Correlation of the base of the Serpukhovian Stage (Carboniferous; Mississippian) in northwest Europe

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Abstract - The Task Group charged with proposing the GSSP for the base of the Serpukhovian Stage (Mississippian: Lower Carboniferous) is likely to use the global First Appearance Datum (FAD: evolutionary first appearance) of the conodont *Lochriea ziegleri* in the lineage *Lochriea nodosa-L. ziegleri* for the definition and correlation of the base of the stage. It is important to establish that the FOD (First Occurrence Datum) of *L. ziegleri* in different basins is essentially penecontemporaneous. Ammonoids provide high-resolution biostratigraphy in the late Mississippian but their use for international correlation is limited by provincialism. However, it is possible to assess the levels of diachronism of the FOD of *L. ziegleri* in sections in northwest Europe using ammonoid zones. Published compilations of conodont distribution in the Rhenish Slate Mountains of Germany show the FOD of *L. ziegleri* in the *Emstites novalis* Biozone (upper part of the P_{2c} zone of the British/Irish ammonoid biozonation) but *L. ziegleri* has also been reported as occurring in the *Neoglyphioceras spirale* Biozone (P_{1d} zone). In the Yoredale Group of northern England, the FOD of *L. ziegleri* is in either the P_{1c} or P_{1d} zone. In NW Ireland, the oldest records of both *L. nodosa* and *L. ziegleri* are from the *Lusitanoceras granosum* Biozone (P_{2a}). Although there is some discrepancy in the recorded levels of the FOD of *L. ziegleri* in northwest

Europe, this may be as a result of collection failure. The base of the Serpukhovian based on the FAD of *Lochriea ziegleri* will be in the middle of the Brigantian regional Sub-stage, a horizon substantially older than the base of the Namurian Regional Stage.

1. Introduction

In recent years, the Subcommission for Carboniferous Stratigraphy (SCCS) of the International Commission of Stratigraphy has been working towards the realisation of an international scheme of chronostratigraphic divisions of the Carboniferous System (Heckel & Clayton, 2006), which are anchored by formally defined and internationally agreed Global Boundary Stratotype Sections and Points (GSSPs) (Cowie, 1986). The Carboniferous now comprises the Mississippian and Pennsylvanian Subsystems; a GSSP has been selected and ratified for the base of the Pennsylvanian. The Subsystems have themselves been divided into Stages: in the case of the Mississippian, the Tournaisian, Viséan and Serpukhovian Stages. The GSSP for the base of the Carboniferous and thus for the Tournaisian Stage has been ratified, although this boundary is currently under review (Kaiser, 2009). The GSSP for the base of the Viséan has also been ratified (Work, 2008). Considerable progress has been made in the selection of a GSSP for the base of the Serpukhovian, a horizon of particular relevance to palaeoclimatic studies, because of the onset, or at least significant expansion of a major cooling phase of the Late Palaeozoic Ice Age, believed to have occurred at that time (Rygel *et al.* 2008). In addition, it has been claimed that the Serpukhovian coincides with one of the most severe (in terms of ecological impact) biodiversity crises of the Phanerozoic (McGhee *et al.* 2012; 2013).

2. The Serpukhovian Stage

The Serpukhovian Stage was proposed by Nikitin (1890) for rocks in the vicinity of the city of Sepukhov, south of Moscow. The Stage became formally incorporated in the Russian stratigraphical lexicon in 1974. The Zaborie Quarry section, south of Moscow, historically was generally regarded as the lectostratotype section (Gibshman, 2003; Kabanov, 2003). When the decision was taken by the SCCS to adopt the Russian Stages from the Serpukhovian to Gzhelian as the international divisions of the younger part of the Carboniferous and to relegate the Namurian, Westphalian and Stephanian to the status of regional stages, applicable only in western Europe, it is clear that the base of the Serpukhovian was considered to be equivalent or close to the base of the Namurian (see, for example, Heckel & Clayton, 2006, Table 1). It is now known that this is not the case (see Section 4b below).

Zaborie Quarry is not an appropriate section in which to establish the GSSP because the base of the Serpukhovian is represented there by an unconformity and, in addition, the boundary beds are now flooded (Nikolaeva *et al*. 2002; Kabanov, 2003). Other, currently unofficial, functional stratotype sections, such as the Novogurovskii Quarry section (Kabanov, 2012), will become obsolete since they are not currently being considered as candidates for the new GSSP. A Task Group of the Subcommission of Carboniferous Stratigraphy was created in 2002 to establish a GSSP for the base of the Serpukhovian as close as possible to the Viséan-Serpukhovian boundary, as it was then understood (Richards, 2003). The Task Group, before evaluating potential GSSPs, had to decide on the biostratigraphical tool, or tools, with which to identify the boundary. Candidate fossil groups were ammonoids, conodonts and foraminiferans. By 2005, the most favoured group was conodonts; in particular an evolutionary lineage within the genus *Lochriea* was considered to offer the best possibility of providing a tool to identify the boundary.

3. The conodont genus *Lochriea*

The genus *Lochriea* contains at least ten species. The multi-element composition of *Lochriea commutata* (Branson & Mehl, 1941), the type species of the genus, is known (R. D. Norby, 1976, unpub. PhD thesis, Univ. of Illinois at Urbana-Champaign, 1976; Varker, 1993; Purnell & Donoghue, 1998). Diagnoses of all the species are based on the character of the P_1 elements. As far as is known the other elements are shared vicariously by different species.

The ranges of the following species which have an ornamented platform jointly span the Viséan/Serpukhovian boundary, irrespective of exactly at what level (within the range being considered) the boundary is defined: *Lochriea costata* (Pazukhin & Nemirovskaya, 1992); *L. cruciformis* (Clarke, 1960); *L. monocostata* (Pazukhin & Nemirovskaya, 1992); *L. mononodosa* (Rhodes, Austin & Druce, 1969); *L. multinodosa* (Wirth, 1967); *L. nodosa* (Bischoff, 1957); *L. senckenbergica* (Nemirovskaya, Perret & Meischner, 1994); and *L. ziegleri* (Nemirovskaya, Perret & Meischner, 1994).

To date there has not been an explicit study of the evolutionary relationship of all these species. However, Meischner (1970) indicated the potential use of species now assigned to *Lochriea* in biostratigraphy and since then various authors (for example, Nemyrovska, 2005) have suggested that *L. commutata*, an unornamented and long ranging form, gave rise to progressively more ornamented *Lochriea,* such as *L. mononodosa* with a single node on the caudal side of the platform and *L. nodosa,* with a node on each side. *L. nodosa* in turn gave rise to *L. ziegleri*, in which rows of large, discrete nodes are located on thick ridge-like elevations on both sides of the platform close to its posterior margin. *L. multinodosa*, which is characterised by a wide, large platform ornamented by numerous small nodes, is likely to have also been derived from *L. nodosa*. *L. senckenbergica,* which is characterised by large, high nodes or bars located on both sides of the central part of the platform and *L. cruciformis*, characterised by thin, straight ridges on both sides of the platform that connect

to the carina, were probably both derived from *L. ziegleri*. *L. monocostata* is similar to *L. mononodosa* with the single node replaced by a ridge, typically perpendicular to the carina, and *L. costata* similarly has two ridges replacing the two nodes of *L. nodosa*. Intermediates between several of these taxa have been referred to and illustrated: for example, between *L. senckenbergica* and *L. cruciformis* (Nemyrovska *et al*. 2011), *L. nodosa* and *L. ziegleri* (Qi *et al*. 2010), *L. nodosa* and *L. senckenbergica* (Skompski *et al*. 1995; Qi *et al*. 2010), and *L. ziegleri* and *L. cruciformis* (Skompski *et al*. 1995; Qi *et al*. 2010).

3. Correlation of the base of the Serpukhovian

3.a. The *Lochriea nodosa – L. ziegleri* lineage

The favoured biostratigraphical tool for the definition and subsequent correlation of the base of the Serpukhovian is the evolutionary (or global) first occurrence (First Appearance Datum - FAD) of *Lochriea ziegleri* in the lineage *Lochriea nodosa-L. ziegleri*. Detailed investigations of two candidate sections for the GSSP, the Naqing (formerly Nashui) section in Guizhou Province, China (Qi *et al*. 2010) and the Verkhnyaya Kardailovka section, in the southern Urals, Russia (Nikolaeva *et al*. 2009; Pazukhin *et al*. 2010), have been based on this premise.

For stability of the Serpukhovian as a chronostratigraphical unit, it is important to establish that the first occurrence of *L. ziegleri* in different basins is penecontemporaneous in a practical stratigraphic sense. It is commonly assumed that the first appearance of a taxon in two or more sections, in each of which an 'evolutionary lineage' has been demonstrated, is necessarily penecontemporaneous. However, as discussed by Sevastopulo & Nudds (1987), this is not always the case. Where there is little or no overlap in stratigraphical range of the putative ancestral and descendant taxa (the evolution of *Dollymae bouckaerti* Groessens,

1971 from *Eotaphrus bultyncki* (Groessens, 1971) was used by Sevastopulo & Nudds as an example), it is reasonable to regard the first occurrence of the daughter taxon within the lineage as a near isochronous marker. However in many evolutionary lineages, an ancestral taxon does not become extinct at the inception of its daughter taxon, and the two taxa and intermediates between them, may co-exist for some time. This is the case in the lineage *L. commutata – L. mononodosa – L. nodosa – L. ziegleri*: both in the Nashui section (Qi *et al.* 2010, Fig. 1) and in the Verkhnyaya Kardailovka section (Pazukhin *et al.* 2010, Fig. 2), all four of the taxa listed above occur together at several horizons. This can lead to a situation in which the First Occurrence Datum (FOD: the lowest occurrence of the taxon in a stratigraphical section) of the daughter taxon is not its evolutionary earliest occurrence (FAD: globally earliest occurrence of the taxon), even where an 'evolutionary lineage' has apparently been demonstrated. An obvious way in which this can happen is through collection failure below the FOD. More intractable cases arise from ecological/biogeographical causes, where the daughter taxon has migrated from the region of origin to the region in which the section under study is situated. The consequence for biostatigraphers will be diachronous correlations. What are needed are additional tools with which to check the consistency of correlations. These will generally be biostratigraphical, but chemostratigraphy, magnetostratigraphy and particularly radiometric dating (see, for example, Schmitz & Davydov, 2012) may also be useful.

3.b. Other biostratigraphical tools

In the Naqing section in China (Qi *et al.* 2010), which consists largely of deep-water, slope deposits, the only other potential biostratigraphical tools are foraminiferans, which Groves *et al.* (2012) reported are relatively rare and do not include any of the basal Serpukhovian index species. In an attempt to overcome these difficulties, Groves and co-workers also examined the Yashui section, approximately 90 km NNE of Naqing, where a shallower

water sequence is exposed, Although the Viséan-Serpukhovian boundary beds at Yashui contained more diverse and abundant calcareous microfaunal assemblages, the paucity of conodonts precluded identification of the FOD of *L. ziegleri* and consequently correlation to the Naqing section was not possible. Therefore, at the current state of knowledge, it is not possible using foraminiferans to assess whether the FOD of *L. ziegleri* in southwest China is at the same horizon as in other regions.

The Verkhnyaya Kardailovka section in the Urals is faunally much richer than the Naqing section and contains ammonoids, foraminiferans, and ostracodes, in addition to conodonts (Pazukhin *et al*. 2010). Ammonoid biozones provide high-resolution biostratigraphy in the Late Mississippian and an ideal test of the degree of diachroneity of the FODs of *L. ziegleri* in different basins would be to compare the conodonts position against a global ammonoid biozonal scheme. Unfortunately, ammonoids around the base of the Serpukhovian are strongly provincial in their distribution (Korn *et al*. 2010). For example, the ammonoid faunas of the Urals are totally different at the level of species and largely different at the level of genus from those of northwest Europe. At the present state of knowledge of both the conodont and ammonoid stratigraphical records, it is possible to make detailed comparisons of the FOD of *L. ziegleri* against a biozonation based on ammonoids only within a single ammonoid faunal province. Here, we assess the levels of diachronism of the FOD of *L. ziegleri* in widely separated sections in northwest Europe, using the existing high resolution, ammonoid biozonal scheme and also establish the level of the FOD of *L. ziegleri* with relation to the base of the Namurian Regional Stage.

4. The ranges of *Lochriea* spp. in terms of ammonoid biozones in northwest Europe

A high-resolution ammonoid biozonal framework has been developed in the Rhenish Mountains in Germany (summarized in Korn, 1996, 2010) and in Britain and Ireland (summarized in George *et al*. 1976; Riley, 1993). Korn & Titus (2011, Fig. 11) have

provided a correlation of the two biozonal schemes, which is used here to compare the ranges of *Lochriea* spp. in Germany, Britain and Ireland.

4.a. The Rhenish Slate Mountains (Rheinisches Schiefergebirge), Germany

The ranges of *Lochriea* spp. in the Rhenish Slate Mountains (Fig. 1) are documented in

<mark>(Figure 1 hereabouts)</mark>

Meischner (1967; 1995) and Nemirovskaya, Perret & Meischner (1994), which are the sources of the data presented here. In Meischner (1995, Fig. 3), reproduced here in slightly amended form (Fig.1), the entry of *L. mononodosa* was shown as preceding that of *L. nodosa*; the latter was stated to be at the base of the *Neoglyphioceras spirale* Biozone. The entry of *L. cruciformis* was shown as preceding those of *L. ziegleri* and *L. senckenbergica*. The entry of all three species was stated to be within the *Emstites schaelkensis* Biozone, the name-giving taxon of which, according to Korn (1994), first occurs in the *Edmooroceras pseudocoronula* Biozone, at the base of the Namurian Regional Stage. However, Nemirovskaya, Perret & Meischner (1994) reported rare *L. ziegleri* from the *Neoglyphioceras spirale* Biozone and the earliest *L. senckenbergica* was stated to be from the *Lusitanoceras poststriatum* Biozone. Korn (2010, Fig. 2) showed the base of the *L. ziegleri* Biozone corresponding to the base of the *Edmooroceras pseudocoronula* Biozone and the base of the *L. nodosa* Biozone corresponding to that of the *Neoglyphioceras spirale* Biozone. Korn & Titus (2011, Fig. 11) correlated the base of the *L. ziegleri* Biozone with a horizon within the *Emstites novalis* Biozone. There is an urgent need to restudy the range of *L. ziegleri* relative to the ammonoid zones in Germany. The degree of the existing uncertainty is illustrated in Figure 2.

<mark>Figure 2 hereabouts</mark>

4.b. Northern England

The most complete published information on the occurrences of stratigraphically important species of *Lochriea* in northern England is contained in Varker (1995) and is derived from limestones within the shallow water cyclothemic limestones, shales and sandstones of the Yoredale Group (Fig. 3). *Lochriea* spp. were obtained from all the limestones,

most of which can be correlated with the ammonoid biozonation through the occurrence of rare ammonoids in the intervening shales (Ramsbottom, 1974, Fig. 25). The FODs of both *L. mononodosa* and *L. nodosa* are in the Gayle Limestone, which lies between shales containing *Arnsbergites falcatus* of P_{1b} age and *Goniatites sphaericostriatus* of P_{1c} age (Rayner, 1953). The FOD of *L. ziegleri* is within the Middle Limestone. As the Middle Limestone is traced laterally from the locality on the Askrigg block studied by Varker to the Alston Block, it divides into three distinct units: in ascending order, the Single Post, the Cockleshell and the Scar Limestone (Ramsbottom, 1974, Fig. 24). Mark Dean (pers. comm. 2010) has confirmed that the FOD of *L. ziegleri* is in the lower part of the Middle Limestone, which is correlated with the Single Post Limestone. This horizon lies below a level which has yielded *Paraglyphioceras rudis* (Hicks, 1959), assigned by Ramsbottom (1974, Fig. 25) to the P_{1d} Biozone but stated by Korn (1996) to indicate the *Arnsbergites gracilis* Biozone of the Rhenish Slate Mountains, which is correlated with P_{1c} of the British/Irish ammonoid biozonal scheme (Korn & Titus, 2011). This discrepancy is clearly important in the context of the FOD of *L. ziegleri* and needs to be resolved. The Scar Limestone is overlain by shales with *Lusitanoceras granosum*, indicating the P_{2a} Biozone. The FOD of both *L. cruciformis* and *L. multinodosa* are in the Main Limestone, which lies above shales with *Edmooroceras tornquisti*, indicating the E_{1a} Biozone.

Surprisingly the information from the basinal areas, where the ammonoid biozonation was first established, is sparse. Higgins (1975) did not sample below the P_2 Biozone. However, he did record *Lochriea* spp. (under the generic name *Paragnathodus*) including *L. commutata*, *L. mononodosa*, *L. nodosa*, and *L. cruciformis* from a section of P_2 age at Cawdor quarry, Matlock, Derbyshire. Dr Mark Dean (pers. comm. 2010) has confirmed that the specimen figured by Higgins (1975, Pl. 7, Fig. 10) as *L. cruciformis* is *L. ziegleri*, as suggested by Nemirovskaya *et al.* (1994, p.312). Metcalfe (1981) did not record ornamented *Lochriea* spp. (all referred by him to *Gnathodus nodosus*) below the P_{2b} Biozone in the section at Bank's Gill, near Skipton, Yorkshire, in the Craven Basin.

4.c. Ireland

Important information on the range of ornamented *Lochriea* spp. is available in northwest Ireland. Brandon & Hodson (1984) summarized the distribution of ammonoids in the upper Viséan and Serpukhovian Leitrim Group and additional information has been added by Korn (1990). The Leitrim Group, exposed throughout large parts of the Lough Allen Basin, consists of several primarily terrigenous formations of which the Carraun Shale Formation, ranging in age from P_{1b} to $P_{2c,}$ is most relevant to the current investigation. The Carraun Shale Formation is composed predominantly of dark grey, occasionally pyritic, commonly fossiliferous, calcareous shale. Five carbonate-rich members have been identified and can be correlated throughout the basin (Fig. 4). Fossils are common throughout the formation, predominantly as flattened, crushed or impressed specimens, although three dimensional fossils may also be recovered. The Carraun Shale is interpreted as having been deposited in an overall deepening environment (with the exception of the shallow-water Tawnyunshinagh Member) with limestone becoming more infrequent and the fauna becoming dominated by pelagic taxa, such as orthoconic nautiloids, ammonoids and associated bivalves such as *Posidonia* and *Dunbarella*, up sequence. Conodonts from late Viséan and Serpukhovian

levels in northwest Ireland have previously been

described by Aldridge *et al.* (1968) and Austin & Husri (1974) but new detailed sampling carried out in the Carraun Shale Formation in the Lugasnaghta stream section on the northeast side of Dough Mountain, Co. Leitrim (M. Barham 2010, unpublished Ph.D. thesis, National University of Ireland Galway) has augmented the previous records. The sequence (approximately 130 m thick) is exposed in the stream cut of a small tributary of the Sraduffy River over a distance of approximately one kilometre on the northwest side of Dough Mountain, Co. Leitrim. The locality represents the type section of the Carraun Shale Formation and despite some minor gaps in exposure and local faulting, it is thought the measured section (Fig. 4) provides an accurate temporal record. Samples of carbonate rock typically weighing 2 kg, but up to 4kg where microfossil yields were low, were dissolved in dilute formic acid and conodonts picked from the insoluble residues.

A range chart showing the distribution of *Lochriea* spp. is shown in Figure 4. The Derreens Limestone Member, which contains *Arnsbergites sphaericostriatus* and *Goniatites lepidus* of P_{1c} Biozonal age, has yielded *L. commutata* transitional to *L. mononodosa*. The shale-rich succession between the Derreens Limestone Member and the Ardvarney Limestone Member, which contains a rich ammonoid fauna assigned to the P_{1d} Biozone, has yielded small numbers of conodonts but no specimens of *Lochriea* spp. The Ardvarney Limestone Member contains *Lusitanoceras granosum* and *Sudeticeras crenistriatus* of P_{2a} age and marks the FOD of *L. nodosa* and *L.* cf. *cruciformis*. The FOD of undoubted *L. ziegleri* occurs 2.2m higher and *L.* cf. *senckenbergica* first occurs 6.7m higher, both within the P_{2a} Biozone.

5. Discussion and conclusions

A comparison of the ranges of *Lochriea* spp. in the Rhenish Slate Mountains, northern

England and northwest Ireland is shown in Figure 5. The FODs of *L. nodosa* are within P_{1c} of the British and Irish ammonoid biozonal scheme in the Yoredale sequence in northern England; in the equivalent of P_{1d} in the Rhenish Slate Mountains; and at the base of P_{2a} in northwest Ireland.

<mark>Figure 5 hereabouts</mark>

The FODs of *L. ziegleri* are comparable, but not exactly the same, in the Yoredale sequence of northern England and in northwest Ireland (within P_{1d}, or possibly P_{1c} in the former, and at the base of P_{2a} in the latter). Given the poor conodont record in P_{1d} in northwest Ireland, it will not be surprising if further collecting lowers the FOD of *L. nodosa* and *L. ziegleri* there. The situation in the Rhenish Slate Mountains is confusing with the FOD of *L. ziegleri* being variously reported as being within the equivalents of P_{1d}, P_{2c} or E_{1a}. It is essential that these contradictions be resolved.

The FOD of *L. senckenbergica* is either in the equivalent of the upper part of P_{2a} or P_{2c} in the Rhenish Slate Mountains and possibly in P_{2b} in northwest Ireland. Varker (1995) did not record *L. senckenbergica* from northern England.

The FOD of *L. cruciformis* appears to be the most variable, as high as E_{1a} in the north of England and possibly as low as P_{2a} in northwest Ireland. The FOD in the Rheinisches Schiefergebirge was shown by Meischner (1995, Fig. 3) to be below that of *L. ziegleri*. Different authors may have different taxonomic concepts of *L. cruciformis*.

In conclusion, the lower boundary of the Serpukhovian, based on the FAD of *L. ziegleri*, will be at a substantially lower horizon than the lower boundary of the Namurian Regional Stage, approximately in the middle of the Brigantian Regional Sub-stage. The FOD of *L. ziegleri* in sections in northwest Europe may be close to isochronous but conflicting information from the Rhenish Slate Mountains and sections in Britain and Ireland needs to be resolved to confirm this.

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Captions to Figures

Figure 1. (Colour online) Distribution of *Lochriea* spp. in the Rhenish Slate Mountains, Germany. Lithostratigraphy and conodont ranges modified from Meischner (1995). Columns from left to right record the Stage, Regional Sub-stage, conodont biozone and standard ammonoid biozone. "lmst" = limestone.
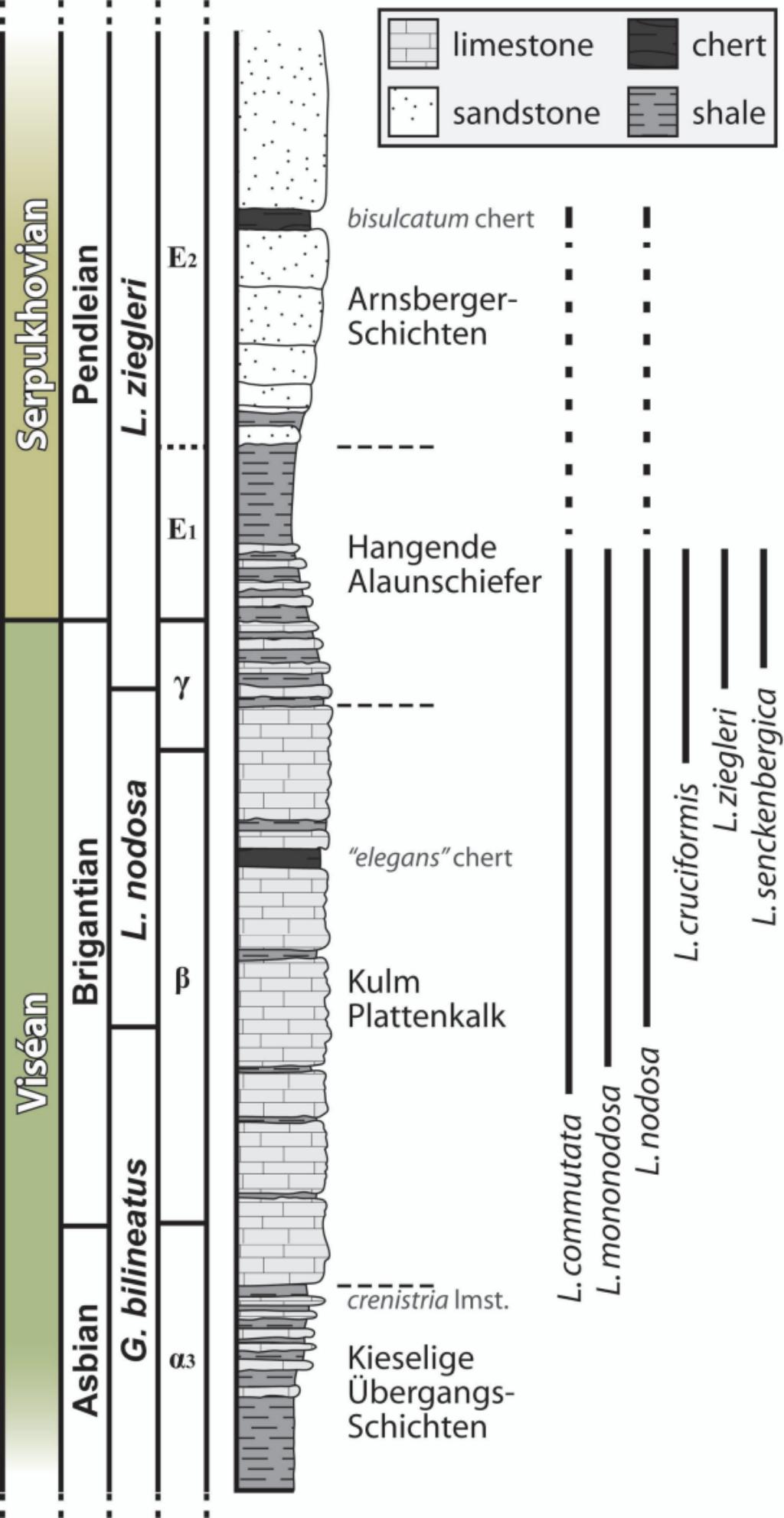
Figure 2. Location of the Rhenish Slate Mountains and correlation of the various FOD's (reported in the texts discussed) of important *Lochriea* species with relevant ammonoid biozonation schemes. Conodont ranges predominantly derived from Meischner (1995) with extensions and disagreements of ranges, shown as dashed lines, from Nemirovskaya, Perret & Meischner (1994), Korn (2010) and Korn & Titus (2011). Standard ammonoid biozones derived from Korn (1996), correlation with British and Irish ammonoid biozation schemes taken from Korn & Titus (2011).

Figure 3. (Colour online) Distribution of *Lochriea* spp. in sections in northern England. (a) Geographic location of discussed sections in northern England. Stippled areas on the location map represent highs; unornamented areas represent basins. (b) Distribution of *Lochriea* spp. in the Yoredale Group, Alston and Askrigg Blocks, northern England (from Varker, 1995). Generalised lithostratigraphy of the Alston and Askrigg Blocks modified from Varker (1995) and Davies *et al.* (1993). GSL G. = Great Scar Limestone Group and MG G. = Millstone Grit Group. Correlation of the ammonoid biozones with the named limestone units is from Rayner (1953) and Ramsbottom (1974). The correlation of the Single Post Limestone with the ammonoid biozones is discussed in the text. (c) Distribution of
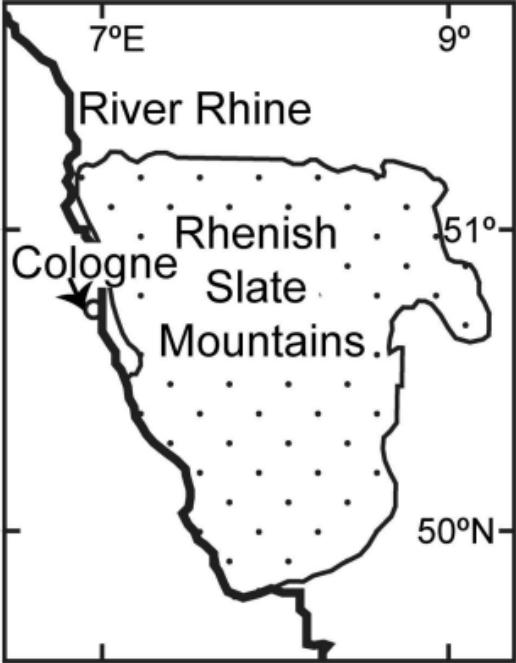
Lochriea spp. in the basinal facies of the Craven Basin near Skipton, Yorkshire (from Metcalfe, 1981) and on the margins of the Widmerpool Gulf at Matlock, Derbyshire (from Higgins, 1975).

Figure 4. (Colour online) Distribution of *Lochriea* spp. in the Carraun Shale Formation, Lugasnaghta stream section (Irish Grid GR G95578 43058 to GR G95105 42710, see also inset location map), County Leitrim, Ireland. Information from M. Barham 2010, unpublished Ph.D. thesis, National University of Ireland Galway. Ammonoid zones from Brandon & Hodson (1984). Dashed line represents an extension of range based on tentative identifications. Conodont abundances per 2 kg sample are shown; other conodont genera were also recovered.
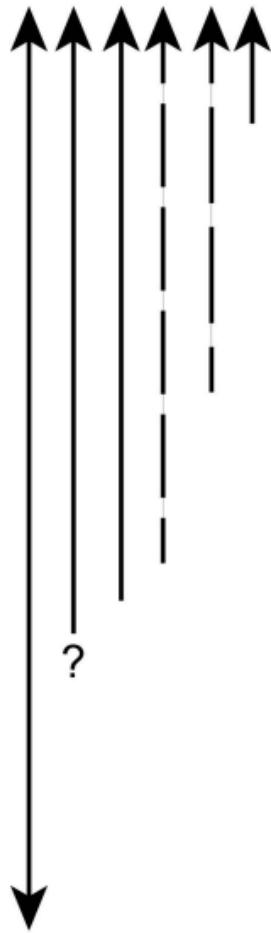
Figure 5. Comparison of the distribution of *Lochriea* spp. in County Leitrim, Ireland, the Alston and Askrigg Blocks, northern England and the Rhenish Slate Mountains, Germany. Dashed lines represent extensions of range that require confirmation. Correlation of the German and Irish/British ammonoid zonal schemes is from Korn & Titus (2011). "Asb." refers to the Asbian and "P." the Pendleian Regional Sub-stages.
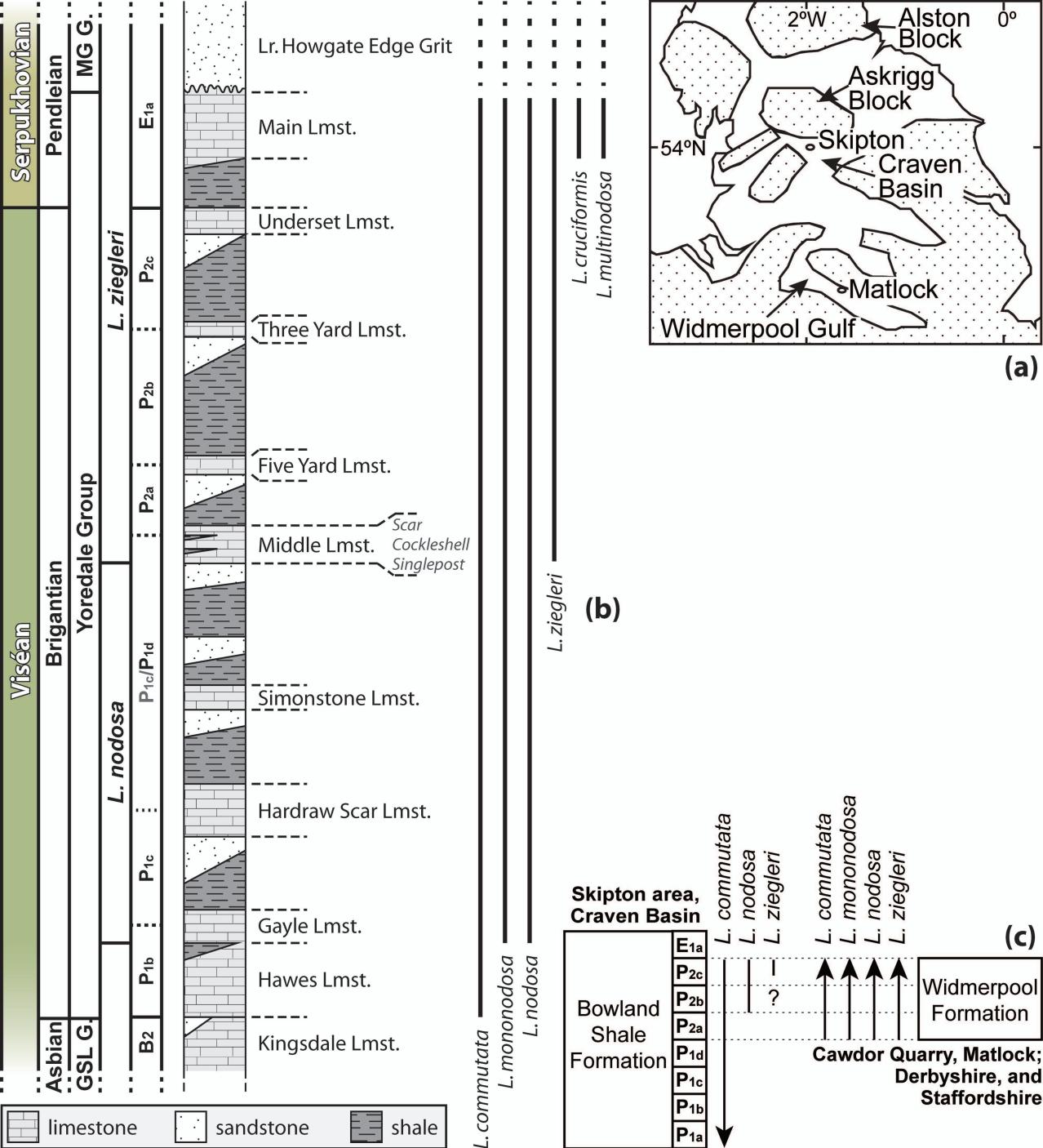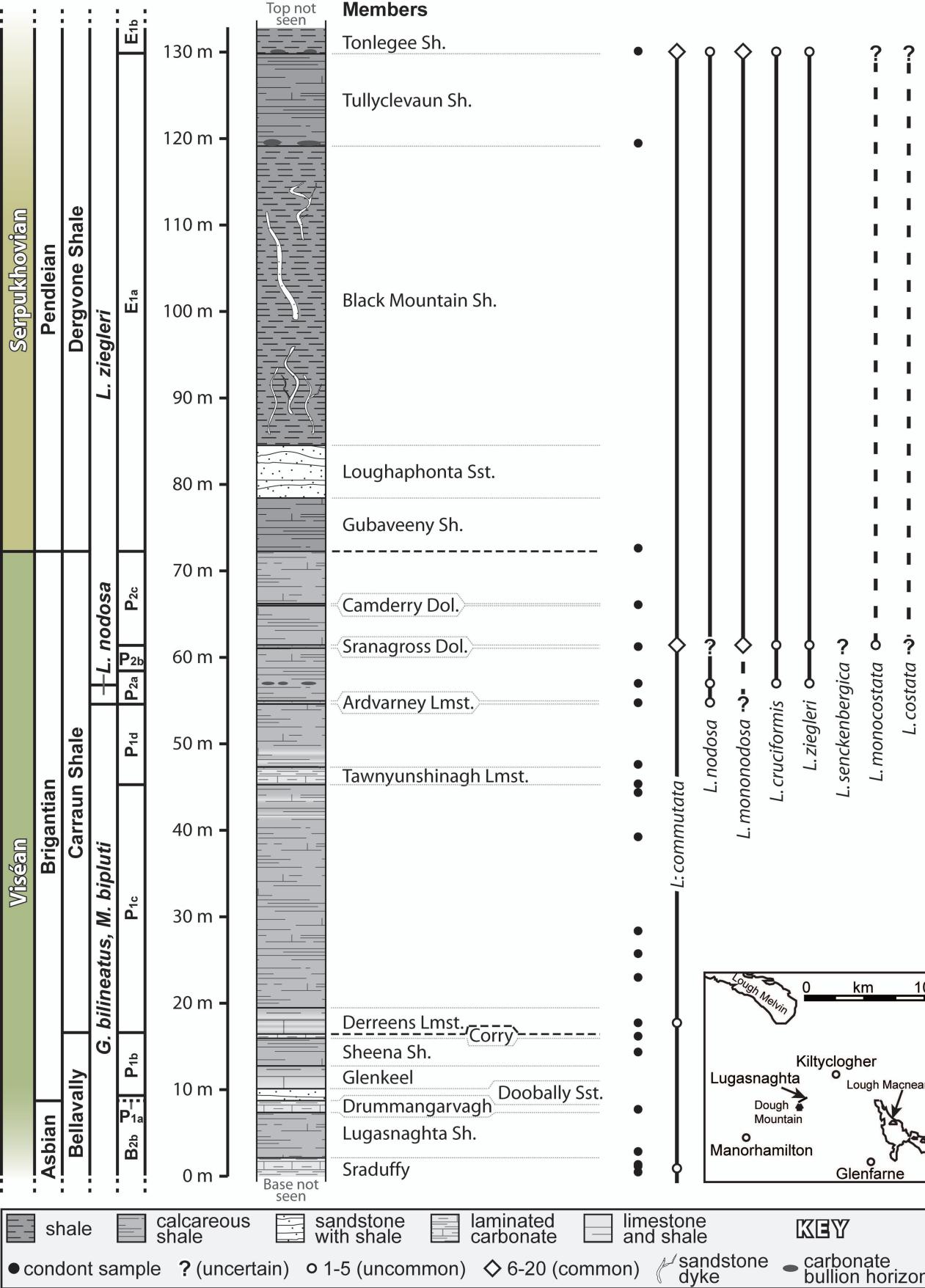
Legend:
- limestone
- sandstone
- chert
- shale

Serpukhovian

Viséan

Pendleian

Brigantian

Asbian

L. ziegleri

L. nodosa

G. bilineatus

E_2

E_1

γ

β

α₃

bisulcatum chert

Arnsberger-Schichten

Hangende Alaunschiefer

"elegans" chert

Kulm Plattenkalk

crenistria lmst.

Kieselige Übergangs-Schichten

L. commutata

L. mononodosa

L. nodosa

L. cruciformis

L. ziegleri

L. senckenbergica

Members

Tonlegee Sh.

Tullyclevaun Sh.

Black Mountain Sh.

Loughaphonta Sst.

Gubaveeny Sh.

Camderry Dol.

Sranagross Dol.

Ardvarney Lmst.

Tawnyunshinagh Lmst.

Derreens Lmst. — Corry

Sheena Sh.

Glenkeel — Doobally Sst.

Drummangarvagh

Lugasnaghta Sh.

Sraduffy

L. commutata
L. nodosa
L. mononodosa ?
L. cruciformis
L. ziegleri
L. senckenbergica ?
L. monocostata
L. costata ?

KEY

shale	calcareous shale	sandstone with shale	laminated carbonate	limestone and shale

● condont sample   ? (uncertain)   ○ 1-5 (uncommon)   ◇ 6-20 (common)   sandstone dyke   carbonate bullion horizon

Species columns (repeated for each region): *L. commutata*, *L. mononodosa*, *L. nodosa*, *L. ziegleri*, *L. senckenbergica*, *L. cruciformis*

Stage	Ammonoid zone	Code		Foraminiferal zone	Stage
P.	*E. pseudocoronula* / *E. leion*	E1a		*E. pseudocoronula*	**P.**
Brigantian	*L. georgiensis*	P2c		*E. novalis*	**Brigantian**
				C. chalicum	
	N. subcirculare	P2b		*L. liethensis*	
				L. eisenbergensis	
	L. granosum	P2a		*L. poststriatum*	
				N. suerlandense	
	P. rotundum [koboldi]	P1d		*P. rotundum*	
	N. spirale			*N. spirale*	
	A. sphaericostriatus	P1c		*A. gracilis*	
	A. falcatus / *G. spirifer*	P1b		*A. falcatus*	
				G. spirifer	
Asb.	*G. crenistria*	P1a		*G. fimbriatus*	**Asb.**
				G. crenistria	
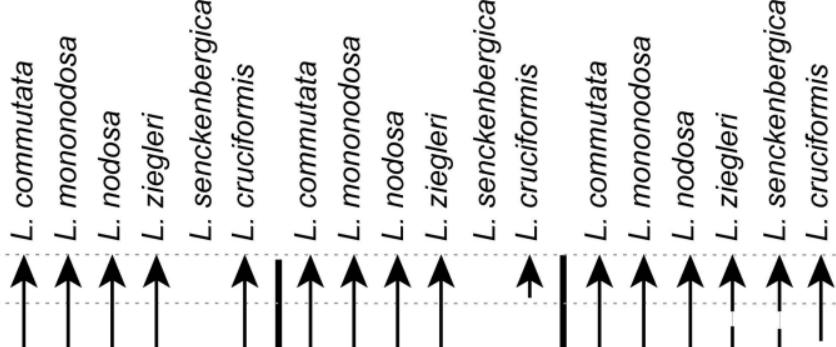
Regions (columns):
County Leitrim, Ireland — **Alston & Askrigg Blocks, England** — **Rhenish Slate Mtns, Germany**

Annotations: cf. (Ireland column), cf. (England column), ? (Germany column)