wyche Formation (Gullet Quarry conglomeratic limestone), the remainder of the Wyche Formation was deposited in an open shelf setting [29]. Similarly, differences in the amount of available accommodation space and water depth are indicated by the differing thicknesses of the Dolyhir Rudite and Wyche Formation: ≥6.88 m and c. 130 m, respectively. Accordingly, while undoubtedly Telychian in age, the nearshore depositional environments exhibited by the conglomeratic limestone base of the Wyche Formation and the base of the Dolyhir Rudite could be diachronous, with deposition presumably starting somewhat earlier within the Malvern Hills.

The unusual coral-algal rudstones of the Dolyhir and Nash Scar Limestone Formation are the best-known feature of the Old Radnor and Presteigne succession. However, previous ambiguity in age constraint, alongside the unusual lithology and deposition in association with the Church Stretton Fault Zone, has resulted in uncertainty as to the relationship with the wider Midland Platform. Broadly, the succession may represent part of the same depositional system as the wider Midland Platform or an isolated depositional system controlled by local tectonics and surrounded by offshore graptolitic silty mudstones. The identification of the early Sheinwoodian CIE, also referred to as the Ireviken CIE, complementary biostratigraphy, and regionally traceable flooding surfaces indicate that the Dolyhir and Nash Scar Limestone Formation is approximately age synchronous with the Sheinwoodian limestones of the wider Midland Platform (Woolhope Limestone, Buildwas, and Barr Limestone formations) (Figure 10) and therefore part of the same depositional system, albeit as developed within a shallower depositional setting. Furthermore, the global nature of the early Sheinwoodian CIE allows the Dolyhir and Nash Scar Limestone to be correlated and compared with other successions from a range of palaeogeographic locations and depositional settings. The early Sheinwoodian CIE is recognized from multiple palaeocontinents, most prominently in tropical to subtropical carbonate platforms across Baltica (e.g., [81]), Laurentia (e.g., [53, 55, 82, 83]), and tropical Gondwana (New South Wales, [84]) but also in higher palaeolatitudes represented by Gondwanan and peri-Gondwanan sections in today's North Africa [85] and the Prague Basin [86], estimated at c. 59°S [87]. The excursion is not restricted to shallow-water intrashelf settings but is also manifested in $\delta^{13}C_{org}$ values in hemipelagic mudstone-dominated settings (e.g., in Wales, [88]; North Africa, [85]; and Poland, [89]). Although the early Sheinwoodian CIE is globally associated with sea-level changes and faunal reorganizations, its forcing mechanisms remain debated. Recent studies proposed new evidence for anoxia or euxinia associated with the excursion in multiple basins [89–91], but no indication of marine anoxia has been observed in the shallow-water deposits examined here. Furthermore, basinward mudstone-dominated sections in the adjacent Welsh Basin, exposing the Trewern Brook Mudstone Formation in Buttington Quarry, indicated an early Sheinwoodian $\delta^{13}C_{carb}$ development consistent with the trend proposed here but also reported no indication of persistent anoxia [92], suggesting that more complex changes in seawater geochemistry were associated with the early Sheinwoodian CIE.

Having identified the early Sheinwoodian CIE within the Dolyhir and Nash Scar Limestone, more detailed stratigraphic comparisons can be made with key successions on the Midland Platform and other palaeocontinents. Across much of the study area, the onset of the early Sheinwoodian CIE occurs immediately above an unconformity, while within the Eastnor Park Borehole [54], near the Malvern Hills, the onset of the CIE is 6.4 m above the boundary between the Wyche and Woolhope Limestone formations. Accordingly, the lowermost Woolhope Limestone times correspond to nondeposition across much of the Old Radnor and Presteigne area, except for at Dolyhir Quarry. Here, an area of rudite that predates the early Sheinwoodian CIE reflects coarse clastic sedimentation at the margin of an island. Much of this island was transgressed, and a thin rudite lag and overlying coral-algal limestones were deposited during the onset of the early Sheinwoodian CIE. Notably, this transgression corresponds to a platform-wide event (fs1 of [54]), which on the southern margin of the Midland Platform (Tortworth inlier) is associated with the replacement of shallow marine sandstones by somewhat deeper marine limestones and silty mudstones and the mass occurrence of solitary rugose corals (*Pycnactis* Band) [54, 93]. The mass occurrence of corals in association with a flooding surface and the onset of the early Sheinwoodian CIE is also reported from Baltica (*Phaulactis* Layer). Here, this coral mass occurrence is considered an important stratigraphic marker during the Ireviken Bioevent [81]. Similarly, the transgression reflected by the Included Shale Band and associated with the negative shift in $\delta^{13}C_{carb}$ values within the middle of the early Sheinwoodian CIE also has its equivalent within the Woolhope Limestone and Buildwas formations and within sections upon Laurentia and Baltica (fs2 of [54]). For example, the Sheinwoodian of the Appalachian foreland basin of New York State (USA) is notable for the interruption of shallow marine bedded limestones, by the deeper marine calcareous shales of the Rochester Shale Formation, whose base contains a negative shift in $\delta^{13}C_{carb}$ values [55]. The final submergence of the study area approximates to the end of the early Sheinwoodian CIE and is associated with the replacement of a regional carbonate platform by the offshore graptolitic silty mudstones of the Coalbrookdale Formation. This transgression, like those documented from older parts of the succession, appears to have a eustatic origin (highstand 5 of the global sea-level curve of [77]) and demonstrates apparent synchronicity of depositional events between the Old Radnor and Presteigne area and the wider Silurian world.

Data Availability

Large files, i.e. thin-section scans and conodont photographs, are archived at osf.io/kuh4e (doi:10.17605/OSF.IO/KUH4E).

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

We are grateful to Tarmac, John Sergeant, and Ian Brewer for access to Dolyhir, Strinds, and Nash Scar quarries and accompanying borehole records. Additional borehole data is based upon records provided by the British Geological Survey (NERC). Bill and Noorissa Davies are thanked for access to Haxwell Quarry. Elsa Harflett (Radnorshire Society), John Davies, and Roger Coward (Abbey Cwmhir Heritage Trust) are thanked for their assistance in locating disused quarries. Thanks are due to David Loydell for the identification of graptolite specimens and helpful comments upon our biostratigraphic interpretations. Alan Thomas and Carlton Brett are thanked for insightful discussions during exploratory fieldwork. Isotopic measurements were undertaken at Plymouth University (Strinds Quarry S1 and Dolyhir Quarry S4) and the University of Erlangen-Nuremberg (all other measurements), with particular thanks to Michael Joachimski (University of Erlangen-Nuremberg). Thanks are due to Nigel Woodcock and two anonymous reviewers for helpful comments. The study was funded by the following: Deutsche Forschungsgemeinschaft project JA 2718/1-1 to EJ and Palaeontological Association Research Grant to HEH.

Supplementary Materials

Supplementary materials include details of analytical methods of conodont extraction and isotope measurements, conodont counts (Table SM1), thelodont scale descriptions and illustrations (Figure SM2), stable carbon and oxygen isotope measurements (Table SM2), and crossplots (Figure SM1). *(Supplementary Materials)*

References

[1] R. Kendall and R. Roberts, "Mapping the Knighton Sheet–the final piece of the jigsaw," *Earth Heritage*, vol. 49, pp. 23-24, 2018.

[2] C. W. Thomas and R. Kendall, *Welsh Borderland Geological Framework Project : the geology and applied geological issues of the region around Knighton, Powys : a scoping study*, Publication-Report IR/11/069, 2017.

[3] N. H. Woodcock, "Strike-slip faulting along the Church Stretton Lineament, Old Radnor inlier, Wales," *Journal of the Geological Society*, vol. 145, no. 6, pp. 925–933, 1988.

[4] N. H. Woodcock, N. Jack Soper, and A. J. Miles, "Age of the Acadian deformation and Devonian granites in northern England: a review," *Proceedings of the Yorkshire Geological Society*, vol. 62, no. 4, pp. 238–253, 2019.

[5] E. J. Garwood and E. Goodyear, "On the geology of the Old Radnor district with special reference to an algal development in the Woodhope Limestone," *Quarterly Journal of the Geological Society*, vol. 74, no. 1-4, 1919.

[6] T. Cantrill, "On a boring for Coal at Presteign, Radnorshire," *Geological Magazine*, vol. 4, no. 11, pp. 481–492, 1917.

[7] J. E. Davis, "On the age and position of the limestone of Nash, near Presteign, South Wales," *Quarterly Journal of the Geological Society*, vol. 6, no. 1-2, pp. 432–439, 1850.

[8] R. I. Murchison, *Siluria: A History of the Oldest Rocks in the British Isles and Other Countries; with Sketches of the Origin and Distribution of Native Gold, the General Succession of Geological Formations, and Changes of the Earth's Surface*, p. 107, John Murray, Fifth edition, 1872.

[9] R. J. Aldridge, "The Silurian conodont *Ozarkodina sagitta* and its value in correlation," *Palaeontology*, vol. 18, pp. 323–332, 1975.

[10] N. H. Kirk, "The Upper Llandovery and Lower Wenlock rocks of the area between Dolyhir and Presteigne, Radnorshire," *Abstracts of the Proceedings of the Geological Society of London*, vol. 1471, pp. 56–58, 1951.

[11] A. M. Ziegler, "Unusual stricklandiid brachiopods from the Upper Llandovery beds near Presteigne, Radnorshire," *Palaeontology*, vol. 9, pp. 346–350, 1966.

[12] C. Brooke, "Dolyhir Limestone, Old Radnor, Powys," in *4th International Symposium on Fossil Algae, Cardiff July 1987*, R. Riding, Ed., pp. 23–26, Pre-Symposium Field Excursion, 1987.

[13] A. T. Thomas, "Trilobite associations in the British Wenlock," *Geological Society, London, Special Publications*, vol. 8, no. 1, pp. 447–451, 1979.

[14] L. R. M. Cocks, C. H. Holland, and R. B. Richards, *A Revised Correlation of Silurian Rocks in the British Isles*, vol. 21, Geological Society of London, 1992.

[15] H. M. Green, *Calcareous algae of the Silurian of the Welsh Border [Ph.D. thesis]*, Prifysgol Bangor University, 1959.

[16] P. H. Swire, *Palynology of a Lower Wenlock (Silurian) shelf-basin transect, Wales and the Welsh Borderland [Ph.D. thesis]*, University of Nottingham, 1991.

[17] N. H. Kirk, *Geology of the anticlinal disturbance of Breconshire and Radnorshire: Pont Faen to Presteigne [Ph.D. thesis]*, University of Cambridge, 1949.

[18] D. C. Ray, E. Jarochowska, H. E. Hughes et al., *Supporting Data for the Silurian Transgression of a Paleo-shoreline: the Area between Old Radnor and Presteigne, Welsh Borderlands*, OSF, 2020.

[19] B. D. Cramer, C. E. Brett, M. J. Melchin et al., "Revised correlation of Silurian Provincial Series of North America with global and regional chronostratigraphic units and $\delta^{13}C_{carb}$ chemostratigraphy," *Lethaia*, vol. 44, no. 2, pp. 185–202, 2011.

[20] J. G. Ogg, G. M. Ogg, and F. M. Gradstein, *A Concise Geologic Time Scale*, Elsevier, 2016.

[21] H. E. Boynton and C. H. Holland, "Geology of the Pedwardine district, Herefordshire and Powys," *Geological Journal*, vol. 32, no. 3, pp. 279–292, 1997.

[22] J. Parnell, "Secondary porosity in hydrocarbon-bearing transgressive sandstones on an unstable Lower Palaeozoic continental shelf, Welsh Borderland," *Geological Society, London, Special Publications*, vol. 36, no. 1, pp. 297–312, 1987.

[23] J. Parnell and P. Eakin, "Thorium–bitumen mineralization in Silurian sandstones, Welsh Borderland," *Mineralogical Magazine*, vol. 53, no. 369, pp. 111–116, 1989.

[24] W. Gibbons and A. L. Harris, *A Revised Correlation of Pre-Cambrian Rocks in the British Isles*, vol. 22, Geological Society of London, 1994.

[25] D. I. Schofield, I. L. Millar, P. R. Wilby, and J. A. Evans, "A new, high precision U–Pb date from the oldest known rocks in southern Britain," *Geological Magazine*, vol. 147, no. 1, pp. 145–150, 2010.

[26] N. H. Woodcock, "The Precambrian and Silurian of Old Radnor and Presteigne area," in *Geological Excursions in Powys Central Wales*, N. H. Woodcock and M. G. Bassett, Eds., pp. 229–241, University of Wales Press, 1993.

[27] A. H. Cox, "On an inlier of Longmyndian and Cambrian rocks at Pedwardine (Herefordshire)," *Quarterly Journal of the Geological Society*, vol. 68, no. 1-4, pp. 364–373, 1912.

[28] J. Moseley, "The Longmyndian Rocks of the Pedwardine Inlier, North Herefordshire," *North West Geologist*, vol. 15, pp. 22–32, 2008.

[29] A. M. Ziegler, L. R. M. Cocks, and W. S. McKerrow, "The Llandovery transgression of the Welsh Borderland," *Palaeontology*, vol. 11, pp. 736–782, 1968.

[30] L. R. M. Cocks, "Llandovery brachiopods from England and Wales," *Monographs of the Palaeontographical Society*, vol. 172, no. 652, pp. 1–262, 2019.

[31] M. G. Bassett, B. J. Bluck, R. Cave, C. H. Holland, and J. D. Lawson, "Silurian," in *Geological Society memoir*, J. C. W. Cope, J. K. Ingham, and P. F. Rawson, Eds., vol. 13 of Atlas of Palaeogeography and Lithofacies, pp. 17–56, 1992.

[32] J. R. Davies, R. A. Waters, S. G. Molyneux, M. Williams, J. A. Zalasiewicz, and T. R. A. Vandenbroucke, "Gauging the impact of glacioeustasy on a mid-latitude early Silurian basin margin, mid Wales, UK," *Earth-Science Reviews*, vol. 156, pp. 82–107, 2016.

[33] I. E. K. Brewer, N. Lykakis, and A. P. Wilkinson, "Structural mapping and modelling of Dolyhir Quarry, Powys as a basis for a refined reserve assessment and quarry development strategy," in *Proceedings of the 17th Extractive Industry Geology Conference*, pp. 35–44, EIG Conferences Ltd, Ormskirk, Lancashire, 2014.

[34] R. J. Aldridge, D. J. Siveter, D. J. Siveter, P. D. Lane, D. Palmer, and N. H. Woodcock, *British Silurian Stratigraphy*, vol. 19 of Geological Conservation Review Series, 542 pages, Joint Nature Conservation Committee, Peterborough, 2000.

[35] M. Brooks and E. C. Druce, "A Llandovery conglomeratic limestone in Gullet Quarry, Malvern Hills, and its conodont fauna," *Geological Magazine*, vol. 102, no. 5, pp. 370–382, 1965.

[36] L. Cherns, L. R. M. Cocks, J. R. Davies, R. D. Hillier, R. A. Waters, and M. Williams, "Silurian: the influence of extensional tectonics and sea-level changes on sedimentation in the Welsh Basin and on the Midland Platform," in *The Geology of England and Wales*, P. J. Brenchley and P. F. Rawson, Eds., pp. 75–102, The Geological Society, 2006.

[37] R. D. Hillier and L. B. Morrissey, "Process regime change on a Silurian siliciclastic shelf: controlling influences on deposition of the Gray Sandstone Formation, Pembrokeshire, UK," *Geological Journal*, vol. 45, no. 1, pp. 26–58, 2010.

[38] B. G. Baarli, "Orthacean and Strophomenid Brachiopods from the lower Silurian of the Central Oslo Region," *Fossils and strata*, vol. 39, 1995.

[39] O. A. Hoel, "Strophomenidae, Leptostrophiidae, Strophodontidae and Shaleriidae (Brachiopoda, Strophomenida) from the Silurian of Gotland, Sweden," *Paläontologische Zeitschrift*, vol. 85, no. 2, pp. 201–229, 2011.

[40] H. C. Squirrell and E. V. Tucker, "The geology of the Woolhope inlier (Herefordshire)," *Quarterly Journal of the Geological Society*, vol. 116, no. 1-4, pp. 139–181, 1960.

[41] K. Brood, "Bryozoans," in *Lower Wenlock Faunal and Floral Dynamics-Vattenfallet Section*, V. Jaanusson, S. Laufeld, and R. Skoglund, Eds., vol. 7623, pp. 172–180, C, NR, Gotland, 1979.

[42] E. Jarochowska, D. C. Ray, P. Röstel, G. Worton, and A. Munnecke, "Harnessing stratigraphic bias at the section scale: conodont diversity in the Homerian (Silurian) of the Midland Platform, England," *Palaeontology*, vol. 61, no. 1, pp. 57–76, 2018.

[43] L. Jeppsson, J. A. Talent, R. Mawson et al., "High-resolution late Silurian correlations between Gotland, Sweden, and the Broken River region, NE Australia: lithologies, conodonts and isotopes," *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 245, no. 1-2, pp. 115–137, 2007.

[44] C. H. Holland and M. G. Bassett, *Telychian Rocks of the British Isles and China (Silurian, Llandovery Series)*, Geological series, no. 21, 2002National Museum Wales, 2002.

[45] L. Jeppsson, M. E. Eriksson, and M. Calner, "A latest Llandovery to latest Ludlow high-resolution biostratigraphy based on the Silurian of Gotland—a summary," *GFF*, vol. 128, no. 2, pp. 109–114, 2006.

[46] P. Männik, "Evolution and taxonomy of the Silurian conodont *Pterospathodus*," *Palaeontology*, vol. 40, pp. 1001–1050, 1998.

[47] T. Märss and P. Männik, "Revision of Silurian vertebrate biozones and their correlation with the conodont succession," *Estonian Journal of Earth Sciences*, vol. 62, no. 4, p. 181, 2013.

[48] R. J. Aldridge and S. Turner, "Britain's oldest agnathans," *Geological Magazine*, vol. 112, no. 4, pp. 419-420, 1975.

[49] T. Marss and C. Miller, "Thelodonts and distribution of associated conodonts from the Llandovery–lowermost Lochkovian of the Welsh Borderland," *Palaeontology*, vol. 47, no. 5, pp. 1211–1265, 2004.

[50] S. Turner, "New Llandovery to early Pridoli microvertebrates including early Silurian zone fossil, *Loganellia avonia* nov. sp., from Britain," in *Palaeozoic Microvertebrates*, A. Blieck and S. Turner, Eds., pp. 91–127, IGCP 328, 2000.

[51] P. Männik, "An updated Telychian (Late Llandovery, Silurian) conodont zonation based on Baltic faunas," *Lethaia*, vol. 40, no. 1, pp. 45–60, 2007.

[52] E. U. Hammarlund, D. K. Loydell, A. T. Nielsen, and N. H. Schovsbo, "Early Silurian $\delta^{13}C_{org}$ excursions in the foreland basin of Baltica, both familiar and surprising," *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 526, pp. 126–135, 2019.

[53] P. I. McLaughlin, P. Emsbo, C. E. Brett, A. M. Bancroft, A. Desrochers, and T. R. A. Vandenbroucke, "The rise of pinnacle reefs: a step change in marine evolution triggered by perturbation of the global carbon cycle," *Earth and Planetary Science Letters*, vol. 515, pp. 13–25, 2019.

[54] H. E. Hughes and D. C. Ray, "The carbon isotope and sequence stratigraphic record of the Sheinwoodian and lower Homerian stages (Silurian) of the Midland Platform, UK," *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 445, pp. 97–114, 2016.

[55] B. D. Cramer, D. K. Loydell, C. Samtleben et al., "Testing the limits of Paleozoic chronostratigraphic correlation via high-resolution (<500 k.y.) integrated conodont, graptolite, and carbon isotope ($^{13}C_{carb}$) biochemostratigraphy across the Llandovery-Wenlock (Silurian) boundary: is a unified Phanerozoic time scale achievable?," *Geological Society of America Bulletin*, vol. 122, no. 9-10, pp. 1700–1716, 2010.

[56] J. L. Banner and G. N. Hanson, "Calculation of simultaneous isotopic and trace element variations during water-rock interaction with applications to carbonate diagenesis," *Geochimica et Cosmochimica Acta*, vol. 54, no. 11, pp. 3123–3137, 1990.

[57] M. E. Johnson and W. S. McKerrow, "The Sutton Stone: an Early Jurassic rocky shore deposit in South Wales," *Palaeontology*, vol. 38, no. 3, pp. 529–541, 1995.

[58] T. H. Sheppard, "Sequence architecture of ancient rocky shorelines and their response to sea-level change: an Early Jurassic example from South Wales, UK," *Journal of the Geological Society*, vol. 163, no. 4, pp. 595–606, 2006.

[59] J. M. Hurst, N. J. Hancock, and W. S. McKerrow, "Wenlock stratigraphy and palaeogeography of Wales and the Welsh Borderland," *Proceedings of the Geologists' Association*, vol. 89, no. 3, pp. 197–226, 1978.

[60] M. G. Bassett, "The articulate brachiopods from the Wenlock Series of the Welsh Borderland and South Wales," in *Part 4*, pp. 123–176, Monograph of the Palaeontographical Society, London, 1977.

[61] C. Brooke and R. Riding, "Ordovician and Silurian coralline red algae," *Lethaia*, vol. 31, no. 3, pp. 185–195, 1998.

[62] M. D. Sutton, D. J. Siveter, D. J. Siveter, and D. E. G. Briggs, "The geological significance of the Dolyhir and Nash Scar Limestone (Silurian) of the Welsh Borderland," *Tarmac Papers*, vol. 4, pp. 253–265, 2000.

[63] A. T. Thomas, *British Wenlock trilobites*, pp. 1–56, Monograph of the Palaeontographical Society, London, 1978.

[64] D. J. Siveter, "Evolution of the Silurian trilobite Tapinocalymene from the Wenlock of the Welsh Borderlands," *Palaeontology*, vol. 23, pp. 783–802, 1980.

[65] M. G. Bassett, "Review of the stratigraphy of the Wenlock Series in the Welsh Borderland and South Wales," *Palaeontology*, vol. 17, pp. 745–777, 1974.

[66] T. F. Cotterell, D. I. Green, N. Hubbard, J. S. Mason, R. E. Starkey, and A. G. Tindle, "The mineralogy of Dolyhir Quarry, Old Radnor, Powys, Wales," *UK Journal of Mines and Minerals*, vol. 32, pp. 5–61, 2011.

[67] D. J. Siveter, D. E. G. Briggs, D. J. Siveter, and M. D. Sutton, "The Herefordshire Lagerstätte: fleshing out Silurian marine life," *Journal of the Geological Society*, vol. 177, no. 1, pp. 1–13, 2020.

[68] R. J. Aldridge, "The stratigraphic distribution of conodonts in the British Silurian," *Journal of the Geological Society*, vol. 131, no. 6, pp. 607–618, 1975.

[69] P. Männik and A. Munnecke, "New biostratigraphic and chemostratigraphic data from the Chicotte Formation (Llandovery, Anticosti Island, Laurentia) compared with the Viki core (Estonia, Baltica)," *Estonian Journal of Earth Sciences*, vol. 58, pp. 159–169, 2009.

[70] L. Jeppsson, "A new latest Telychian, Sheinwoodian and early Homerian (early Silurian) standard conodont zonation," *Earth and Environmental Science Transactions of the Royal Society of Edinburgh*, vol. 88, no. 2, pp. 91–114, 1997.

[71] M. J. Melchin, P. M. Sadler, B. D. Cramer, R. A. Cooper, F. M. Gradstein, and O. Hammer, "The Silurian period," in *The Geologic Time Scale*, F. M. Gradstein, J. G. Ogg, M. Schmitz, and G. M. Ogg, Eds., pp. 525–558, Elsevier, 2012.

[72] T. Steeman, T. R. A. Vandenbroucke, M. Williams et al., "Chitinozoan biostratigraphy of the Silurian Wenlock–Ludlow boundary succession of the Long Mountain, Powys, Wales," *Geological Magazine*, vol. 153, no. 1, pp. 95–109, 2016.

[73] J. Verniers, "Calibration of Wenlock Chitinozoa versus graptolite biozonation in the Wenlock of Builth Wells district (Wales, U. K.), compared with other areas in Avalonia and Baltica," *Bollettino della Societa Paleontologica Italiana*, vol. 38, pp. 359–380, 1999.

[74] A. J. Storey, *Late Silurian trilobite palaeobiology and biodiversity [Ph.D. thesis]*, University of Birmingham, 2012.

[75] J. Zalasiewicz and M. Williams, "Graptolite biozonation of the Wenlock Series (Silurian) of the Builth Wells district, central Wales," *Geological Magazine*, vol. 136, no. 3, pp. 263–283, 1999.

[76] J. M. Hurst, "*Resserella sabrinae* Bassett, in the Wenlock of Wales and the Welsh Borderland," *Journal of Paleontology*, vol. 49, pp. 316–328, 1975.

[77] M. E. Johnson, "Relationship of Silurian sea-level fluctuations to oceanic episodes and events," *GFF*, vol. 128, no. 2, pp. 115–121, 2006.

[78] D. K. Loydell, "Early Silurian sea-level changes," *Geological Magazine*, vol. 135, no. 4, pp. 447–471, 1998.

[79] S. Lüning, J. Craig, D. K. Loydell, P. Štorch, and B. Fitches, "Lower Silurian `hot shales' in North Africa and Arabia: regional distribution and depositional model," *Earth-Science Reviews*, vol. 49, no. 1-4, pp. 121–200, 2000.

[80] P. H. Bridges, "The transgression of a hard substrate shelf; the Llandovery (lower Silurian) of the Welsh Borderland," *Journal of Sedimentary Research*, vol. 45, pp. 79–94, 1975.

[81] A. Munnecke, C. Samtleben, and T. Bickert, "The Ireviken Event in the lower Silurian of Gotland, Sweden - relation to similar Palaeozoic and Proterozoic events," *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 195, no. 1-2, pp. 99–124, 2003.

[82] M. R. Saltzman, "Silurian δ^{13}C stratigraphy: a view from North America," *Geology*, vol. 29, no. 8, pp. 671–674, 2001.

[83] J. V. Strauss, T. Fraser, M. J. Melchin et al., "The Road River Group of northern Yukon, Canada: early Paleozoic deep-water sedimentation within the Great American Carbonate Bank," *Canadian Journal of Earth Sciences*, vol. 57, no. 10, pp. 1193–1219, 2020.

[84] J. A. Talent, R. Mawson, A. S. Andrew, P. J. Hamilton, and D. J. Whitford, "Middle Palaeozoic extinction events: faunal and isotopic data," *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 104, no. 1-4, pp. 139–152, 1993.

[85] M. Vecoli, A. Riboulleau, and G. J. M. Versteegh, "Palynology, organic geochemistry and carbon isotope analysis of a latest Ordovician through Silurian clastic succession from borehole Tt1, Ghadamis Basin, southern Tunisia, North Africa: palaeoenvironmental interpretation," *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 273, no. 3-4, pp. 378–394, 2009.

[86] J. Frýda, O. Lehnert, and M. M. Joachimski, "First record of the early Sheinwoodian carbon isotope excursion (ESCIE) from the Barrandian area of northwestern peri-Gondwana," *Estonian Journal of Earth Sciences*, vol. 64, no. 1, pp. 42–46, 2015.

[87] N. Wright, S. Zahirovic, R. D. Müller, and M. Seton, "Towards community-driven paleogeographic reconstructions: integrating open-access paleogeographic and paleobiology data with plate tectonics," *Biogeosciences*, vol. 10, no. 3, pp. 1529–1541, 2013.

[88] D. K. Loydell and J. Frýda, "Carbon isotope stratigraphy of the upper Telychian and lower Sheinwoodian (Llandovery–Wenlock, Silurian) of the Banwy River section, Wales," *Geological Magazine*, vol. 144, no. 6, pp. 1015–1019, 2007.

[89] N. B. Sullivan, D. K. Loydell, P. Montgomery et al., "A record of Late Ordovician to Silurian oceanographic events on the margin of Baltica based on new carbon isotope data, elemental geochemistry, and biostratigraphy from two boreholes in central Poland," *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 490, pp. 95–106, 2018.

[90] J. Smolarek, W. Trela, D. P. G. Bond, and L. Marynowski, "Lower Wenlock black shales in the northern Holy Cross Mountains, Poland: sedimentary and geochemical controls on the Ireviken Event in a deep marine setting," *Geological Magazine*, vol. 154, no. 2, pp. 247–264, 2017.

[91] S. A. Young, A. Kleinberg, and J. D. Owens, "Geochemical evidence for expansion of marine euxinia during an early Silurian (Llandovery-Wenlock boundary) mass extinction," *Earth and Planetary Science Letters*, vol. 513, pp. 187–196, 2019.

[92] D. K. Loydell and R. R. Large, "Biotic, geochemical and environmental changes through the early Sheinwoodian (Wenlock, Silurian) carbon isotope excursion (ESCIE), Buttington Quarry, Wales," *Palaeogeography, Palaeoclimatology, Palaeoecology*, vol. 514, pp. 305–325, 2019.

[93] H. E. Hughes, D. C. Ray, and C. E. Brett, "$\delta^{13}C_{carb}$ data recording the early Sheinwoodian carbon isotope excursion on the Midland Platform, UK," *GFF*, vol. 136, no. 1, pp. 110–115, 2014.

[94] T. H. Torsvik, A. Trench, I. Svensson, and H. J. Walderhaug, "Palaeogeographic significance of mid-Silurian palaeomagnetic results from southern Britain-major revision of the apparent polar wander path for eastern Avalonia," *Geophysical Journal International*, vol. 113, no. 3, pp. 651–668, 1993.