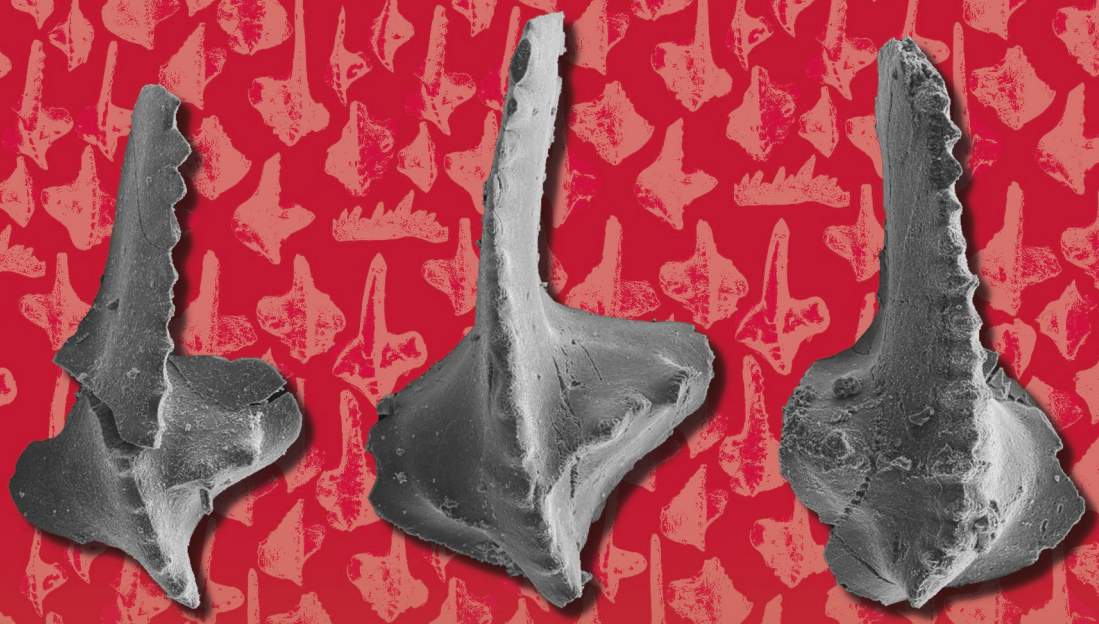
geodiversitas

2024 • 46 • 18

# A new species, *Lochriea monocarinata* n. sp., and its position in the morphospace of the genus *Lochriea* Scott, 1942 (Conodonta, Mississippian)

Andrey V. ZHURAVLEV



art. 46 (18) — Published on 21 November 2024
www.geodiversitas.com

PUBLICATIONS SCIENTIFIQUES

MUSÉUM NAL HIST NATURELLE

*Geodiversitas* est indexé dans / Geodiversitas *is indexed in:*
– Science Citation Index Expanded (SciSearch®)
– ISI Alerting Services®
– Current Contents® / Physical, Chemical, and Earth Sciences®
– Scopus®

*Geodiversitas* est distribué en version électronique par / Geodiversitas *is distributed electronically by:*
– BioOne® (http://www.bioone.org)

Les articles ainsi que les nouveautés nomenclaturales publiés dans *Geodiversitas* sont référencés par /
*Articles and nomenclatural novelties published in* Geodiversitas *are referenced by:*
– ZooBank® (http://zoobank.org)

***Geodiversitas*** est une revue en flux continu publiée par les Publications scientifiques du Muséum, Paris
**Geodiversitas** *is a fast track journal published by the Museum Science Press, Paris*

Les Publications scientifiques du Muséum publient aussi / *The Museum Science Press also publish:* ***Adansonia***, ***Zoosystema***, ***Anthropozoologica***, ***European Journal of Taxonomy***, ***Naturae***, ***Cryptogamie*** **sous-sections** ***Algologie***, ***Bryologie***, ***Mycologie, Comptes Rendus Palevol***

Diffusion – Publications scientifiques Muséum national d'Histoire naturelle
CP 41 – 57 rue Cuvier F-75231 Paris cedex 05 (France)
Tél. : 33 (0)1 40 79 48 05 / Fax : 33 (0)1 40 79 38 40
diff.pub@mnhn.fr / http://sciencepress.mnhn.fr


ISSN (imprimé / *print*) : 1280-9659/ ISSN (électronique / *electronic*) : 1638-9395

# A new species, *Lochriea monocarinata* n. sp., and its position in the morphospace of the genus *Lochriea* Scott, 1942 (Conodonta, Mississippian)

**Andrey V. ZHURAVLEV**
Institute of Geology FRC Komi SC, UrB RAS, Pervomayskaya 54, 167000 Syktyvkar (Russia)
micropalaeontology@gmail.com

Submitted on 26 January 2024 | accepted on 19 March 2024 | published on 21 November 2024

urn:lsid:zoobank.org:pub:D872A2ED-D694-429F-99E0-5A81F360339E

Zhuravlev A. V. 2024. — A new species, *Lochriea monocarinata* n. sp., and its position in the morphospace of the genus *Lochriea* Scott, 1942 (Conodonta, Mississippian). *Geodiversitas* 46 (18): 955-965. https://doi.org/10.5252/geodiversitas2024v46a18. http://geodiversitas.com/46/18

ABSTRACT
The new species of the Mississippian conodonts *Lochriea monocarinata* n. sp. extends the diversity of the ornamented representatives of the genus *Lochriea* Scott, 1942. *Lochriea monocarinata* n. sp. differs from its close relatives by the presence of a nodose ridge only on the inner (caudal) part of the asymmetrical basal cup. The range of the new species, restricted to the *Lochriea ziegleri* Zone, allows it to be used as an auxiliary biostratigraphic marker of the lower Serpukhovian.

KEY WORDS
Conodonts, morphology, Carboniferous, Serpukhovian, new species.

RÉSUMÉ
*Une espèce nouvelle,* Lochriea monocarinata *n. sp., et sa position dans le morphoespace du genre* Lochriea *Scott, 1942 (Conodonta, Mississippien).*
La nouvelle espèce de conodontes du Mississippian *Lochriea monocarinata* n. sp. élargit la diversité des représentants ornementés du genre *Lochriea* Scott, 1942. *Lochriea monocarinata* n. sp. diffère de ses proches parents par la présence d'une crête nodosée uniquement sur la partie interne (caudale) de la coupe basale asymétrique. L'aire de répartition de la nouvelle espèce, limitée par la zone à *Lochriea ziegleri*, permet de l'utiliser comme marqueur biostratigraphique auxiliaire du Serpukhovien inférieur.

MOTS CLÉS
Conodontes, morphologie, Carbonifère, Serpukhovian, espèce nouvelle.

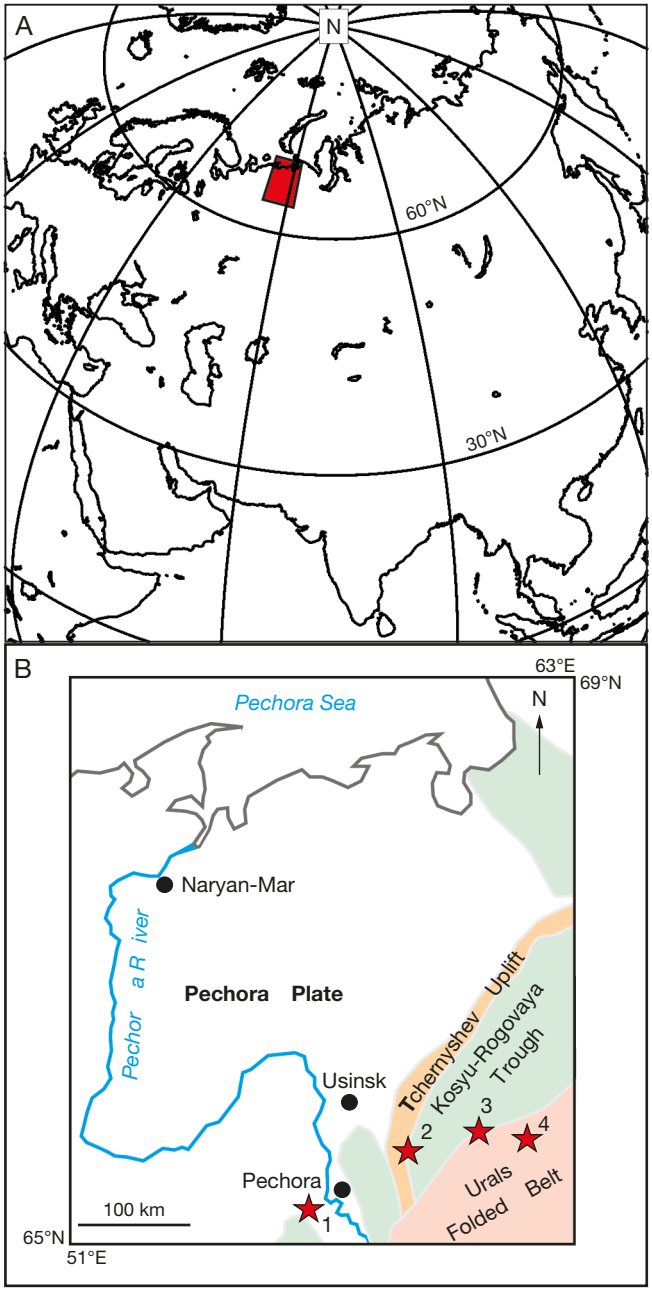



Fig. 1. — Location of the studied sections (★): **A**, general geographical position of the studied area; **B**, location of the sections: **1**, Kamenka section; **2**, Izyayu section; **3**, Kozhim section; **4**, Bolshaya Nadota section.

## INTRODUCTION

Conodonts are a group of small free-swimming, probably nektic or nektonplanktic, marine animals (Briggs *et al.* 1983) that became extinct during the latest Triassic-earliest Jurassic (Du *et al.* 2023). The only mineralised parts of conodonts are tooth-like phosphate elements arranged in a bilaterally subsymmetrical feeding apparatus. Current conodont taxonomy is based on the structure of the apparatus and the morphology of the conodont elements (e.g. Dzik 1976; Sweet 1988). Due to their rapid morphological evolution, conodont elements are widely used in Palaeozoic and Triassic biostratigraphy, including part of the definition of the GSSPs (Global Boundary Stratotype Sections and Points) in the International Chronostratigraphic Scale.

According to Nemyrovska *et al.* (2006), the conodont genus *Lochriea* appeared in the early Viséan, and *Lochriea saharae* Nemyrovska, Perret-Mirouse & Weyant, 2006 is the oldest known species of the genus. Another genus concept includes "*Lochriea*" *symmutata* (Rhodes, Austin & Druce, 1969) and "*L.*" *homopunctata* (Ziegler, 1960) to the genus *Lochriea* (Atakul-Özdemir *et al.* 2012). In this case the oldest species of the genus is "*Lochriea*" *symmutata*, which appears in the middle Tournaisian (Zhuravlev 2003). The last representatives of the genus *Lochriea* are known from the early Pennsylvanian (e.g. Kulagina *et al.* 1992; Mizuno 1997; Sanz-López *et al.* 2013; Hu *et al.* 2019). Some species of this genus compose the basis of the conodont zonation of the Viséan-Serpukhovian interval (Mississippian): lower Viséan *Lochriea commutata* Zone, upper Viséan *Lochriea mononodosa* Zone and *Lochriea nodosa* Zone, lower Serpukhovian *Lochriea ziegleri* Zone and *Lochriea cruciformis* Zone (Metcalfe 1981; Belka 1985; Skompski 1996; Qi & Wang 2005; Vevel *et al.* 2017; Sudar *et al.* 2018). The first appearance datum (FAD) of *Lochriea ziegleri* Nemirovskaya, Perret & Meischner, 1994, is considered a probable biostratigraphic marker of the base of Serpukhovian Stage (Richards 2010; Richards *et al.* 2011, 2017; Sevastopulo & Barham 2014; Nikolaeva *et al.* 2020).

The genus *Lochriea* has been established as multielement taxon (Scott 1942; von Bitter *et al.* 2022). However, species-level taxonomy is based solely on the morphology of P1 elements (e.g., Nemirovskaya *et al.* 1994; Nemyrovska *et al.* 2006; Qi *et al.* 2018). Therefore, the morphology of P1 elements has attracted the most attention from researchers (e.g. Barham *et al.* 2015). Combinations of traits of P1 elements allow for distinguishing a number of species and proposing the phylomorphogeny of the genus (e.g. Barham *et al.* 2015; Vevel *et al.* 2017; Qi *et al.* 2018). Twelve species of the genus are known, and several forms have been described in open nomenclature (e.g. Barham *et al.* 2015). Some species similar to *Lochriea* have debated affinities ("*Lochriea*" *symmutata*, "*L.*" *homopunctata*, "*L.*" *mermaidus* (Austin & Husri, 1975), "*L.*" *lineatus* (Austin & Husri, 1975), *Pseudognathodus posadachaconae* Sanz-López, Blanco-Ferrera & Miller, 2018) (see Atakul-Özdemir *et al.* 2012; Sanz-López *et al.* 2018 for discussion). In any case the P1 elements of these discussed species compose a different morphospace close to that of *Protognathodus*, with a smooth cup or a cup ornamented with a few small nodes, rows of nodes, or short costae (e.g. Sanz-López *et al.* 2018).

The early representatives of the genus *Lochriea* (*L. saharae*, *L. commutata* (Branson & Mehl, 1934), *L. scotiaensis* (Globensky, 1967), *L. cracoviensis* (Belka, 1985)) show a simple morphology of P1 elements similar to that of *Bispathodus* or early *Protognathodus*. Advanced species of *Lochriea* (*L. monocostata* (Pazukhin & Nemirovskaya in Kulagina *et al.*, 1992), *L. costata* (Pazukhin & Nemirovskaya in Kulagina *et al.*, 1992), *L. ziegleri*, *L. senckenbergica* Nemirovskaya, Perret &

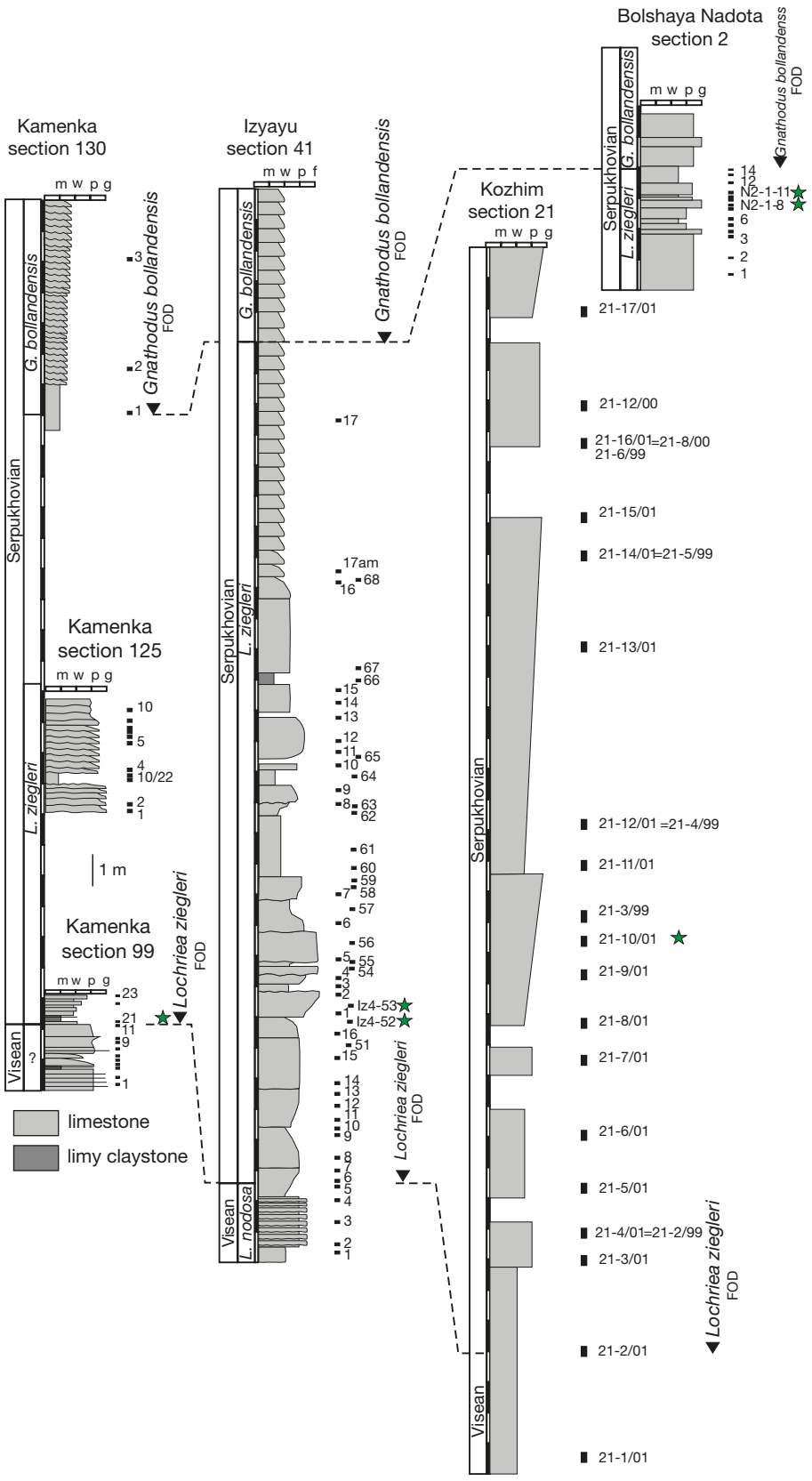



FIG. 2. — Correlation of the key sections of the uppermost Viséan-Serpukhovian interval in the North Urals and Cis-Urals (Vevel *et al.* 2018; Zhuravlev *et al.* 2023). Abbreviations: **m**, mudstone; **w**, wackestones; **p**, packstone; **g**, grainstone; **f**, floatstone; **FOD**, first occurrence datum; ***G.***, *Gnathodus* Pander, 1856; ***L.***, *Lochriea* Scott, 1942. The **stars** mark occurrences of *Lochriea monocarinata* n. sp.

Meischner, 1994, *L. mononodosa* (Rhodes, Austin & Druce, 1969), *L. nodosa* (Bischoff, 1957), *L. cruciformis* (Clarke, 1960), *L. multinodosa* (Wirth, 1967)) from the Late Viséan and Serpukhovian show complication of morphology, mainly in the ornamentation of the basal cup (e.g. Qi *et al.* 2018).

This study aims to describe a new species of advanced *Lochriea* with an ornamented basal cup and to characterise the position of this species in the morphospace of the genus.

## MATERIAL AND METHODS

This study is based on the author's conodont collections from the late Mississippian key sections of the northern Cis-Urals and Subpolar Urals (Figs 1; 2), and analyses of published data (Metcalfe 1981; Kulagina *et al.* 1992; Nemirovskaya *et al.* 1994, Skompski *et al.* 1995; Belka & Lehmann 1998; Nemyrovska *et al.* 2006; Qi *et al.* 2014, 2018; Barham *et al.* 2015; Richards *et al.* 2017; Wang *et al.* 2018; Nikolaeva *et al.* 2020, etc.).

The upper Viséan-Serpukhovian carbonate platform deposits cropping out in the northern Cis-Urals and Subpolar Urals regions yield diverse conodonts including *Lochriea* species (e.g. Zhuravlev 2003; Vevel *et al.* 2017; Zhuravlev *et al.* 2023). In total, about 480 P1 elements represent *Lochriea* species in the studied collections. About 300 of them belong to advanced *Lochriea* species with ornamentation on the basal cup. *Lochriea commutata* represents about 25% of the total P1 elements of *Lochriea* in the studied collections, but each highly ornamented species composes 2-15% of the total P1 elements of the genus.

The Figure 3 explains the terminology used in this study. In general, P1 elements of the genus *Lochriea* show a carminiscaphate morphology with the basal cup located in the middle or posterior (dorsal) part of the element. The cup ornamentation can be represented by node(s), costa, and ridges. Specific terminology is used here to distinguish variations in cup ornamentation in advanced *Lochriea*. The term costa is used to refer to swell-like elongated, smooth or poorly ornamented with smooth nodes structures. The term ridge is used for elongated structures consisting of a series of crenulated nodes arranged on the raised area. In some cases, the nodes form an array covering almost the entire surface of the basal cup (e.g. *Lochriea multinodosa*). The ornamentation of the outer (rostral) and inner (caudal) parts of the cup and the morphology of the carina are the main specific traits of the members of the genus *Lochriea*. The terms for the orientation of the elements (Fig. 3) follow Purnell *et al.* (2000).

## MORPHOSPACE OF THE P1 ELEMENTS OF *LOCHRIEA*

Various combinations of basal cup position, cup ornamentation type and distribution, and carina morphology make up the morphospace of P1 elements of the genus (Fig. 4). The subdivision of the morphospace is conventional due to the presence of numerous transitional forms (Fig. 5; see also Barham *et al.* 2015; Qi *et al.* 2014, 2018).

The cup ornamentation can be divided into the following types: smooth cup, cup ornamented with node (nodes) (e.g. Fig. 5G, L, Q, X), cup ornamented with costa (costae) (e.g. Fig. 5K, Y), cup ornamented with ridge (ridges), and cup ornamented with numerous nodes (nodose platform). The smooth cup is characteristic of early *Lochriea*, but the ornamented cup is characteristic of advanced *Lochriea*. The node, costa or ridge can ornament the cup on both sides (rostral and caudal) or only on the inner (caudal) side (Fig. 4). The most taxonomically diverse morphological group, consisting of three species (*Lochriea cruciformis*, *L. senckenbergica*, and *L. ziegleri*), shows ridges ornamenting both sides of the basal cup (Figs 4; 5A-F, H, I, M). The ornamentation can be located in the middle part of the cup (*Lochriea cruciformis* and *L. senckenbergica*), or the posterior (dorsal) part of the cup (*Lochriea ziegleri*).

The carina can be narrow or wide in the posterior part. The wide posterior carina is characteristic of species with a smooth basal cup (*Lochriea scotiaensis* and *L. cracoviensis*) (Fig. 4).

A posterior (dorsal) position of the basal cup is found in most species of *Lochriea*. Some early representatives of the genus (*Lochriea saharae*, *L. cracoviensis*) show a basal cup located near the middle part of the P1 element. The posterior displacement of the basal cup and the increasing asymmetry of the basal cup in *Lochriea commutata* during ontogeny is remarkable (Gatovskii & Zhokina 2014). This ontogenetic transformation probably repeats the phylogenetic transformation in the lineage from *Lochriea saharae* to *Lochriea commutata*.

The early *Lochriea* species show the symmetry between the dextral and sinistral P1 elements (Class II symmetry of Lane 1968). Most advanced *Lochriea* demonstrate a weak asymmetry between the dextral and sinistral P1 elements (transition from Class II to Class III symmetry). Only *Lochriea senckenbergica* shows a distinct asymmetry between the dextral and sinistral P1 elements (Class III symmetry of Lane 1968) (Vevel *et al.* 2017: fig. 6).

The morphospace of the P1 elements allows the prediction of the existence of a number of new, previously unknown species. One of these species, *Lochriea monocarinata* n. sp. is described here. It is noteworthy that forms corresponding to the new species were first characterised by Bahram *et al.* (2015) as specimens with complex ornament on only one side of the P1 element. P1 elements of *L. monocarinata* n. sp. represent about 2% of all studied specimens of the genus in the author's collections. Another probable new form with P1 elements bearing a nodose platform only on the inner part of the basal cup remains hypothetical (marked as *Lochriea* sp. B? in Fig. 4).

The morphological types represented in the morphospace (Fig. 4) are linked to each other by a large number of transitional forms. The morphological transitions are known between *Lochriea saharae* and *L. commutata* (Nemyrovska *et al.* 2006), as well as between *L. commutata* and *L. cracov-*

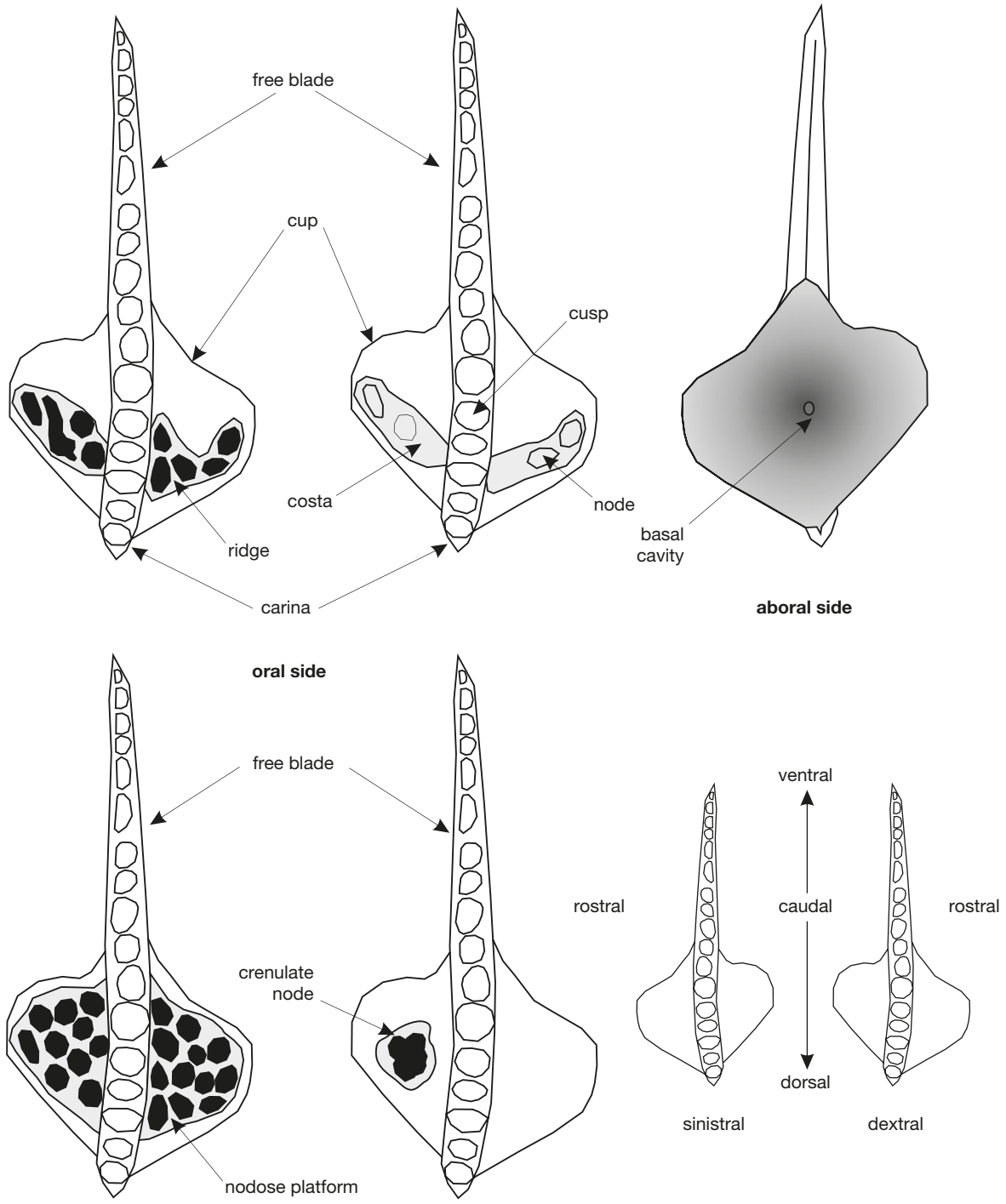



FIG. 3. — Morphology of the P1 element of *Lochriea* Scott, 1942 and the terms for the orientation of the elements (Purnell *et al.* 2000).

*iensis* (Belka 1985) in early *Lochriea*. Transitions between *L. commutata* and *L. monocostata* (e.g. Qi *et al.* 2018: fig. 4), between *L. commutata* and *L. costata* (e.g. Barham *et al.* 2015: fig. 10.6), between *L. commutata* and *L. mononodosa* (Fig. 5O, T) (see also Barham *et al.* 2015: fig. 13) connect early and advanced *Lochriea*. Advanced *Lochriea* show morphological transitions between *L. mononodosa* and *L. nodosa* (Qi *et al.* 2018: fig. 4); *L. mononodosa* and *L. monocostata* (e.g. Barham *et al.* 2015: fig. 10.1a, b); *L. mononodosa* and *L senckenbergica* (e.g. Barham *et al.* 2015: figs 11.7, 11.12); *L. mononodosa* and *L. ziegleri* (e.g. Barham *et al.* 2015: figs 10.8, 11.11); *L. mononodosa* and *L. cruciformis* (e.g. Barham *et al.* 2015: figs 11.4, 11.5); *L. nodosa* and *L. costata* (Barham *et al.* 2015: fig. 10.2a, b; Kullmann *et al.* 2008: figs. 9.1, 9.5; Nikolaeva *et al.* 2009: fig. 6J); *L. nodosa* and *L. senckenbergica* (e.g. Qi *et al.* 2018: fig. 4); *L. nodosa* and *L. ziegleri* (e.g. Qi *et al.* 2018: fig. 4; Barham *et al.* 2015: figs 10.4a, b, 10.7, 10.9, 10.11, 11.9, 11.13; Nemirovskaya

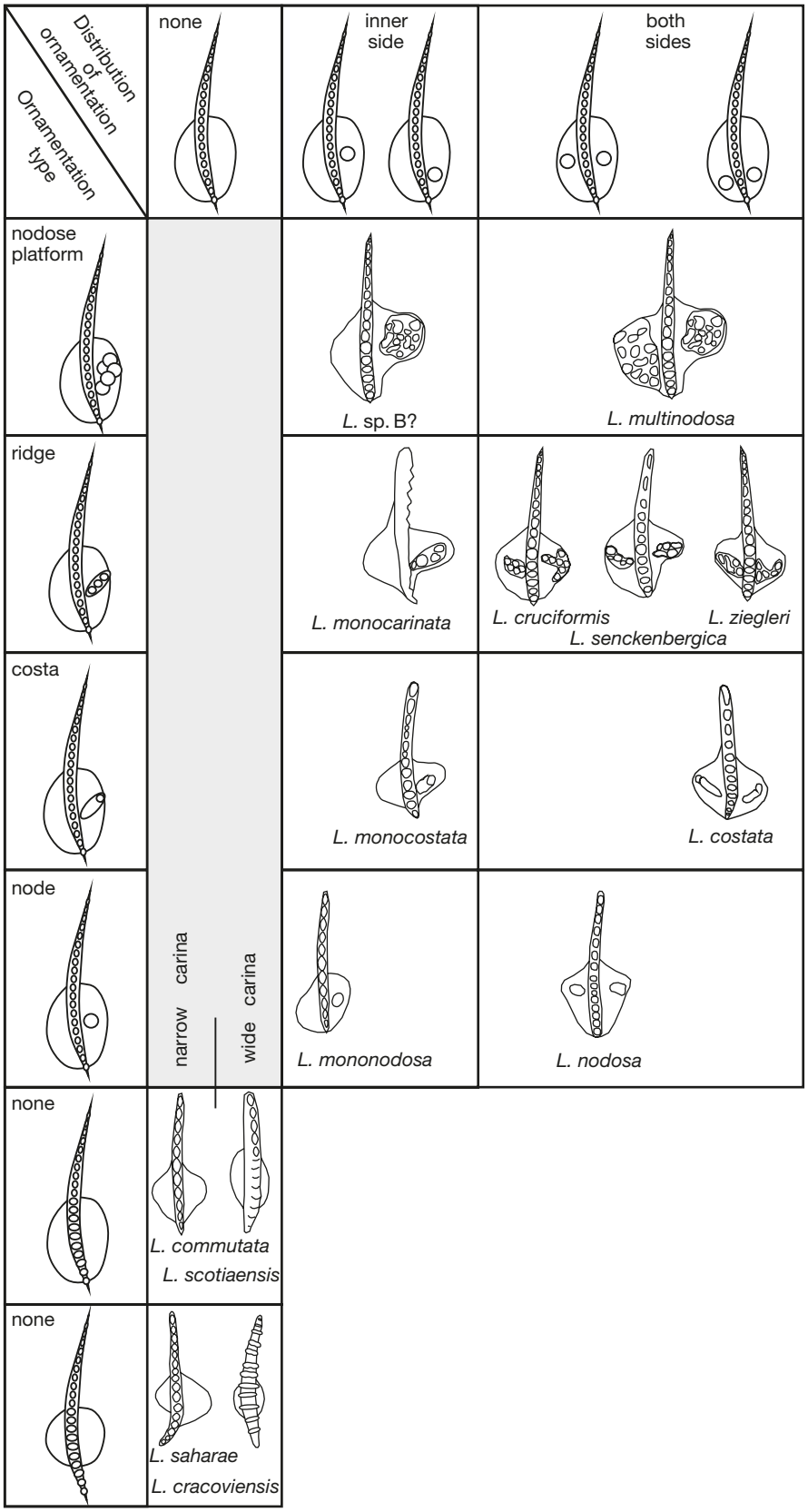



Fig. 4. — Morphospace of the P1 elements of *Lochriea* Scott, 1942.

*et al.* 1994: pl.2, fig. 6); *L. nodosa* and *L. cruciformis* (e.g. Barham *et al.* 2015: fig. 10.3a,b; Nemyrovska 2005: pl.8, fig. 9); *L. nodosa* and *L. multinodosa* (e.g. Kullmann *et al.* 2008: fig. 10.3; Nemyrovska 2005: pl. 8, fig. 15). Also, transitional forms are known between *L. monocostata* and *L. costata* (e.g. Qi *et al.* 2018: fig. 4; Nikolaeva *et al.* 2020: fig. 12C as *L. monocostata*); *L. costata* and *L senckenbergica* (e.g. Qi *et al.* 2018: fig. 4); *L senckenbergica* and *L. ziegleri* (e.g. Nemirovskaya *et al.* 1994: pl. 2, fig. 14); *L. ziegleri* and *L. cruciformis* (e.g. Barham *et al.* 2015: figs 10.5, 10.10); *L. senckenbergica* and *L. cruciformis* (Fig. 5E, F). These morphological transitions complicate the taxonomic diagnostics of *Lochriea* species, especially among the advanced *Lochriea* (e.g. Herbig 2017).

The morphological diversity, the known problems with the holotypes of a number of species of *Lochriea*, and the lack of knowledge about the apparatus composition of most species prevent an adequate taxonomic revision of this genus (Alekseev & Nikolaeva 2019). The complete taxonomic revision of the genus is beyond the scope of this paper.

## SYSTEMATIC PALAEONTOLOGY

Class CONODONTA Pander, 1856
Order OZARKODINIDA Dzik, 1976
Suborder OZARKODININA Dzik, 1976
Family SPATHOGNATHODONTIDAE Hass, 1959

### Genus *Lochriea* Scott, 1942

TYPE SPECIES. — *Lochriea montanaensis* Scott, 1942 by original designation.

### ***Lochriea monocarinata*** n. sp.
(Fig. 5N, P, R, S, U-W, Z)

urn:lsid:zoobank.org:act:76E819C9-6E67-454A-BA37-C8CEA4BAF80E

*Gnathodus nodosus* – Metcalfe 1981: 47, pl. 7, fig. 3.

*Paragnathodus monocostatus* – Kulagina *et al.* 1992: pl. XXIX, fig. 7.

*Lochriea* sp. – Barham *et al.* 2015: 15, figs 11.1, 11.12, 11.4, 11.5, 11.7.

*Lochriea* sp. – Wang *et al.* 2018: 438, figs 3.53, 3.54.

*Lochriea monocostata* – Nikolaeva *et al.* 2020: fig. 12J.

ETYMOLOGY. — According to the ornamentation of basal cup represented by a single ridge.

TYPE MATERIAL. — **Russia** • North Cis-Urals, Tchenyshev Ridge, Izyayu section; 65°33'9.53"N, 58°38'50.32"E; Mississippian, early Serpukhovian, *L. ziegleri* Zone; holotype: specimen 445/12, sample Iz4-52/98 (Fig. 5Z), housed in Chernov Museum of Institute of Geology FRC Komi SC UrB RAS, Syktyvkar.

TYPE LOCALITY. — Izyayu section, Tchenyshev Ridge, North Cis-Urals, Russia (65°33'9.53"N, 58°38'50.32"E).

TYPE AGE. — Mississippian, early Serpukhovian, *L. ziegleri* Zone.

DIAGNOSIS. — Species of *Lochriea* with P1 element bearing the nodose ridge on the inner (caudal) part of the asymmetrical basal cup.

MATERIAL EXAMINED. — Nine specimens from the Serpukhovian of North Urals and North Cis-Urals.

DISTRIBUTION. — The new species is known from the lower Serpukhovian (*L. ziegleri* Zone) of the North Cis-Urals, Sub-Polar Urals, South Urals (Eastern Laurussia), Rhenish Mountains (Wang *et al.* 2018), northwest Ireland (Barham *et al.* 2015) and Craven Lowlands of northern England (Metcalfe 1981) (Southern Laurussia).

#### DESCRIPTION

The carminiscaphate P1 element has a basal cap located near the posterior (dorsal) end. Carina is high with denticles of almost uniform height. Upper part of denticles in posterior part of carina is broad and bears pustulation. Cup is asymmetrical and bears the nodose crenulated ridge on the inner (caudal) side.

Sinistral and dextral P1 elements compose an almost symmetrical pair (transition from Class II symmetry to Class III symmetry). The dextral elements are characterised by less cup asymmetry and a ventrally displaced nodose ridge (Fig. 6E-G). The sinistral elements show a more developed ridge ornamentation compared to the dextral elements at the same stage of ontogeny (Fig. 6A-D). Sinistral P1 elements have isometric nodes on ridge, but dextral P1 elements have elongated nodes on ridge. This difference in node shape probably provides better occlusion of the sinistral and dextral elements. The asymmetry of the sinistral and dextral P1 elements ensures that they are occluded in the apparatus in a "dextral in front of the sinistral" pattern (Fig. 6H). The apparatus composition of the new species has not yet been reconstructed. *Lochriea monocarinata* n. sp. probably shares S, M, and P2 elements with other advanced representatives of the genus *Lochriea* (e.g. Fig. 5AA).

#### REMARKS

The new species differs from *Lochriea monocostata* by distinct crenulate nodose ornamentation on the inner ridge. Transitional forms from *L. monocostata* to *L. monocarinata* n. sp. possess weak nodose ornamentation of the costa consisting of one or two small and smooth nodes (Fig. 5Y) (see also Nemirovskaya *et al.* 1994: pl. 2, fig. 3; Nemyrovska *et al.* 2011: pl. 2, fig. 2; Nikolaeva *et al.* 2020: fig. 12A). The morphological transitions from *L. mononodosa* to *L. monocarinata* n. sp. (Fig. 5Q) and from *L. monocarinata* n. sp. to *L. ziegleri* (Fig. 5J) also occur. *Lochriea monocarinata* n. sp. can be distinguished from *L. mononodosa* and *L. monocostata* by the presence of at least three crenulate nodes forming the ridge. The ornamentation of the P1 elements of *L. monocarinata* n. sp. in the early stages of ontogeny is almost identical to that of *L. monocostata* or *L. mononodosa*. If the nodes are crenulated, specimens with a ridge decorated with two nodes in the early stages of ontogeny can be identified as *L. monocarinata* n. sp. (e.g. Figs 5Q; 6A, E).

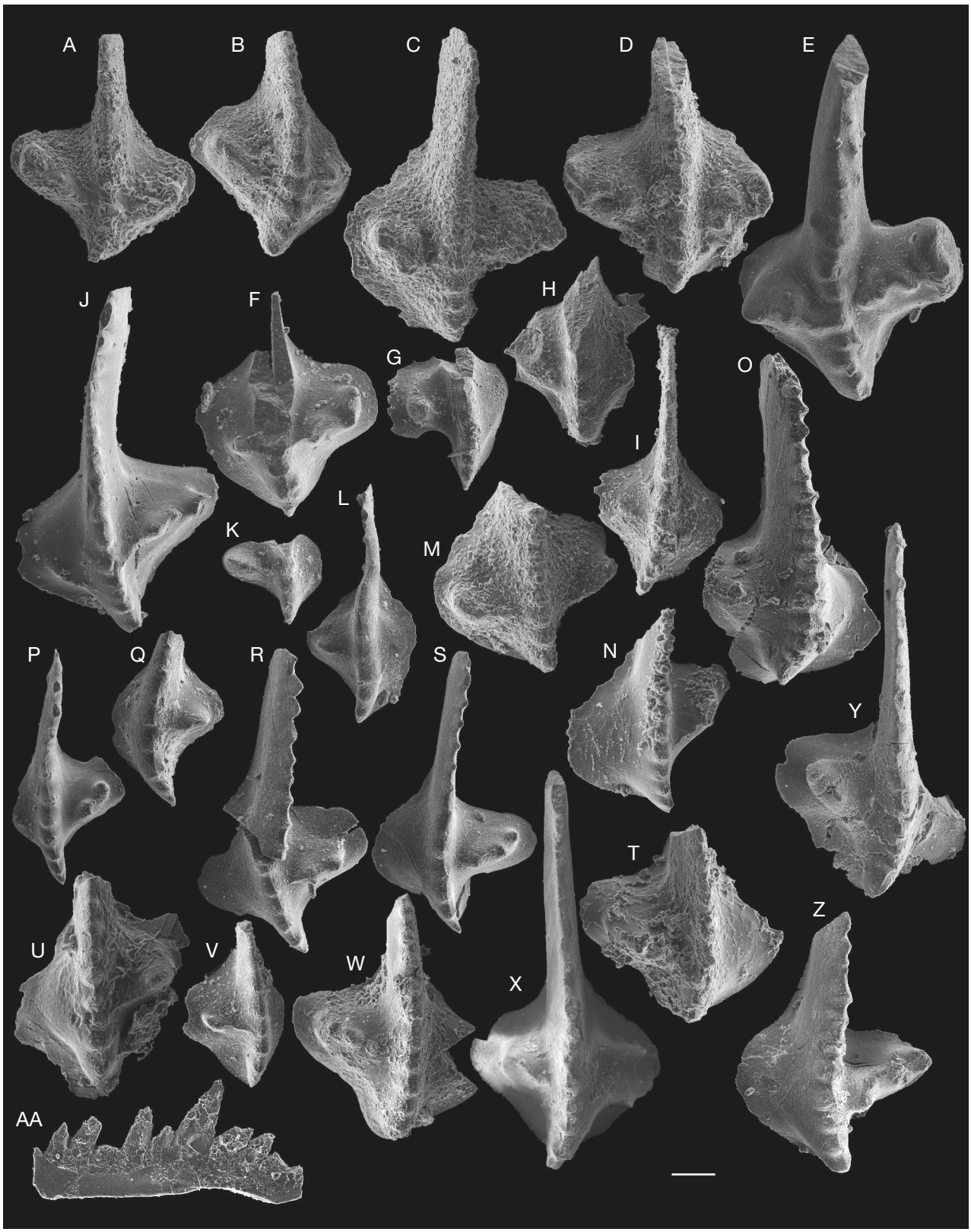



Fig. 5. — Some advanced *Lochriea* from the Serpukhovian (*Lochriea ziegleri* Zone) of North of Urals and Cis-Urals region: **A**, *Lochriea ziegleri* Nemirovskaya, Perret-Mirouse, Meischner, 1994, specimen 145/24, sample Iz4-51/98, Izyayu section; **B**, *Lochriea ziegleri* Nemirovskaya, Perret & Meischner, 1994, specimen 145/19, sample K99-21/22, Kamenka section; **C**, *Lochriea senckenbergica* Nemirovskaya, Perret & Meischner, 1994, specimen 145/22, sample 125-19/22, Kamenka section; **D**, *Lochriea ziegleri* Nemirovskaya, Perret & Meischner, 1994, specimen 145/20, sample K99-21/22, Kamenka section; **E**, *Lochriea senckenbergica* Nemirovskaya, Perret & Meischner, 1994-*Lochriea cruciformis* (Clarke, 1960) transition, specimen 145/23, sample Iz4-52/98, Izyayu section; **F**, *Lochriea senckenbergica* Nemirovskaya, Perret & Meischner, 1994 – *Lochriea cruciformis* (Clarke, 1960) transition, specimen 145/27, sample Iz4-53/98, Izyayu section; **G**, *Lochriea mononodosa* (Rhodes, Austin & Druce, 1969), specimen 145/15, sample N2-1-11/99, Bolshaya Nadota section; **H**, *Lochriea* sp., specimen 145/12,

## CONCLUDING REMARKS

The wide geographical distribution in the narrow stratigraphic interval (*L. ziegleri* Zone) of the forms described here as *Lochriea monocarinata* n. sp. suggests that these forms are not teratomorphic, but represent the evolutionary stage of advanced *Lochriea*. The presence of dextral and sinistral elements with morphological features of the new species also supports the validity of this taxon. The position of P1 elements of *L. monocarinata* n. sp. in the morphospace of the genus allows the author to assume evolutionary or at least morphogenetic relationships of this species with *L. monocostata* and *L. ziegleri*. In any case, the range of *L. monocarinata* n. sp. restricted by the *L. ziegleri* Zone allows this species to be used as an auxiliary biostratigraphic marker of the lower Serpukhovian.

**Acknowledgements**
The author would like to thank E. M. Tropnikov and A. S. Shuisky (Institute of Geology FRC Komi SC, UrB RAS, Syktyvkar, Russia) for their assistance with the SEM work. The author is grateful to Dr. Javier Sanz-López (Facultad de Geología, Oviedo, Spain) and to an anonymous reviewer for providing constructive comments and recommendations toward the improvement of the manuscript.

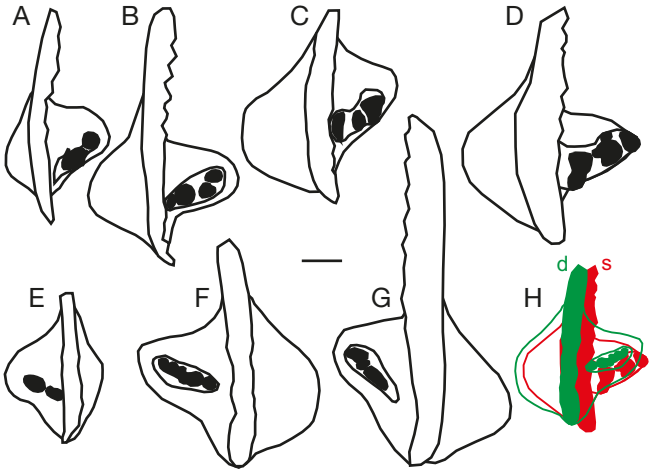



FIG. 6. — Morphological schemes of sinistral (**A**-**D**) and dextral (**E**-**G**) P1 elements of *Lochriea monocarinata* n. sp. and scheme of probable occlusion of sinistral (**red**) and dextral (**green**) elements (**H**). The line drawings are based on the SEM microphotographs (see Fig. 5). **D**, holotype, specimen 445/12. Abbreviations: **d**, dextral; **s**, sinistral.

## REFERENCES

ALEKSEEV A. S. & NIKOLAEVA S. V. 2019. — Compendium of the genus *Lochriea* (Conodonta, Mississippian). *Bulletin MOIP. Geology* 94 (3): 56-78.

ATAKUL-ÖZDEMIR A., PURNELL M. A. & RILEY N. J. 2012. — Cladistic tests of monophyly and relationships of biostratigraphically significant conodonts using multielement skeletal data – *Lochriea homopunctatus* and the genus *Lochriea*. *Palaeontology* 55(6): 1279-1291. https://doi.org/10.1111/j.1475-4983.2012.01190.x

AUSTIN R. L. & HUSRI S. 1974. — Dinantian conodont faunas of County Clare, County Limerick, and County Leitrim. An appendix, *in* BOUCKAERT J. & STREEL M. (eds), Namur-1974. International Symposium on Belgian Micropaleontological Limits. From Emsian to Viséan. September 1st to 10th. Publication no. 3. Geological Survey of Belgium, Brussels: 18-69.

BARHAM M., MURRAY J, SEVASTOPULO G. D. & WILLIAMS D. M. 2015. — Conodonts of the genus *Lochriea* in Ireland and the recognition of the Viséan-Serpukhovian (Carboniferous) boundary. *Lethaia*: 12096. https://doi.org/10.1111/let.12096

BELKA Z. 1985. — Lower Carboniferous conodont biostratigraphy in the northern part of the Morvia-Silesia Basin. *Acta Geologica Polonica* 35: 1-60.

BELKA Z. & LEHMANN J. 1998. — Late Visean/early Namurian conodont succession from the Esla area of the Cantabrian Mountains, Spain. *Acta Geologica Polonica* 48 (1): 31-41.

BISCHOFF G. 1957. — Die Conodonten-Stratigraphie des rhenoherzynischen Unterkarbons mit Berucksichtigung der Wocklumeria-Stufe und der Devon/Karbon-Grenze. *Abhandlungen des Hessischen Landesamtes für Bodenforschung* 19: 1-64.

BRANSON E. B. & MEHL M. G. 1941. — New and little known Carboniferous conodont genera. *Journal of Paleontology* 15: 97-106. https://www.jstor.org/stable/1298937

BRIGGS D. E. G., CLARKSON E. N. K. & ALDRIDGE R. 1983. — The conodont animal. *Lethaia* 16: 1-14.

CLARKE W. J. 1960. — Scottish Carboniferous conodonts. *Transactions of the Edinburgh Geological Society* 18: 1-31.

DZIK J. 1976. — Remarks on the evolution of Ordovician conodonts. *Acta Palaeontologica Polonica* 21: 395-455.

DU Y., ONOUE T., TOMIMATSU Y., WU Q. & RIGO M. 2023. — Lower Jurassic conodonts from the Inuyama area of Japan: implications for conodont extinction. *Frontiers in Ecology and Evolution* 11: 1135789. https://doi.org/10.3389/fevo.2023.1135789

GATOVSKII YU. A. & ZHOKINA M. A. 2014. — The ontogenesis of several Late Visean conodonts from the Verkhnyaya Kardailovka section (Southern Urals). *Moscow University Geology Bulletin* 69(6): 452-457.

GLOBENSKY Y. 1967. — Middle and Upper Mississippian conodonts from the Windsor Group of the Atlantic Province. *Journal of Palaeontology* 41: 432-448.

sample N2-1-7/99, Bolshaya Nadota section; **I**, *Lochriea ziegleri* Nemirovskaya, Perret & Meischner, 1994, specimen 145/18, sample K99-21/22, Kamenka section; **J**, *Lochriea monocarinata* n. sp.-*Lochriea ziegleri* Nemirovskaya, Perret & Meischner, 1994 transition, specimen 145/14, sample N2-1-10/99, Bolshaya Nadota section; **K**, *Lochriea monocostata* (Pazukhin & Nemirovskaya in Kulagina *et al.*, 1992), specimen 145/4, sample lz4-53/98, Izyayu section; **L**, *Lochriea mononodosa* (Rhodes, Austin & Druce, 1969), specimen 145/8, sample lz4-52/98, Izyayu section; **M**, *Lochriea ziegleri* Nemirovskaya, Perret & Meischner, 1994, specimen 145/21, sample K99-21/22, Kamenka section; **N**, *Lochriea monocarinata* n. sp., specimen 145/16, sample N2-1-11/99, Bolshaya Nadota section; **O**, *Lochriea commutata* (Branson & Mehl, 1941)-*Lochriea mononodosa* (Rhodes, Austin & Druce, 1969) transition, specimen 145/11, sample N2-1-5/99, Bolshaya Nadota section; **P**, *Lochriea monocarinata* n. sp., specimen 145/17, sample N2-1-11/99, Bolshaya Nadota section; **Q**, *Lochriea mononodosa* (Rhodes, Austin & Druce, 1969)-*Lochriea monocarinata* n. sp. transition, specimen 145/3, sample lz4-53/98, Izyayu section; **R**, *Lochriea monocarinata* n. sp., specimen 145/7, sample lz4-52/98, Izyayu section; **S**, *Lochriea monocarinata* n. sp., specimen 145/6, sample lz4-52/98, Izyayu section; **T**, *Lochriea mononodosa* (Rhodes, Austin & Druce, 1969)-*Lochriea monocarinata* n. sp. transition, specimen145/9, sample lz4-60/98, Izyayu section; **U**, *Lochriea monocarinata* n. sp., specimen 145/10, sample N2-1-5/99, Bolshaya Nadota section; **V**, *Lochriea monocarinata* n. sp., specimen 145/2, sample lz4-53/98, Izyayu section; **W**, *Lochriea monocarinata* n. sp., specimen 145/1, sample K99-21/22, Kamenka section; **X**, *Lochriea mononodosa* (Rhodes, Austin & Druce, 1969), specimen 145/25, sample lz4-45/98, Izyayu section; **Y**, *Lochriea monocostata* (Pazukhin & Nemirovskaya in Kulagina *et al.*, 1992)-*Lochriea monocarinata* n. sp. transition, specimen 145/13, sample N2-1-8/99, Bolshaya Nadota section; **Z**, *Lochriea monocarinata* n. sp., holotype, specimen 445/12, sample lz4-52/98, Izyayu section; **AA**, *Lochriea* sp., P2 element, specimen 145/26, sample lz4-51/98, Izyayu section. Scale bar: 0.1 mm.

HASS W. H. 1959. — Conodonts from the Chappel Limestone of Texas. *US Geological Survey Professional Paper* 294-J: 385-399.
HERBIG H.-G. 2017. — Taxonomic and stratigraphic problems concerning the conodonts *Lochriea senckenbergica* Nemirovskaya, Perret & Meischner, 1994 and *Lochriea ziegleri* Nemirovskaya, Perret & Meischner, 1994 – consequences for defining the Viséan-Serpukhovian boundary. *Newsletter on Carboniferous Stratigraphy* 33: 28-35.
HU K., QI Y. & NEMYROVSKA T. I. 2019. — Mid-Carboniferous conodonts and their evolution: new evidence from Guizhou, South China. *Journal of Systematic Palaeontology* 17 (6): 451-489. https://doi.org/10.1080/14772019.2018.1440255
KULAGINA E. I., RUMYANTSEVA Z. S., PAZUKHIN V. N. & KOCHETOVA N. N. 1992. — *Lower/Middle Carboniferous Boundary in the South Urals and Central Tien Shan*. Nauka Publ., Moscow, 112 p. (in Russian).
KULLMANN J., PERRET MIROUSE M.-F. & DELVOLVÉ J.-J. 2008. — Late Visean/Serpukhovian goniatites and conodonts from the Central and Western Pyrenees, France. *Geobios* 41: 635-656. https://doi.org/10.1016/j.geobios.2007.09.003
LANE H. R. 1968. — Symmetry in conodont element-pairs. *Journal of Paleontology* 42 (5): 1258-1263.
METCALFE I. 1981. — Conodont zonation and correlation of Dinantian and early Namurian strata of the Craven Lowlands of Northern England. *Institute of Geological Science, London HMSO, Report* 80/10: 1-70.
MIZUNO Y. 1997. — Conodont faunas across the Mid-Carboniferous boundary in the Hina Limestone, Southwest Japan. *Paleontological Research* 1 (4): 237-259. https://doi.org/10.2517/prpsj.1.237
NEMYROVSKA T. I. (with an appendix by Samankassou E.) 2005. — Late Viséan/early Serpukhovian conodont succession from the Triollo section, Palencia (Cantabrian Mountains, Spain). *Scripta Geologica* 129: 13-89.
NEMIROVSKAYA T., PERRET M.-F. & MEISCHNER D. 1994. — *Lochriea ziegleri* and *Lochriea senckenbergica* – new conodont species from the latest Viséan and Serpukhovian in Europe. *Courier Forschungsinstitut Senckenberg* 168: 311-317.
NEMYROVSKA T. I., PERRET-MIROUSE M.-F. & WEYANT M. 2006. — The early Viséan (Carboniferous) conodonts from the Saoura Valley, Algeria. *Acta Geologica Polonica* 56 (3): 361-370.
NEMYROVSKA T. I., WAGNER R. H., WINKLER PRINS C. F. & MONTANEZ I. 2011. — Conodont faunas across the mid-Carboniferous boundary from the Barcaliente Formation at La Lastra (Palentian Zone, Cantabrian Mountains, northwest Spain); geological setting, sedimentological characters and faunal descriptions. *Scripta Geologica* 143: 127-183.
NIKOLAEVA S. V., ALEKSEEV A. S., KULAGINA E. I., GATOVSKY Y. A., PONOMAREVA G. Y. & GIBSHMAN N. B. 2020. — An evaluation of biostratigraphic markers across multiple geological sections in the search for the GSSP of the base of the Serpukhovian Stage (Mississippian). *Palaeoworld* 29: 270-302. https://doi.org/10.1016/j.palwor.2019.01.006
NIKOLAEVA S. V., KULAGINA E. I., PAZUKHIN V. N., KOCHETOVA N. N. & KONOVALOVA V. A. 2009. — Paleontology and Microfacies of the Serpukhovian in the Verkhnyaya Kardailovka Section, South Urals, Russia: potential candidate for the GSSP for the Viséan-Serpukhovian boundary. *Newsletters on Stratigraphy* 43: 165-193. https://doi.org/10.1127/0078-0421/2009/0043-0165
PANDER C. H. 1856. — *Monographie der fossilen Fische des silurischen Systems der russischbaltischen Gouvernements*. Akademie der Wissenschaften, St. Petersburg, 91 p.
PURNELL M. A., DONOGHUE P. C. J. & ALDRIDGE R. J. 2000. — Orientation and anatomical notation in conodonts. *Journal of Paleontology* 74: 113-122. https://www.jstor.org/stable/1306889
QI Y., NEMYROVSKA T. I., WANG X., CHEN J., WANG Z., LANE H. R., RICHARDS B. C., HU K. & WANG Q. 2014. — Late Viséan-early Serpukhovian conodont succession at the Naqing (Nashui) section in Guizhou, South China. *Geological Magazine* 151: 254-268. https://doi.org/10.1017/S001675681300071X
QI Y., NEMYROVSKA T. I., WANG Q., HU K., WANG X. & LANE H. R. 2018. — Conodonts of the genus *Lochriea* near the Viséan-Serpukhovian boundary (Mississippian) at the Naqing section, Guizhou Province, South China. *Palaeoworld* 27 (4): 423-437. https://doi.org/10.1016/j.palwor.2018.09.001
QI Y. P. & WANG Z. H. 2005. — Serpukhovian conodont sequence and the Visean-Serpukhovian boundary in South China. *Rivista Italiana di Paleontologia e Stratigrafia* 111: 3-10.
RHODES F. H. T., AUSTIN R. L. & DRUCE E. C. 1969. — British Avonian (Carboniferous) conodont faunas and their value in local and intercontinental correlation. *Bulletin of the British Museum (Natural History). Geology. Supplement* 5: 1-314.
RICHARDS B. C. 2010. — Report of the task group to establish a GSSP close to the existing Viséan-Serpukhovian boundary. *Newsletter on Carboniferous Stratigraphy* 28: 30-34.
RICHARDS B. C., ARETZ M., BARNETT A., BARSKOV I., BLANCO-FERRERA S., BRENCKLE P. L., CLAYTON G., DEAN M., ELLWOOD B., GIBSHMAN N., HECKER M., KONOVALOVA V. A., KORN D., KULAGINA E., LANE R., MAMET B., NEMYROVSKA T., NIKOLAEVA S. V., PAZUKHIN V., QI Y.-P., SANZ-LÓPEZ J., SALTZMAN M. R., TITUS A., UTTING J. & WANG X. 2011. — Report of the Task Group to establish a GSSP close to the existing Viséan-Serpukhovian boundary. *Newsletter on Carboniferous Stratigraphy* 29: 26-30.
RICHARDS B. C., NIKOLAEVA S. V., KULAGINA E. I., ALEKSEEV A. S., GOROZHANINA E. N., GOROZHANIN V. M., KONOVALOVA V. A., GOREVA N. V., JOACHIMSKI M. M. & GATOVSKY Y. A. 2017. — A candidate for the Global Stratotype Section and Point at the base of the Serpukhovian in the South Urals, Russia. *Stratigraphy and Geological Correlation* 25 (7): 697-758. https://doi.org/10.1134/S0869593817070036
SANZ-LÓPEZ J., BLANCO-FERRERA S. & SANCHEZ DE POSADA L. C. 2013. — Conodont chronostratigraphical resolution and *Declinognathodus* evolution close to the Mid-Carboniferous Boundary in the Barcaliente Formation type section, NW Spain. *Lethaia* 46 (4): 438-453. https://doi.org/10.1111/let.12021
SANZ-LÓPEZ J., BLANCO-FERRERA S. & MILLER C. G. 2018. — Morphologic variation in the P1 element of Mississippian species of the conodont genus *Pseudognathodus*. *Revista Espanola de Paleontologia* 33: 185-204. https://doi.org/10.7203/sjp.33.1.13248.
SCOTT H. W. 1942. — Conodont assemblages from the Heath Formation, Montana. *Journal of Paleontology* 16: 293-300. https://www.jstor.org/stable/1298905
SEVASTOPULO G. D. & BARHAM M. 2014. — Correlation of the base of the Serpukhovian Stage (Mississippian) in NW Europe. *Geological Magazine* 152: 244-253. https://doi.org/10.1017/S0016756813000630
SKOMPSKI S. 1996. — Stratigraphic position and facies significance of the limestone bands in the subsurface Carboniferous succession of the Lublin Upland. *Acta Geologica Polonica* 46 (3-4): 171-268.
SKOMPSKI S., ALEKSEEV A., MEISCHNER D., NEMIROVSKAYA T., PERRET M.-F. & VARKER W. J. 1995. — Conodont distribution across the Viséan/Namurian boundary. *Courier Forschungsinstitut Senckenberg* 188: 177-209.
SUDAR M. N., NOVAK M., KORN D. & JOVANOVIĆ D. 2018. — Conodont biostratigraphy and microfacies of the Late Devonian to Mississippian Milivojevića Kamenjar section (Družetić, NW Serbia). *Bulletin of Geosciences* 93 (2): 163-183. https://doi.org/10.3140/bull.geosci.1690
SWEET W. 1988. — *The Conodonta. Morphology, Taxonomy, Paleoecology, and Evolutionary History of a Long Extinct Animal Phylum*. Clarendon Press, New York, Oxford, 212 p.
VEVEL Y. A., GRUZDEV D. A. & ZHURAVLEV A. V. 2017. — Foraminifers and conodonts of shallow-water deposits of the early Serpukhovian age in the Kamenka River section (south of Pechora-Kozhva Megaswell). *Syktyvkar Palaeontological Miscellany* 9: 14-23. (In Russian).

VEVEL Y. A., ZHURAVLEV A. V. & GRUZDEV D. A. 2018. — Lower Serpukhovian (Lower Carboniferous) of the Kozhim River basin (Subpolar Urals). *Neftegazovaya Geologiya. Teoriya i Praktika* 13 (4): 35_2018. https://doi.org/10.17353/2070-5379/35_2018

VON BITTER P. H., NORBY R. D. & STAMM R. G. 2022. — The Carboniferous conodont *Lochriea commutata* (Branson and Mehl, 1941), the type species of *Lochriea* Scott, 1942: nomenclatural history, apparatus composition and effects on *Lochriea* species. *Journal of Paleontology* 96 (87): 1-38. https://doi.org/10.1017/jpa.2021.2

WANG Q. L., KORN D., NEMYROVSKA T. & QI Y. P. 2018. — The Wenne River bank section — an excellent section for the Viséan-Serpukhovian boundary based on conodonts and ammonoids (Mississippian; Rhenish Mountains, Germany). *Newsletters on Stratigraphy* 51 (4): 427-444. https://doi.org/10.1127/nos/2018/0440

WIRTH M. 1967. — Zur Gliederung des höheren Paläozoikums (Givet-Namur) im Gebiet Quinto Real (Westpyrenän) mit Hilfe von Conodonten. *Neues Jahrbuch für Geolologie und Paläontologie. Abhandlungen* 127 (2): 179-244.

ZHURAVLEV A. V. 2003. — *Konodonty verhnego devona-nizhnego karbona Severo-Vostoka Evropejskoj Rossii*. VSEGEI Publ., Saint-Petersburg, 85 p. (in Russian).

ZHURAVLEV A. V., VEVEL Y. A., GRUZDEV D. A. & EROFEEVSKY A. V. 2023. — Late Mississippian (early Serpukhovian) carbon isotope record of northern Laurussia: A proposal for the Viséan/ Serpukhovian boundary. *Revista Mexicana de Ciencias Geológicas* 40(1): 35-43. https://doi.org/10.22201/cgeo.20072902e.2023.1.1722

ZIEGLER W. 1960. — Die Conodonten aus den Gerollen des Zechsteinconglomerate von Rossenay (sudwestlich Rheinland/Niederrhein). *Forschritte in der Geologie von Rheinland und Westfalen* 6: 1-15.

*Submitted on 26 January 2024;*
*accepted on 19 March 2024;*
*published on 21 November 2024.*