

## The type Ludlow Series: Biostratigraphy - shelly faunas

It has long been recognized that the shelly faunas of the type Ludlow Series constitute a succession of distinct assemblages (e.g. Lawson 1975, and references therein). These formed the basis of the Eltonian, Bringewoodian, Leintwardinian and Whitcliffian stages of Holland *et al.* (1963), terms that are no longer used in a chronostratigraphical sense, but which are reflected in the formation names of the type area.

Watkins (1979) identified six faunal associations throughout the Ludlow successions of the Welsh Borderland (i.e. the type area and the inliers of Ludlow rocks to the south-east). The associations were defined on a spatial basis, as the total fauna of a designated stratigraphical interval (Watkins 1979, p. 210), and are as follows.

*Glassia obovata* Association (lowest)  
*Mesopholidostrophia laevigata* Association  
*Sphaerirhynchia wilsoni* Association (lower phase)  
*Atrypa reticularis*-coral Association  
*Sphaerirhynchia wilsoni* Association (upper phase)  
*Shaleria ornatella* Association  
*Protochonetes ludloviensis* Association (highest)

The *Atrypa reticularis*-coral Association divides the *Sphaerirhynchia wilsoni* Association into lower and upper phases in the inliers south-east of Ludlow, but only the upper phase is represented in the type area.

Only five of these associations were recognized by Watkins in the type Ludlow succession, the *Atrypa reticularis*-coral Association being absent. Watkins & Aithie (1980) added the *Kirkidium knightii* Association, based on faunas from the Upper Bringewood Formation west of Ludlow.

See [‘The use of shelly faunas in stratigraphical correlation’](#) for discussion of stratigraphical applications, and individual associations for details of composition and occurrence.

Holland, C.H., Lawson, J.D & Walmsley, V.G. 1963. The Silurian rocks of the Ludlow district, Shropshire. *Bulletin of the British Museum (Natural History)*, Geology, **8**, 95-171, pls 1-7.

Lawson, J.D. 1975. Ludlow benthonic assemblages. *Palaeontology*, **18**, 509-525.

Watkins, R. 1979. Benthic community organization in the Ludlow Series of the Welsh Borderland. *Bulletin of the British Museum (Natural History)*, Geology, **31**, 175-280.

Watkins, R. & Aithie, C.J. 1980. Carbonate shelf environments and faunal communities in the Upper Bringewood Beds of the British Silurian. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **29**, 341-368.

See: [Atrypa reticularis](#)-coral Association, [Glassia obovata](#) Association, [Kirkidium knightii](#) Association, [Mesopholidostrophia laevigata](#) Association, [Protochonetes ludloviensis](#) Association, [Shaleria ornatella](#) Association, [Sphaerirhynchia wilsoni](#) Association (lower phase), [Sphaerirhynchia wilsoni](#) Association (upper phase), [The use of shelly faunas in stratigraphical correlation](#).

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## **The use of shelly faunas in stratigraphical correlation**

Lawson & White (1989, p. 77) commented that 'Environmentally-controlled benthic species would not be expected to serve as good biozonal index fossils', but pointed out that the Ludlow shelly faunal associations did not cross the biozones of more reliable index fossils. They concluded that the shelly benthos could be used in the correlation of Ludlow rocks of the Welsh Borderland, although it might be of little use outside that area.

Lawson, J.D. & White, D.E. 1989. The Ludlow Series in the Ludlow area. *In* Holland, C.H. & Bassett, M.G. (eds) *A global standard for the Silurian System*. National Museum of Wales, Geological Series No. 9, Cardiff. 73-90.

For further discussion see:

[The succession of Ludlow shelly faunas](#)

[Synchronicity of Ludlow shelly faunas](#)

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[Author: SGM]

## The succession of Ludlow shelly faunas

In general terms, the succession of shelly faunas in the type area can be recognized in other Ludlow shelf successions (data from Watkins 1979). (See '[Stratigraphical relationships of shelly faunal associations](#)'.)

- The *Glassia obovata* Association occurs in the lowest part of the Ludlow (Lower and Middle Elton formations) in the type area, on the dip slope of Wenlock Edge, at Perton Quarry in the Woolhope Inlier, and at Ledbury in the Malverns.
- The *Glassia obovata* Association is succeeded by the *Mesopholidostrophia laevigata* Association at Ludlow, on the dip slope of Wenlock Edge, in Perton Quarry, and at Ledbury. At Perton Quarry and Ledbury, there is a transition through tens of metres of strata from one association to the other (at least 30 m at Perton Quarry, and at least 20 m at Ledbury). At Ludlow and on Wenlock Edge, the *Glassia obovata* and *Mesopholidostrophia laevigata* associations are separated by an interval in which benthic faunas are poorly developed, largely equivalent to the Upper Elton Formation.
- The *Mesopholidostrophia laevigata* Association is represented across the Ludlow shelf, occurring in the west around Ludlow and near Wenlock Edge, and farther east in the Abberley Hills, the Malverns and at Woolhope.
- In the Abberley Hills, the Malverns and at Woolhope, the *Mesopholidostrophia laevigata* Association is succeeded by the lower phase of the *Sphaerirhynchia wilsoni* Association. This is succeeded in turn by the *Atrypa reticularis*-coral Association. Neither the lower phase of the *S. wilsoni* Association nor the *A. reticularis*-coral Association are represented farther west in the type Ludlow succession, where the *Mesopholidostrophia laevigata* Association is succeeded by the upper phase of the *Sphaerirhynchia wilsoni* Association. West of Ludlow, the *Mesopholidostrophia laevigata* Association is interbedded and intergradational with the *Kirkidium knightii* Association (Watkins & Aithie 1980). The latter is considered to be synchronous with the *Atrypa reticularis*-coral Association. (See '[Distribution of upper Gorstian shelly faunal associations](#)'.)
- The upper phase of the *Sphaerirhynchia wilsoni* Association is represented in upper Ludlow strata from the type area near Ludlow, and from the inliers south-east of Ludlow. In all these areas, the *S. wilsoni* Association is succeeded by the *Shaleria ornatella* Association, which is succeeded in turn by the *Protochonetes ludloviensis* Association.

(continued...)

## **The succession of Ludlow shelly faunas (continued)**

Watkins, R. 1979. Benthic community organization in the Ludlow Series of the Welsh Borderland. *Bulletin of the British Museum (Natural History), Geology*, **31**, 175-280.

Watkins, R. & Aithie, C.J. 1980. Carbonate shelf environments and faunal communities in the Upper Bringewood Beds of the British Silurian. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **29**, 341-368.

See: [Stratigraphical relationships of shelly faunal associations](#), [Synchronicity of Ludlow shelly faunas](#), [The use of shelly faunas in stratigraphical correlation](#).

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## Synchronicity of Ludlow shelly faunas

Establishing a pattern in the succession of faunal associations (see [‘The succession of Ludlow shelly faunas’](#)) is only one aspect of the use of shelly faunas in stratigraphical correlation. Establishing synchronicity in the occurrence of associations at separate locations is a second important consideration.

The problem of synchronicity was addressed by Watkins (1979, pp. 181-182, 232, 236-237). He argued that two communities seen in the Ludlow shelf successions south-east of Ludlow (Abberley Hills, Malvern Hills, Woolhope Inlier) could only be explained ecologically if their occurrences across the shelf were considered to be synchronous.

The first of these communities is the restricted *Atrypa reticularis*-coral Association, interposed between lower and upper phases of the *Sphaerirhynchia wilsoni* Association in the eastern inliers. This was considered to be a stratigraphical anomaly, and was interpreted as having occupied a restrictive, back-barrier environment. Only one interval at Ludlow was identified as containing barrier-type deposits, namely the Upper Bringewood Formation with the *Kirkidium knightii* Association, leading Watkins to conclude that deposition of the Upper Bringewood Formation was synchronous with the development of the *A. reticularis*-coral Association in the more easterly inliers. A corollary of this, however, is that the highest occurrence of the *Mesopholidostrophia laevigata* Association is diachronous across the shelf. The *M. laevigata* Association is interbedded with the *K. knightii* Association west of Ludlow, but its highest occurrence lies well below the *A. reticularis*-coral Association in the inliers to the south and east. (See [‘Stratigraphical relationships of shelly faunal associations’](#).)

The second synchronous ecological phenomenon identified by Watkins is the appearance of the *Shaleria ornatella* Association. Watkins (1979, p. 235) argued that this interrupted what would otherwise be a gradation between the *Sphaerirhynchia wilsoni* and *Protochonetes ludloviensis* associations. He also considered it to represent a type of biofacies different from that of the adjacent associations, and so to be anomalous. He concluded that it represented a synchronous ecological event across the entire Ludlow shelf.

Lawson (1975, pp. 523-524) had earlier concluded that diachroneity was not noticeable in shelf successions, but that some Ludlow shelly assemblages were markedly diachronous from shelf to basin.

(continued...)

## Synchronicity of Ludlow shelly faunas (continued)

Lawson, J.D. 1975. Ludlow benthonic assemblages. *Palaeontology*, **18**, 509-525.

Watkins, R. 1979. Benthic community organization in the Ludlow Series of the Welsh Borderland. *Bulletin of the British Museum (Natural History)*, Geology, **31**, 175-280.

See: [Stratigraphical relationships of shelly faunal associations](#), [The succession of Ludlow shelly faunas](#), [The use of shelly faunas in stratigraphical correlation](#).

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## ***Glassia obovata* Association**

### **Fauna**

The *Glassia obovata* Association (Watkins 1979) is dominated by small brachiopods, bivalves and trilobites. Species content is fairly constant, although relative abundances may vary. See [‘Composition of Ludlow shelly faunal associations’](#) for full details.

### **Brachiopods**

The small, probably epiplanktonic strophomenid brachiopod *Aegiria grayi* (Davidson) is most abundant. Also characteristic are small specimens of *Atrypa reticularis* (Linnaeus) and *Craniops implicatus* (J. de C. Sowerby), with *Dalejina*, *Dicoelosia biloba* (Linnaeus), *Glassia obovata* (J. de C. Sowerby), *Isorthis clivosa* Walmsley, *Ludfordina pixis* Kelly, *Parastrophinella*, *Plagiorhyncha*, *Protochonetes minimus* (J. de C. Sowerby), ?*Protozeuga*, *Resserella* and *Skenidioides*. In total, about thirty brachiopod species comprise 85% of individuals in the association, and most are below 15 mm in size.

### **Bivalves**

Bivalves are represented by, among others, small praecardiaceans, considered to have had an epiplanktonic mode of life, and small free-burrowing nuculoids attributed to *Nuculites* and *Praenucula*. In total, twenty-two species of bivalve have been identified from the association, mostly rare and sporadic in occurrence, suggesting small, widely separated populations.

### **Gastropods**

Gastropods are continuously present throughout the association, but are generally rare. The bellerophonaceans *Cymbularia* and *Sphenosphaera*, and the high-spined *Loxonema* and *Sinuspira*, predominate.

### **Cephalopods**

The orthoconic cephalopods ‘*Orthoceras*’ *dimidiatum* (J. de C. Sowerby) and ‘*O.*’ *gregarium* (J. de C. Sowerby) are common components of the association, but decrease in relative numbers eastwards across the Ludlow shelf of the Welsh Borderland. Their distribution pattern suggests a pelagic mode of life. A second group of cephalopods are much rarer. These include species of *Cyrtocycloceras*, ‘*Cyrtoceras*’, *Dawsonoceras* and *Kionoceras*. Their distribution suggests a nektobenthic mode of life.

(continued...)

## ***Glassia obovata* Association: Fauna (continued)**

### **Trilobites**

Characteristic trilobites include *Dalmanites myops* (König), *Leonaspis coronata* (Salter) and *Rhaphiophorus parvulus* (Forbes). *D. myops* comprises 90% of the trilobite fauna, and is the most ubiquitous species of the association. Altogether six species of trilobite have been recorded from the association, their maximum diversity in Ludlow communities.

### **Minor groups**

The hyolithid *Hyolithes forbesi* (Sharpe) is a minor but characteristic component of the association. Ostracodes, crinoid ossicles, bryozoa, solitary corals and tentaculitids occur rarely.

Watkins, R. 1979. Benthic community organization in the Ludlow Series of the Welsh Borderland. *Bulletin of the British Museum (Natural History)*, Geology, **31**, 175-280.

See: [Composition of Ludlow shelly faunal associations, \*Glassia obovata\* Association - Occurrence.](#)

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## ***Glassia obovata* Association**

### **Occurrence**

The *Glassia obovata* Association is represented in the type Ludlow area by faunas from the Lower Elton Formation, for example at Pitch Coppice Quarry and in the Goggin Road section, and by faunas from the Middle Elton Formation of the Goggin Road section.

The association is regarded as appearing at the base of the Ludlow Series, coinciding with the change in facies from the Much Wenlock Limestone Formation to the Lower Elton Formation, but the faunal change is neither abrupt nor fully achieved within the section exposed in Pitch Coppice Quarry, the stratotype for the base of the series.

The highest occurrence of the association in the type area is certainly as high as locality A18 on the Goggin Road, and may be as high as locality A21, both in the Middle Elton Formation. Localities A16-A18 of the Goggin Road section are equivalent to section 2I of Watkins (1979), the higher of two sections in the Middle Elton Formation of the Goggin Road from which he recorded the *Glassia obovata* Association. Section 2J of Watkins (1979), the lower of the two sections, is believed to be equivalent to localities A12-A14.

Watkins (1979) recorded the *Glassia obovata* Association from the lower part of the Ludlow successions near Ledbury in the Malvern Hills and in the Perton area of the Woolhope Inlier, as well as from the Middle Elton Formation of the Ludlow area and at Upper Millichope on the dip slope of Wenlock Edge.

Watkins, R. 1979. Benthic community organization in the Ludlow Series of the Welsh Borderland. *Bulletin of the British Museum (Natural History)*, Geology, **31**, 175-280.

See: [Glassia obovata Association - Fauna, Goggin Road, Pitch Coppice Quarry, Stratigraphical relationships of shelly faunal associations.](#)

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## ***Mesopholidostrophia laevigata* Association**

### **Fauna**

The *Mesopholidostrophia laevigata* Association (Watkins 1979) is the most diverse association of the Ludlow shelf fauna, and is dominated by brachiopods and bryozoa.

See '[Composition of Ludlow shelly faunal associations](#)' for full details.

### **Brachiopods**

Large strophomenid brachiopods, for example *Amphistrophia funiculata* (M'Coy), *Leptaena depressa* (J. de C. Sowerby), *Mesopholidostrophia laevigata* (J. de C. Sowerby) and *Strophonella euglypha* (Hisinger), are conspicuous elements of the association, constituting about a third of the total fauna. Also present is the small strophomenid *Shagamella minor* (Salter), locally abundant and possibly epiplanktonic. Species of *Isorthis*, *Howellella*, *Gypidula*, *Sphaerirhynchia* and *Atrypa* are important elements of the brachiopod fauna. Any one of several species may dominate the brachiopod fauna at specific levels, although no single species dominates extensive stratigraphical intervals.

### **Bryozoa**

Bryozoa comprise a significant proportion of the association, 7% according to Watkins (1979, p. 226), with a high species diversity. Lamellose, globular and ramose colonies occur. Lamellose colonies encrust shell fragments, and also grew partially or wholly on the sediment surface.

### **Bivalves**

Bivalves comprise only 2% of the association according to Watkins (1979, p. 226), but are represented by at least 22 species. Most species occur in small numbers at wide stratigraphical intervals. Watkins (1979) concluded that they must have had small, geographically restricted populations.

### **Gastropods**

Nine species of gastropods comprise about 2% of the association. *Bembexia lloydi* (J. de C. Sowerby), *Leptozone striatissima* (Salter) and *Oriostoma* sp. are characteristic forms.

### **Cephalopods**

Rare cephalopods, interpreted as nektobenthic forms, are present.

(continued...)

## ***Mesopholidostrophia laevigata* Association: Fauna (continued)**

### **Trilobites**

Trilobites comprise a minor component of the association, but occur continuously throughout the stratigraphical profile. *Dalmanites myops* (König) comprises about 40% of the trilobite fauna, accompanied by encrinurids, calymenids and proetids.

### **Minor groups**

Tentaculites, cornulites and conularids are represented by single species, and occur sporadically. Rare ceratiocarid crustaceans may also belong to this association. Solitary trochoid corals, the solitary coral *Rhabdocyclus porpitoides* (Lang & Smith) and syringoporids are rare. Ostracodes are locally common. Crinoids, rare echinoids and an ophiuroid are also represented.

Watkins, R. 1979. Benthic community organization in the Ludlow Series of the Welsh Borderland. *Bulletin of the British Museum (Natural History)*, Geology, **31**, 175-280.

See: [Composition of Ludlow shelly faunal associations, \*Mesopholidostrophia laevigata\* Association - Occurrence.](#)

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## ***Mesopholidostrophia laevigata* Association**

### **Occurrence**

Watkins (1979, fig. 16) recorded the *Mesopholidostrophia laevigata* Association from the Lower Bringewood and Upper Bringewood formations in his sections 2D, 2E and 2F of the Ludlow area.

Section 2F is the original basal boundary stratotype for the base of the Lower Bringewood Formation in the Mary Knoll Valley ([SO 4873 7292]; locality 196 of Holland *et al.* 1963, p. 141, fig. 12). The incoming of the *Mesopholidostrophia laevigata* Association was depicted by Watkins (1979, fig. 16) as coinciding with the base of the Lower Bringewood Formation. In the Goggin Road section, about 1.5 km SW of the original basal stratotype, characteristic species of the association appear over an extended interval, from the top of the Upper Elton Formation (locality A28) through the lowest 12 m of the Lower Bringewood Formation (up to locality A31).

Section 2E of Watkins (1979) is within the Upper Bringewood Formation exposed on the south side of the Whitcliffe Spur Road [SO 4722 7376].

Section 2D is at Sunnyhill Quarry where Watkins (1979, fig. 16) placed the top of the *Mesopholidostrophia laevigata* Association just over 1 m below the top of the Upper Bringewood Formation, above the last common occurrences of *Gypidula lata* Alexander, *Mesopholidostrophia laevigata* (J. de C. Sowerby), *Dalejina hybrida* (J. de C. Sowerby), *Leptostrophia filosa* (J. de C. Sowerby), *Leptaena*, stropheodontid brachiopods and solitary corals, and below the level at which a sharp increase occurs in the abundance of *Isorthis*, *Dayia navicula* (J. de C. Sowerby) and *Microsphaeridiorhynchus nucula* (J. de C. Sowerby). This differs slightly from the level determined by Lawson & White (1989) for the faunal change from the *Mesopholidostrophia laevigata* Association to the *Sphaerirhynchia wilsoni* Association, at the Upper Bringewood Formation - Lower Leintwardine Formation boundary.

Faunas characteristic of the *Mesopholidostrophia laevigata* Association also occur in the Lower Bringewood and Upper Bringewood formations of the Deer Park Road section, and Watkins & Aithie (1980, fig. 14) showed the association to have a wide distribution in the Upper Bringewood Formation west of Ludlow, in places intergrading and interbedded with the *Kirkidium knightii* Association. (See '[Distribution of upper Gorstian shelly faunal associations](#)'.)

The *Mesopholidostrophia laevigata* Association also occurs in the Abberley, Malvern and Woolhope areas (Watkins 1979, fig. 2). The stratigraphical extent of the association in these areas is considered to be less than in the Ludlow area, and it is restricted to equivalents of the lower part of the Lower Bringewood Formation. (See '[Stratigraphical relationships of shelly faunal associations](#)', '[Synchronicity of Ludlow shelly faunas](#)'.)

(continued...)

### ***Mesopholidostrophia laevigata* Association: Occurrence (continued)**

- Holland, C.H., Lawson, J.D & Walmsley, V.G. 1963. The Silurian rocks of the Ludlow district, Shropshire. *Bulletin of the British Museum (Natural History)*, Geology, **8**, 95-171, pls 1-7.
- Watkins, R. 1979. Benthic community organization in the Ludlow Series of the Welsh Borderland. *Bulletin of the British Museum (Natural History)*, Geology, **31**, 175-280.
- Watkins, R. & Aithie, C.J. 1980. Carbonate shelf environments and faunal communities in the Upper Bringewood Beds of the British Silurian. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **29**, 341-368.

See: [Deer Park Road, Goggin Road, \*Kirkidium knightii\* Association, \*Mesopholidostrophia laevigata\* Association - Fauna, Stratigraphical relationships of shelly faunal associations, Sunnyhill Quarry.](#)

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## ***Sphaerirhynchia wilsoni* Association (lower phase)**

### **Fauna**

The *Sphaerirhynchia wilsoni* Association (Watkins 1979) has the widest ecological range of any of the benthic associations recognized in the Ludlow shelf fauna, and has two separate stratigraphical occurrences, a lower phase in the eastern Silurian inliers of the Welsh Borderland (Woolhope, Malvern and Abberley areas), and an upper phase distributed more widely throughout the Welsh Borderland. (See '[Stratigraphical relationships of shelly faunal associations](#)'.)

The lower phase of the association resembles the *Mesopholidostrophia laevigata* Association in being dominated by brachiopods and bryozoa. The two associations have certain other features in common, for example the trilobite and coral elements of their faunas. The brachiopod fauna of the lower phase of the *S. wilsoni* Association differs from that of the *M. laevigata* Association in having fewer large strophomenid brachiopods. The stratigraphical boundary between the *M. laevigata* Association and lower phase of the *S. wilsoni* Association in the Malvern and Abberley sections is marked by the disappearance, or a sharp reduction in abundance and frequency of occurrence, of species of '*Schuchertella*', *Strophonella*, *Amphistrophia*, *Mesopholidostrophia*, *Leptostrophia*, *Gypidula* and *Eospirifer*. At the same level, or slightly higher, *Sphaerirhynchia wilsoni* (J. Sowerby), *Microsphaeridiorhynchus nucula* (J. de C. Sowerby) and *Howellella elegans* (Muir-Wood) increase in abundance, and become the dominant species. These changes in the brachiopod fauna occur over a stratigraphical interval of about 5 m, are not accompanied by either a change in the lithofacies or by changes in the composition of the other faunal elements of the association, and represent a permanent alteration in the brachiopod fauna.

See '[Composition of Ludlow shelly faunal associations](#)' for full details.

### **Brachiopods**

Twenty-seven species of brachiopods comprise 81% of the total fauna of the lower phase, the dominant forms being species of *Sphaerirhynchia*, *Atrypa*, *Howellella*, *Microsphaeridiorhynchus*, *Dalejina* and *Isorthis*. Stratigraphical patterns of abundance are similar to those of the *M. laevigata* Association. The lower phase of the *S. wilsoni* Association is also characterized by the occurrence in low numbers of species that are dominant in the *M. laevigata* Association.

### **Bryozoa**

Bryozoa comprise 9% of the total fauna of the lower phase, and show the same diversity and morphological forms as those of the *M. laevigata* Association.

(continued...)

## ***Sphaerirhynchia wilsoni* Association (lower phase): Fauna (continued)**

### **Bivalves**

Bivalves comprise 2% of the fauna of the lower phase. The seventeen species recorded are known also from the *M. laevigata* Association, and have the same sporadic pattern of occurrence.

### **Gastropods**

The gastropod fauna of the lower phase is a continuation of that of the *M. laevigata* Association, with the same sporadic pattern of occurrence.

### **Cephalopods**

Cephalopods are a minor component of the lower phase of the *S. wilsoni* Association.

### **Trilobites**

Trilobites are a minor component of the lower phase of the *S. wilsoni* Association, but occur fairly consistently. They comprise the same species as those present in the *M. laevigata* Association, and are dominated by *Dalmanites myops* (König).

### **Minor Groups**

Tentaculites and cornulites are each represented sporadically by a single species. The coral fauna of the *M. laevigata* Association is present in small numbers. Ostracodes occur sporadically, and crinoids columnals are locally abundant.

Watkins, R. 1979. Benthic community organization in the Ludlow Series of the Welsh Borderland. *Bulletin of the British Museum (Natural History)*, Geology, **31**, 175-280.

See: [Composition of Ludlow shelly faunal associations, \*Sphaerirhynchia wilsoni\* Association \(lower phase\) - Occurrence.](#)

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## ***Sphaerirhynchia wilsoni* Association (lower phase)**

### **Occurrence**

The lower phase of the *Sphaerirhynchia wilsoni* Association occurs in the inliers south-east of Ludlow. It was recorded from the Abberley, Malvern and Woolhope areas by Watkins (1979). Based on the inferred relationship between the *Atrypa reticularis*-coral Association of the eastern inliers and the *Kirkidium knightii* Association of the Ludlow area (see '[Stratigraphical relationships of shelly faunal associations](#)', '[Synchronicity of Ludlow shelly faunas](#)'), the lower phase of the association is considered to pass westwards into the *Mesopholidostrophia laevigata* Association. It succeeds the *Mesopholidostrophia laevigata* Association in the eastern inliers.

Watkins, R. 1979. Benthic community organization in the Ludlow Series of the Welsh Borderland. *Bulletin of the British Museum (Natural History)*, Geology, **31**, 175-280.

See: [Sphaerirhynchia wilsoni Association \(lower phase\) - Fauna, Stratigraphical relationships of shelly faunal associations.](#)

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## ***Atrypa reticularis*-coral Association**

### **Fauna**

The *Atrypa reticularis*-coral Association of Watkins (1979) is a low-diversity community, dominated by *Atrypa reticularis* and solitary trochoid corals. See '[Composition of Ludlow shelly faunal associations](#)' for full details.

### **Brachiopods**

*Atrypa reticularis* (Linnaeus) is the only common brachiopod of the association, comprising 45% of the sampled fauna, although its actual abundance per sample may fluctuate from less than 5% to more than 70%. Other brachiopods comprise species that are more common in the upper and lower phases of the *Sphaerirhynchia wilsoni* Association, such as *S. wilsoni* (J. Sowerby), *Howellella elegans* (Muir-Wood) and *Microsphaeridiorhynchus nucula* (J. de C. Sowerby), accompanied by rare strophomenids that persist from the *Mesopholidostrophia laevigata* Association, notably *Strophonella euglypha* (Hisinger), *Amphistrophia funiculata* (M'Coy) and *M. laevigata* (J. de C. Sowerby) (last occurrences at this level). Although many brachiopod species range through the *Atrypa reticularis*-coral Association, their frequency of occurrence and abundance are much reduced in this interval.

### **Corals**

The coral fauna of the association consists almost wholly of solitary trochoid corals, generally comprising 16% of the sampled fauna, but reaching 70% locally.

### **Minor groups**

Bryozoa comprise 15% of the association, consisting of the same forms as the fauna in the *Mesopholidostrophia laevigata* Association. Crinoid ossicles and the gastropod *Oriostoma* are locally common, the latter comprising about 4% of individuals. Small calcareous algae are present. Bivalves, cephalopods, tentaculites and trilobites comprise less than 1% of the association, and consist of species more commonly found in the *Sphaerirhynchia wilsoni* Association.

Watkins, R. 1979. Benthic community organization in the Ludlow Series of the Welsh Borderland. *Bulletin of the British Museum (Natural History)*, Geology, **31**, 175-280.

See: [Atrypa reticularis-coral Association - Occurrence, Composition of Ludlow shelly faunal associations](#).

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[Author: SGM]

## ***Atrypa reticularis*-coral Association**

### **Occurrence**

The *Atrypa reticularis*-coral Association separates the lower and upper phases of the *Sphaerirhynchia wilsoni* Association in the Woolhope, Malvern and Abberley areas. The *Atrypa reticularis*-coral Association is considered to be synchronous with the *Kirkidium knightii* Association of the Ludlow area (see '[Stratigraphical relationships of shelly faunal associations](#)', '[Synchronicity of Ludlow shelly faunas](#)').

See: [Atrypa reticularis-coral Association - Fauna](#).

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[Author: SGM]

## ***Kirkidium knightii* Association**

### **Fauna**

The *Kirkidium knightii* Association, introduced by Watkins & Aithie (1980), represents a community that occupied high-energy, shelf-edge environments west of Ludlow. It shares most of its taxa with the *Mesopholidostrophia laevigata* Association, but is characterized by coquinas of *K. knightii* (J. Sowerby). It represents temporary abundances of *Kirkidium* within stratigraphical sections containing the *M. laevigata* Association. Intergradation of the two associations is apparent on faunal logs from Aymestrey, Todding and View Edge, west of Ludlow (Watkins & Aithie 1980). Crinoids and brachiopods are the dominant groups. Tabulate corals and stromatoporoids are well represented. Minor groups include trilobites, sponges, bryozoans, ostracodes, gastropods, tetracorals, bivalves and cephalopods.

The following account is based on Watkins & Aithie, 1980, table 1. See [‘Composition of Ludlow shelly faunal associations’ for full details](#).

### **Brachiopods**

*Kirkidium knightii* dominates the brachiopod fauna. *Atrypa reticularis* (Linnaeus) is common, followed in decreasing order of abundance by *Strophonella euglypha* (Hisinger), *Sphaerirhynchia wilsoni* (J. Sowerby), *Gypidula lata* Alexander, *Leptaena depressa* (J. de C. Sowerby), *Mesopholidostrophia laevigata* (J. de C. Sowerby), *Isorthis clivosa* Walmsley, *Leptostrophia filosa* (J. de C. Sowerby), *Lingula lewisii* J. de C. Sowerby, *Amphistrophia funiculata* (M’Coy), *Dayia navicula* (J. de C. Sowerby), *Eospirifer radiatus* (J. de C. Sowerby), *Howellella elegans* (Muir-Wood) and *Shagamella minor* (Salter). It is apparent from this list that strophomenid brachiopods are well represented in the fauna.

### **Bryozoa**

Bryozoa are poorly represented, in contrast to the *Mesopholidostrophia laevigata* Association.

### **Bivalves**

Bivalves are poorly represented, with only two species, *Actinopteria sowerbyi* (M’Coy) and *Goniophora cymbaeformis* (J. de C. Sowerby).

### **Trilobites**

The trilobites are represented by rare specimens of *Dalmanites myops* (König).

(continued...)

## ***Kirkidium knightii* Association: Fauna (continued)**

### **Minor groups**

Sponges, ostracodes, gastropods, solitary trochoid corals and cephalopods comprise minor elements of the fauna, in addition to bryozoans, bivalves and trilobites.

Watkins, R. & Aithie, C.J. 1980. Carbonate shelf environments and faunal communities in the Upper Bringewood Beds of the British Silurian. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **29**, 341-368.

See: [Composition of Ludlow shelly faunal associations, \*Kirkidium knightii\* Association - Occurrence.](#)

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[Author: SGM]

## ***Kirkidium knightii* Association**

### **Occurrence**

The original description of the *Kirkidium knightii* Association (Watkins & Aithie 1980) restricted it to the Upper Bringewood Formation at the edge of the Ludlow shelf, about 10 km W of Ludlow (see '[Distribution of upper Gorstian shelly faunal associations](#)'). There, it is represented in facies 5 and 6 of Watkins & Aithie (1980). In facies 5, closely packed *Kirkidium* valves occur in tabular limestones (biocalcarenes), 10 cm or less thick with sharply defined erosional bases, and are interpreted as having been transported *en masse* from shell banks during storms. Thick tabular beds (e.g. 1 m) of closely packed *Kirkidium* valves are characteristic of facies 6. These beds have gradational upper and lower contacts, and are interpreted as lag deposits formed from dense populations of *Kirkidium* living at or near the site of shell accumulation.

White & Lawson (1978) reported *Kirkidium knightii* (J. Sowerby) to be very common in a 10 cm band, 1.2 m above the base of the Upper Bringewood Formation, at locality B8 of the Deer Park Road section. This may represent an instance of the *Kirkidium knightii* Association east of Watkins & Aithie's (1980) records. Other occurrences of *Kirkidium knightii* nearer Ludlow are reported to comprise scattered specimens, for example in the Upper Bringewood Formation of the Sunnyhill Quarry section (White & Lawson 1978). *Kirkidium knightii* has been recorded from faunas assigned to the *Mesopholidostrophia laevigata* Association (Watkins & Aithie 1980, table 1), so these scattered occurrences probably indicate that association rather than the *Kirkidium knightii* Association.

Lawson & White (1989, fig. 52) showed the *Kirkidium knightii* Association to occur throughout the Upper Bringewood Formation at Ludlow, replacing a *Mesopholidostrophia* Association present in the Lower Bringewood Formation. This is a simplification of the situation described by Watkins & Aithie (1980). The latter authors clearly indicated the *Kirkidium knightii* Association to be interbedded with, and to grade into the *Mesopholidostrophia laevigata* Association in the Upper Bringewood Formation, so the *M. laevigata* Association is present in both the Lower Bringewood and Upper Bringewood formations of the type Ludlow succession. *Kirkidium knightii* is restricted to the Upper Bringewood Formation, however, and together with tabulate corals and stromatoporoids, distinguishes Upper Bringewood faunas from Lower Bringewood faunas.

The *Kirkidium knightii* Association is considered to be synchronous with the *Atrypa reticularis*-coral Association of the eastern Ludlow shelf (see '[Stratigraphical relationships of shelly faunal associations](#)', '[Synchronicity of Ludlow shelly faunas](#)').

(continued...)

### ***Kirkidium knightii* Association: Occurrence (continued)**

- Lawson, J.D. & White, D.E. 1989. The Ludlow Series in the Ludlow area. *In* Holland, C.H. & Bassett, M.G. (eds) *A global standard for the Silurian System*. National Museum of Wales, Geological Series No. **9**, Cardiff. 73-90.
- Watkins, R. & Aithie, C.J. 1980. Carbonate shelf environments and faunal communities in the Upper Bringewood Beds of the British Silurian. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **29**, 341-368.
- White, D.E. & Lawson, J.D. 1978. The stratigraphy of new sections in the Ludlow Series of the type area, Ludlow, Salop, England. *Report of the Institute of Geological Sciences*, No. **78/30**, 1-10.

See: [Deer Park Road, \*Kirkidium knightii\* Association - Fauna, \*Mesopholidostrophia laevigata\* Association, Sunnyhill Quarry.](#)

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[Author: SGM]

## ***Sphaerirhynchia wilsoni* Association (upper phase)**

### **Fauna**

The *Sphaerirhynchia wilsoni* Association (Watkins 1979) has the widest ecological range of any of the benthic associations recognized in the Ludlow shelf fauna, and has two separate stratigraphical occurrences, a lower phase in the eastern Silurian inliers of the Welsh Borderland (Woolhope, Malvern and Abberley areas), and an upper phase distributed more widely throughout the Welsh Borderland (see '[Stratigraphical relationships of shelly faunal associations](#)'). A coquinoid occurrence is typical of the shelly fauna from the upper phase of the *Sphaerirhynchia wilsoni* Association.

See '[Composition of Ludlow shelly faunal associations](#)' for full details.

### **Brachiopods**

A total of nineteen brachiopod species have been reported from the upper phase of the *Sphaerirhynchia wilsoni* Association. Common forms include *Salopina lunata* (J. de C. Sowerby), *Isorthis*, *Protochonetes ludloviensis* Muir-Wood, *Shaleria ornatella* (Davidson), *Sphaerirhynchia wilsoni* (J. Sowerby), *Microsphaeridiorhynchus nucula* (J. de C. Sowerby), *Hyattidina canalis* (J. de C. Sowerby) and *Howellella elegans* (Muir-Wood). Any one of these species may comprise more than 70% of the fauna in individual samples. Extreme fluctuations in relative abundances may occur over stratigraphical intervals of a few centimetres, and major changes in the composition of the brachiopod fauna can occur over distances of about a metre on a single bedding plane.

### **Bryozoa**

Compared with the lower phase of the association, bryozoa decline to 3% of the fauna in the upper phase, and are represented mainly by ramose growth forms, with few of the varied colonies represented in the *Mesopholidostrophia laevigata* Association and the lower phase of the *Sphaerirhynchia wilsoni* Association.

### **Bivalves**

Bivalves generally constitute 5% of the fauna from the upper phase of the association, reaching local abundances of 20%. A total of fifteen species have been recorded, dominant forms being '*Paracyclas*' *insueta* Reed, *Nuculites antiqua* (J. de C. Sowerby), *Pteronitella retroflexa* (Wahlenberg) and *Fuchsella amygdalina* (J. de C. Sowerby).

### **Gastropods**

Six species of gastropod in the upper phase of the association have a sporadic stratigraphical pattern of occurrence.

(continued...)

## ***Sphaerirhynchia wilsoni* Association (upper phase): Fauna (continued)**

### **Cephalopods**

Cephalopods are a minor component of the upper phase of the *Sphaerirhynchia wilsoni* Association, comprising less than 1% of the fauna.

### **Trilobites**

The trilobite fauna from the lower phase of the *Sphaerirhynchia wilsoni* Association is not represented in the upper phase, which generally contains only rare proetids and *Acastella spinosa* (Salter). *Calymene* and *Encrinurus* may appear in the upper part of the association, heralding the fauna of the *Shaleria ornatella* Association.

### **Minor groups**

Tentaculites and cornulites are each represented sporadically by a single species, in each case the same species as in the lower phase of the association. The coral fauna of the lower phase (and the *Mesopholidostrophia laevigata* Association) is absent. The tubiculous annelid *Serpulites longissimus* J. de C. Sowerby is present, but rare. Ostracodes generally occur sporadically and are not consistently present, but become extremely abundant at some levels. Crinoids columnals are locally abundant. Eurypterids are rare.

Watkins, R. 1979. Benthic community organization in the Ludlow Series of the Welsh Borderland. *Bulletin of the British Museum (Natural History)*, Geology, **31**, 175-280.

See: [Composition of Ludlow shelly faunal associations, \*Sphaerirhynchia wilsoni\* Association \(upper phase\) - Occurrence.](#)

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[Author: SGM]



## ***Sphaerirhynchia wilsoni* Association (upper phase)**

### **Occurrence**

Watkins (1979, fig. 16) recorded the upper phase of the *Sphaerirhynchia wilsoni* Association from his sections 2D and 2C in the Ludlow type area.

In section 2D, at Sunnyhill Quarry, Watkins (1979, fig. 16) placed the change from the *Mesopholidostrophia laevigata* Association to the *Sphaerirhynchia wilsoni* Association just over 1 m below the base of the Lower Leintwardine Formation, above the last common occurrences of *Gypidula lata* Alexander, *Mesopholidostrophia laevigata* (J. de C. Sowerby), *Dalejina hybrida* (J. de C. Sowerby), *Leptostrophia filosa* (J. de C. Sowerby), *Leptaena*, stropheodontid brachiopods and solitary corals, and below the level at which he recorded a sharp increase in the abundance of *Isorthis*, *Dayia navicula* (J. de C. Sowerby) and *Microsphaeridiorhynchus nucula* (J. de C. Sowerby). He noted that the changes took place through a stratigraphical interval of about 2 m.

Lawson & White (1989, figs 61, 62), however, recorded *Kirkidium knightii* (J. Sowerby) from bed C8, immediately below the base of the Lower Leintwardine Formation in Sunnyhill Quarry. In addition, Cherns (1988, text-fig. 5) showed solitary rugose corals to persist into the lowest part of the Lower Leintwardine Formation. The change from the *Mesopholidostrophia laevigata* Association to the *Sphaerirhynchia wilsoni* Association at Sunnyhill Quarry, might therefore be regarded as transitional across the Upper Bringewood to Lower Leintwardine Formation boundary. (See '[Stratigraphical relationships of shelly faunal associations](#)'.)

Section 2C of Watkins (1979) includes the basal boundary stratotype for the Upper Leintwardine Formation on The Whitcliffe. Watkins (1979, p. 236, fig. 16) placed the base of the *Shaleria ornatella* Association about 2 m below the base of the Upper Leintwardine Formation, coinciding with an increase in the relative abundance of *Leptaena* and *Shaleria ornatella* (Davidson), and a sharp decrease in the relative abundance of *Dayia navicula*. The faunas below this level represent the *Sphaerirhynchia wilsoni* Association.

Faunas characteristic of the upper phase of the *Sphaerirhynchia wilsoni* Association are also present in the Lower Leintwardine Formation of the Deer Park Road section.

In the inliers south-east of Ludlow, Watkins (1979) recorded the upper phase of the *Sphaerirhynchia wilsoni* Association above the *Atrypa reticularis*-coral Association in the Abberley, Malvern and Woolhope areas. (See '[Stratigraphical relationships of shelly faunal associations](#)'.)

(continued...)

### ***Sphaerirhynchia wilsoni* Association (upper phase): Occurrence (continued)**

- Cherns, L. 1988. Faunal and facies dynamics in the upper Silurian of the Anglo-Welsh basin. *Palaeontology*, **31**, 451-502.
- Lawson, J.D. & White, D.E. 1989. The Ludlow Series in the Ludlow area. *In* Holland, C.H. & Bassett, M.G. (eds) *A global standard for the Silurian System*. National Museum of Wales, Geological Series No. **9**, Cardiff. 73-90.
- Watkins, R. 1979. Benthic community organization in the Ludlow Series of the Welsh Borderland. *Bulletin of the British Museum (Natural History)*, Geology, **31**, 175-280.

See: [Deer Park Road, \*Sphaerirhynchia wilsoni\* Association \(upper phase\) - Fauna, Sunnyhill Quarry, The Whitcliffe.](#)

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[Author: SGM]

## ***Shaleria ornatella* Association**

### **Fauna**

The *Shaleria ornatella* Association (Watkins 1979) is the fauna that characterizes the Upper Leintwardine Formation of the type Ludlow area. It has a restricted vertical extent of about 8 m at Ludlow, and 1 to 5 m in the shelf successions in the Woolhope, Abberley and Malvern areas. The association is present in every upper Ludlow succession in the Welsh Borderland, and can be correlated with successions on the margin of the Welsh Basin.

The *S. ornatella* Association occupies a stratigraphical position between the upper phase of the *Sphaerirhynchia wilsoni* Association and the *Protochonetes ludloviensis* Association, interrupting what would otherwise be an ecological gradation between them. It is marked by the return of forms that characterize lower parts of the Ludlow shelf succession, and resembles the *Mesopholidostrophia laevigata* Association in the prominence of strophomenid brachiopods. The presence of the bivalves *Cypricardinia subplanulata* Reed and *Mytilarca siluriana* Reed also recalls the *M. laevigata* Association, although the dominant bivalve species are the same as those in the upper phase of the *S. wilsoni* Association (Watkins 1979, p. 235). Although they are not necessarily abundant, arthropods comprise important elements of the fauna, notably the trilobites *Calymene puellaris* Reed and *Encrinurus stubblefieldi* Tripp, and the ostracode *Neobeyrichia lauensis* (Kiesow). The coquinoid occurrence of fossils is typical.

According to Watkins (1979, pp. 235, 240), the lower and upper boundaries of the *S. ornatella* Association are sharp enough to be located within centimetres. The base of the association occurs 2 m below the base of the Upper Leintwardine Formation at the latter's type locality on The Whitcliffe (Watkins 1979, p. 236).

See '[Composition of Ludlow shelly faunal associations](#)' for full details.

### **Brachiopods**

*Shaleria ornatella* (Davidson) occurs in low abundance throughout the *Mesopholidostrophia laevigata* Association, is rare in the *Sphaerirhynchia wilsoni* Association, but returns in great abundance in the *Shaleria ornatella* Association across the Welsh Borderland. Other strophomenids with a similar distribution pattern are *Leptaena depressa* (J. de C. Sowerby) and *Lepidoleptaena* sp. Other common brachiopods include *Atrypa reticularis* (Linnaeus), *Dayia navicula* (J. de C. Sowerby) and *Isorthis* (*I. orbicularis* according to Lawson & White 1989; *I. clivosa* according to Watkins 1979), all of which are absent or rare above this association, as well as *Microsphaeridiorhynchus nucula* (J. de C. Sowerby), *Protochonetes ludloviensis* Muir-Wood and *Salopina lunata* (J. de C. Sowerby) which characterize the overlying association. *Shaleria ornatella* has an acme in the east of the type Ludlow area, and *Aegiria grayi* (Davidson) has an acme in the west (Lawson & White 1989).

(continued...)

## ***Shaleria ornatella* Association: Fauna (continued)**

### **Bivalves**

Bivalves are the second most abundant faunal group of the association, comprising 7% of the shelly fauna. The bivalve fauna of the *Shaleria ornatella* Association is a continuation of that in the upper phase of the *Sphaerirhynchia wilsoni* Association, with the same dominant species ('*Paracyclas*' *insueta* Reed, *Nuculites antiqua* (J. de C. Sowerby), *Pteronitella retroflexa* (Wahlenberg) and *Fuchsella amygdalina* (J. de C. Sowerby)). However, *Cypricardinia subplanulata* and *Mytilarca siluriana*, common in the *Mesopholidostrophia laevigata* Association, reappear after being absent from the *Sphaerirhynchia wilsoni* Association.

### **Trilobites**

Trilobites are characteristic of the *Shaleria ornatella* Association. They are present throughout, albeit in small numbers, comprising only about 1% of the fauna. *Calymene puellaris*, *Encrinurus stubblefieldi* and proetids are the principal forms.

### **Minor groups**

Minor groups include ramose bryozoans, gastropods, cephalopods, tentaculites, cornulites, ostracodes and crinoid ossicles. Although ostracodes are included among the minor components of the association, they include the stratigraphically important species *Neobeyrichia lauensis*.

Lawson, J.D. & White, D.E. 1989. The Ludlow Series in the Ludlow area. In Holland, C.H. & Bassett, M.G. (eds) *A global standard for the Silurian System*. National Museum of Wales, Geological Series No. 9, Cardiff. 73-90.

Watkins, R. 1979. Benthic community organization in the Ludlow Series of the Welsh Borderland. *Bulletin of the British Museum (Natural History)*, Geology, **31**, 175-280.

See: [Composition of Ludlow shelly faunal associations, \*Neobeyrichia lauensis\*, \*Shaleria ornatella\* Association - Occurrence.](#)

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[Author: SGM]

## ***Shaleria ornatella* Association**

### **Occurrence**

On The Whitcliffe, Watkins (1979, fig. 16, section 2C; see also Watkins 1979, p. 236) placed the base of the *Shaleria ornatella* Association about 2 m below the base of the Upper Leintwardine Formation, coinciding with an increase in the relative abundance of *Leptaena* and *Shaleria ornatella* (Davidson), and a sharp decrease in the relative abundance of *Dayia navicula* (J. de C. Sowerby). The base of the Upper Leintwardine Formation, in its basal boundary stratotype on The Whitcliffe, coincides with the occurrence of *Aegiria grayi* (Davidson), *Calymene puellaris* Reed and *Encrinurus* (Holland *et al.* 1963; Siveter *et al.* 1989, p. 43; *Encrinurus* sp. subsequently identified as *E. stubblefieldi* Tripp by Watkins, 1979, p. 236). These taxa are characteristic of the *Shaleria ornatella* Association. The change from the *Shaleria ornatella* Association to the overlying *Protochonetes ludloviensis* Association on The Whitcliffe coincides with the boundary between the Upper Leintwardine and Lower Whitcliffe formations.

Many of the characteristic *Shaleria ornatella* Association forms appear just below the base of the Upper Leintwardine Formation on the range chart published for the Sunnyhill section by Cherns (1988, text-fig. 5). For example, *Aegiria grayi* occurs sporadically in the Upper Bringewood and Lower Leintwardine formations, and *Calymene* in the upper part of the Lower Leintwardine Formation, before they both become more persistent less than 1 m below the base of the Upper Leintwardine Formation; *Encrinurus* and *Neobeyrichia* both occur persistently in the highest metre of the Lower Leintwardine Formation and in the Upper Leintwardine Formation; and *Shaleria ornatella* has a persistent occurrence from the upper part of the Lower Leintwardine Formation, from about the level of C22, across the base of the Upper Leintwardine Formation (Cherns 1988, text-fig. 5). It should be noted, however, that the species of *Calymene*, *Encrinurus* and *Neobeyrichia* in the Sunnyhill section were not recorded by Cherns.

White & Lawson (1978) and Siveter *et al.* (1989, p. 57) have indicated that the characteristic arthropod species of the *Shaleria ornatella* Association, namely *Calymene puellaris*, *Encrinurus stubblefieldi* and *Neobeyrichia lauensis* (Kiesow), occur in the Upper Leintwardine Formation of the Sunnyhill track section.

In the Deer Park Road section, *Aegiria grayi*, *Encrinurus* and *Neobeyrichia* appear in the upper part of the Lower Leintwardine Formation (Cherns 1988, text-fig. 6), although the species of *Encrinurus* and *Neobeyrichia* were not recorded. *Aegiria grayi*, *Shaleria ornatella*, *Calymene puellaris*, *Encrinurus stubblefieldi* and *Neobeyrichia lauensis*, indicative of the *Shaleria ornatella* Association, occur at locality B38 in the Upper Leintwardine Formation (White & Lawson 1978, Siveter *et al.* 1989).

(continued...)

## ***Shaleria ornatella* Association: Occurrence (continued)**

Holland *et al.* (1963, p. 117) noted that thin, dark brown, biscuity layers, crowded with weathered specimens of *Aegiria grayi*, *Dayia navicula* (J. de C. Sowerby), *Calymene puellaris*, *Encrinurus* sp. and *Neobeyrichia lauensis*, are characteristic of the Upper Leintwardine Formation in the west of the type Ludlow area, and that such a development is typical of the basin facies.

Watkins (1979) recorded the *Shaleria ornatella* Association from the Abberley, Malvern and Woolhope areas, in each case situated stratigraphically between the upper phase of the *Sphaerirhynchia wilsoni* Association and the *Protochonetes ludloviensis* Association. Watkins (1979, p. 236) argued that that the *Shaleria ornatella* Association resulted from an ecological event which brought a distal shelf fauna into a proximal shelf environment. He concluded that occurrences of the *S. ornatella* Association must therefore be synchronous across the Ludlow shelf (although Cherns' (1988, p. 497) observation that *S. ornatella* itself was strongly concentrated in inshore to mid-shelf regions and virtually absent from offshore shelf regions should be noted).

Cherns, L. 1988. Faunal and facies dynamics in the upper Silurian of the Anglo-Welsh basin. *Palaeontology*, **31**, 451-502.

Holland, C.H., Lawson, J.D & Walmsley, V.G. 1963. The Silurian rocks of the Ludlow district, Shropshire. *Bulletin of the British Museum (Natural History)*, Geology, **8**, 95-171, pls 1-7.

Siveter, D.J., Owens, R.M. & Thomas, A.T. 1989. *Silurian field excursions: a geotraverse across Wales and the Welsh Borderland*. National Museum of Wales, Geological Series No. **10**, Cardiff. 133pp.

Watkins, R. 1979. Benthic community organization in the Ludlow Series of the Welsh Borderland. *Bulletin of the British Museum (Natural History)*, Geology, **31**, 175-280.

White, D.E. & Lawson, J.D. 1978. The stratigraphy of new sections in the Ludlow Series of the type area, Ludlow, Salop, England. *Report of the Institute of Geological Sciences*, No. **78/30**, 1-10.

See: [Deer Park Road, \*Shaleria ornatella\* Association - Fauna, Stratigraphical relationships of shelly faunal associations, Sunnyhill Quarry, The Whitcliffe.](#)

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[Author: SGM]

## ***Protochonetes ludloviensis* Association**

### **Faunas**

The *Protochonetes ludloviensis* Association (Watkins 1979) is a low-diversity association dominated by brachiopods and bivalves. The coquinoid occurrence of the shelly fauna is typical. The association represents a restriction of the *Sphaerirhynchia wilsoni* Association, particularly regarding the brachiopod fauna, rather than a community of species newly appearing (or reappearing) along an environmental gradient.

See '[Composition of Ludlow shelly faunal associations](#)' for full details.

### **Brachiopods**

Brachiopods comprise up to 82% of the fauna. *Microsphaeridiorhynchus nucula* (J. de C. Sowerby), *Protochonetes ludloviensis* Muir-Wood and *Salopina lunata* (Davidson) are the dominant forms. Each may comprise as much as 80% of the fauna in individual samples, showing small-scale fluctuations in abundance in stratigraphical sections. *Dayia navicula* (J. de C. Sowerby) and *Howellella elegans* (Muir-Wood) are locally common, *D. navicula* occurring in the basal part only and *H. elegans* being abundant at some higher levels (Watkins 1979, p. 237; Lawson & White 1989). Other species, including *Atrypa reticularis* (Linnaeus), *Craniops implicatus* (J. de C. Sowerby), *Isorthis*, *Leptaena depressa* (J. de C. Sowerby), *Lepidoleptaena*, *Lingula lewisii* J. de C. Sowerby, *Orbiculoidea rugata* (J. de C. Sowerby), *Shaleria ornatella* (Davidson) and *Sphaerirhynchia wilsoni* (J. Sowerby), are rare and sporadic. Some, survivors from the *Sphaerirhynchia wilsoni* and *Shaleria ornatella* associations, were probably at the extreme of their environmental tolerance.

Considered as single assemblages, any brachiopod sample from the *Protochonetes ludloviensis* Association might duplicate a sample from the *Sphaerirhynchia wilsoni* Association. What distinguishes the brachiopod fauna of the *Protochonetes ludloviensis* Association from its counterpart in the *Sphaerirhynchia wilsoni* Association is the overall reduction in diversity.

### **Bivalves**

Bivalves comprise about 10% of the fauna from the *Protochonetes ludloviensis* Association, locally reaching 30%. Unlike the brachiopods, bivalves show no reduction in diversity compared with the preceding associations. *Fuchsella amygdalina* (J. de C. Sowerby) comprises 42% of the bivalve fauna. Other common species are *Goniophora cymbaeformis* (J. de C. Sowerby), *Ptychopteria tenuistriata* (M'Coy), *Pteronitella retroflexa* (Wahlenberg) and *Nuculites antiqua* (J. de C. Sowerby).

(continued...)

## ***Protochonetes ludloviensis* Association: Faunas (continued)**

### **Minor groups**

Bryozoa are represented by ramose forms. Gastropods are present in low numbers, and are represented mainly by *Bucanopsis expansus* (J. de C. Sowerby) and *Cyclonema corallii* (J. de C. Sowerby). Cephalopods of probable nektobenthic habit are present fairly continuously. The annelid *Serpulites longissimus* J. de C. Sowerby is an important element of the fauna. Ostracodes have a sporadic and occasionally dense occurrence. Rare trilobites include *Acastella spinosa* (Salter) and *Homalonotus knightii* (König); *Encrinurus stubblefieldi* Tripp survives into the basal few metres of the association at Ludlow. The crustacean *Ceratiocaris* and eurypterids are present. Crinoid columnals occur in low density, but are occasionally concentrated in transported shell layers. A low-diversity marine fish fauna occurs.

Lawson, J.D. & White, D.E. 1989. The Ludlow Series in the Ludlow area. In Holland, C.H. & Bassett, M.G. (eds) *A global standard for the Silurian System*. National Museum of Wales, Geological Series No. 9, Cardiff. 73-90.

Watkins, R. 1979. Benthic community organization in the Ludlow Series of the Welsh Borderland. *Bulletin of the British Museum (Natural History)*, Geology, **31**, 175-280.

See: [Composition of Ludlow shelly faunal associations, \*Protochonetes ludloviensis\* Association - Occurrence.](#)

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[Author: SGM]



## ***Protochonetes ludloviensis* Association**

### **Occurrence**

Watkins (1979, fig. 16) recorded the *Protochonetes ludloviensis* Association from the Lower Whitcliffe and Upper Whitcliffe formations on The Whitcliffe at Ludlow (sections 2B, 2C), and from the Upper Whitcliffe Formation and the Ludlow Bone Bed Member of the Downton Castle Sandstone Formation in Whitcliffe Road (section 2A, also known as Ludford Lane). The incoming of the association was placed at the base of the Lower Whitcliffe Formation.

A fauna from the Ludlow Bone Bed Member was described by Watkins (1979, p. 238) as a typical transported assemblage of the *P. ludloviensis* Association. He reported that the *P. ludloviensis* Association completely disappeared above the Ludlow Bone Bed (see also Bassett *et al.* 1982, fig. 6, reproduced as fig. 103 of White & Lawson 1989, which shows *Microsphaeridiorhynchus nucula*, *Protochonetes ludloviensis* and *Salopina lunata* ranging into but not above the Ludlow Bone Bed Member; see '[Whitcliffe Road - vertical section and fossil ranges across the Ludlow-Prídolí boundary](#)').

Elsewhere in the type Ludlow area, the fauna from the Lower Whitcliffe Formation of the Deer Park Road (White & Lawson 1978, pp. 8-9) is typical of the *Protochonetes ludloviensis* Association. The base of the *Protochonetes ludloviensis* Association can be considered to approximate to the base of the Lower Whitcliffe Formation in the Deer Park Road section.

Watkins (1979) recorded the *Protochonetes ludloviensis* Association from highest Ludlow strata in the Abberley, Malvern and Woolhope areas.

Bassett, M.G., Lawson, J.D. & White, D.E. 1982. The Downton Series as the fourth Series of the Silurian System. *Lethaia*, **15**, 1-24.

Watkins, R. 1979. Benthic community organization in the Ludlow Series of the Welsh Borderland. *Bulletin of the British Museum (Natural History)*, Geology, **31**, 175-280.

White, D.E. & Lawson, J.D. 1978. The stratigraphy of new sections in the Ludlow Series of the type area, Ludlow, Salop, England. *Report of the Institute of Geological Sciences*, No. **78/30**, 1-10.

White, D.E. & Lawson, J.D. 1989. The Prídolí Series in the Welsh Borderland. In Holland, C.H. & Bassett, M.G. (eds) *A global standard for the Silurian System*. National Museum of Wales, Geological Series No. **9**, Cardiff. 131-141.

See: [Deer Park Road, \*Protochonetes ludloviensis\* Association - Fauna, Stratigraphical relationships of shelly faunal associations, The Whitcliffe, Whitcliffe Road.](#)

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