Correlation of Early Devonian (Lochkovian–early Pragian) conodont faunas of the South Urals (Russia)

TATYANA MAVRINSKAYA & LADISLAV SLAVÍK

Carbonate successions of the early Lower Devonian (Lochkovian–early Pragian) from the Mindigulovo section (West Zilair Zone, western slope of the South Urals) can be globally correlated using diverse conodont faunas. The number of the documented widespread or cosmopolitan taxa of the Lochkovian and early Pragian age enables the definition of globally recognized conodont successions and the establishment of a refined regional conodont biozonal scale. The present three-fold global subdivision of the Lochkovian Stage can be applied as well to the studied area. The Lochkovian in the South Urals is represented by two Horizons (regional terminology) with different facies development: 1. The Siyak Horizon of the lower Lochkovian characterized by the dominance of shallow-water organogenic limestones of the *hesperius-optima* and *optima-omoalpha* Zones, and 2. The Sherlubai Horizon of the middle and upper Lochkovian age characterized by the dominance of carbonate-terrigenous successions. The middle and upper Lochkovian is subdivided into five biozones (using a binominal system): *omoalpha-eoeleanorae*, *eoeleanorae-eleanorae*, *eleanorae-trigonicus*, *trigonicus-pandora* beta and *pandora* beta-*sulcatus* eta/*steinachensis*. The Lochkovian-Pragian boundary and the early Pragian time are determined by the presence of eognathodontid and icriodontid stocks. The established regional conodont zonal scale in the South Urals provides a solid basis for refined correlation with the Lochkovian–early Pragian carbonate rocks of peri-Gondwana and Euramerica. • Key words: South Urals, West Zilair Zone, Lower Devonian, global conodont correlation, Lochkovian.

MAVRINSKAYA, T. & SLAVÍK, L. Correlation of Early Devonian (Lochkovian–early Pragian) conodont faunas of the South Urals (Russia). *Bulletin of Geosciences 88(2)*, 283–296 (6 figures). Czech Geological Survey, Prague. ISSN 1214-1119. Manuscript received December 19, 2012; accepted in revised form February 11, 2013; published online March 6, 2013; issued June 7, 2013.

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Carbonate successions of Lochkovian age have a high potential with respect to global correlation based on conodont faunas. Regional Lochkovian conodont zonations have been established in many regions in the past decades (*e.g.*, Nevada and Pyrenees, Valenzuela-Ríos & Murphy 1997; Sardinia and Carnic Alps, Corradini & Corriga 2012, Suttner 2007; Prague Synform, Slavík *et al.* 2012). The degree of provincialism during the Lochkovian time was rather low, and the evolution of cosmopolitan lineages enabled a good correlation, even across very distant areas. In spite of the favorable conditions for global correlation, conodont biostratigraphic data from many regions were only fragmentary or lacking for a long time. This paper presents for the first time data from conodont investigation of the interval from the latest Silurian to the early Pragian from the newly described section on the western slope of the South Urals. The stratigraphical framework of the Middle and the Upper Devonian deposits in the South Urals has been already developed. The functional subregional stratigraphic scheme of Devonian, and Lower Devonian especially, is based mostly on brachiopod and coral biostratigraphy (Antsygin *et al.* 1993, Tyazheva & Zhavoronkova 1972, Tyazheva *et al.* 1976). Until now a conodont zonation was established for the Upper Devonian and partly for the Middle Devonian (Abramova 1999, Baryshev & Abramova 1996, Yakupov *et al.* 2002, Abramova & Artyushkova 2004a, b, Artyushkova & Maslov 2008, Maslov & Artyushkova 2010). For a long time, the Lower Devonian conodont biostratigraphy in the South Urals remained undeveloped, as only scattered data have been published (Khalymbadzha *et al.* 1985, Maslov *et al.* 1983, Artyushkova 2009, Maslov & Artyushkova 2010). Accordingly, also the regional conodont zonal scale for the Lochkovian and Pragian was not established and the correlation with former "global" (*i.e.* Cordilleran-based conodont zonation, now obsolete) was performed only indirectly. The main purpose of this paper is to provide a correlation of the freshly presented conodont data from the Lower Devonian

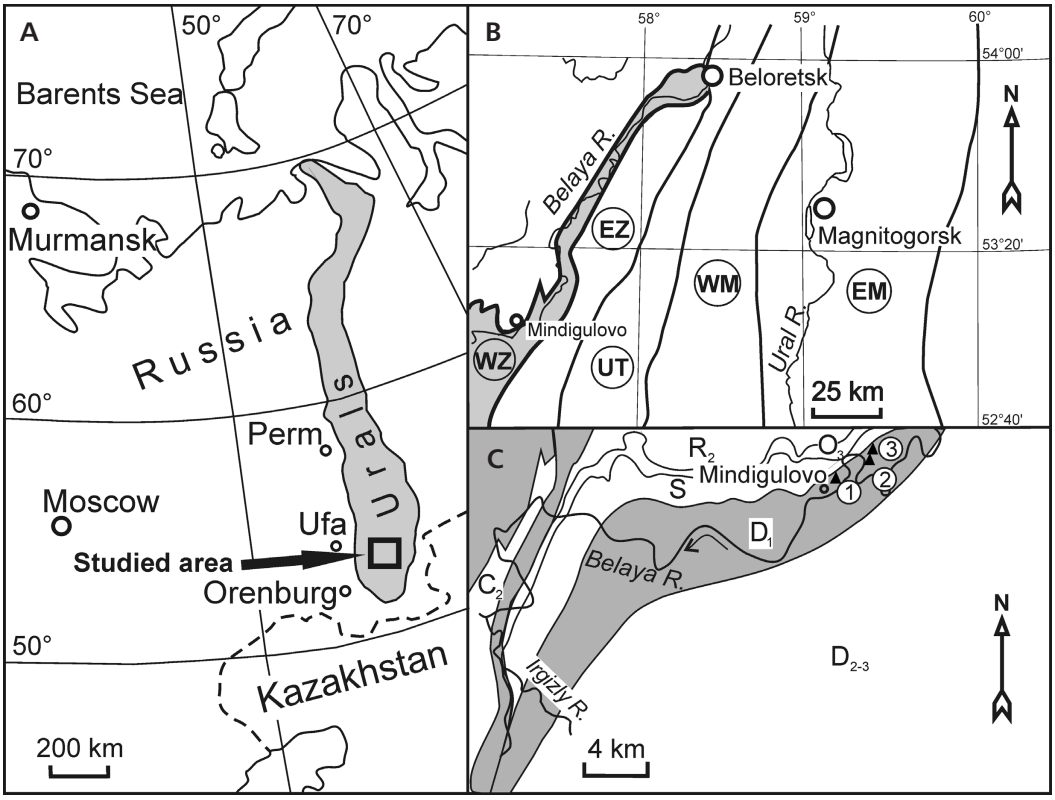


Figure 1. The location maps of the studied area. • A – approximate location of the studied area in the region of Urals Mts. in Russia. • B – a scheme of structural zones of the Urals (fragment). Structural zones are marked with capital letters in circles: WZ – West-Zilair Zone, EZ – East-Zilair Zone, UT – Uraltau Zone, WM – West-Magnitogorsk Megazone, EM – East-Magnitogorsk Megazone. • C – geological map of the area under study (according to Shefer *et al.* 2001 and Knyazev *et al.* 2008) with marked location of outcrops 1, 2 and 3. R_2 – Middle Riphean, O_3 – Upper Ordovician, S – Silurian, D_1 – Lower Devonian, $D_{2–3}$ – Middle–Upper Devonian, C_2 – Middle Carboniferous.

(mostly Lochkovian) of the southern Urals and to test whether the stratigraphic successions of the documented cosmopolitan taxa match with those in other important regions of the Lower Devonian (*i.e.* regions of peri-Gondwana and Euramerica). The prospective applicability of conodont zones widely used in many regions to the area of the South Urals should be the basis for global correlation of the Lower Devonian strata in that part of the World.

A conodont-based subdivision of the Lochkovian Stage was first presented by Klapper (1977) and Klapper & Johnson (1980) on the basis of faunas of the North American Cordillera (see Fig. 2). This first four-fold zonation including the *hesperius*, *eurekaensis*, *delta* and *pesavis* Zones is, however, not globally applicable, as it has limitations that were pointed out by Valenzuela-Ríos (1994a) and Valenzuela-Ríos & Murphy (1997). This applies mostly to the limited regional distribution of the index taxa and poorly defined *pesavis* Zone whose index taxon remains actually unknown. The alternative zonal scheme proposed by Valenzuela-Ríos & Murphy (1997) that was later modified (Murphy & Valenzuela-Ríos 1999) concerns the middle and the upper part of the Lochkovian (*cf.* Fig. 2). In particular, the middle Lochkovian is well elaborated, being based on the successive appearances of taxa within the *Lanea* and *Ancyrodelloides* stocks. Therein, the newly established lineage of *Lanea* has a great importance for detailed subdivision. Slavík (2011) modified the concepts of the *Lanea* and *Ancyrodelloides* lineages by the integration of the taxon *carlsi* in the genus *Lanea* and supported its stratigraphic potential as a marker for the middle Lochkovian because the former taxon *Lanea omoalpha* has much earlier entry and its morphology is not easily distinguishable. Recently, the parts of the middle and upper Lochkovian zonation by Valenzuela-Ríos & Murphy (1997) have been applied with some modifications in Sardinia and Carnic Alps (Corradini & Corriga 2012) and in the Prague Synform (Slavík *et al.* 2012, see Fig. 2).

The conodont investigation was focussed on the Lower Devonian sections located on the banks of the Irgizly, Siyak and Belaya Rivers (see Fig. 1). Studies were carried out on the known limestone exposures with samples taken from each lithological variety. Sampling for conodonts was done both from the bottom and roof of the beds. Homogenous, usually massive organogenic limestones were sampled at 1–3 m intervals. The weight of the rock samples reached 1 to 2 kg on the average. The total number of

samples taken from the sections was 60 (including 10 samples from Irgizly and Siyak sections). Approximate number of obtained conodont elements was about 1100. The samples were processed using standard techniques with formic acid. The volume of insoluble residue was small and thus not subjected to separation in heavy liquids. The number of conodonts per sample varied from 10 to 15 specimens per 1 kg of rock (in massive organogenic limestones) and up to 80–150 specimens per 1 kg of rock (from packstones and micritic limestones). Preservation of conodont elements differed, but in general it was good or satisfactory. Some deformed conodont elements were found in layers owing to effect of tectonics.

The Lower Devonian of the South Urals

Recently, the overall characteristic of the Lower Devonian of the South Urals provided Artyushkova & Maslov (2008). Detailed investigations of the Lower Devonian strata in the western slope were carried out by Krauze & Maslov (1961). Later on, their biostratigraphical subdivision has been done based on monographic research of brachiopods and corals performed by Tyazheva *et al.* (1976). The development of the Early Devonian strata reflects the character of the main facies zones from the Late Silurian. The Lochkovian is underlain by the Ust-Irgizly beds of the Přídolí age. The transition from the underlying Přídolí is gradual and the Silurian-Devonian boundary can be distinguished by the appearance of the typical Devonian brachiopods (genera *Neomphyma* and *Ivdelinia*) and corals (genera *Riphaeolites*, *Pachyfavosites* and *Acanthophyllum*). The Lochkovian is subdivided into two regional Horizons (*i.e.* regional terminology followed herein). The Siyak Horizon characterizes the lower part of the Lochkovian with *Cladopora actuosa*, *Neomphyma originata* and *Lanceomyonia borealiformis* regional biozones (*cf.* Antsygin *et al*. 1993). It is represented by gray-bedded limestones with interbeds of siltstones. The conodonts previously reported from the Siyak Horizon are very poor, represented by early Devonian taxon *Icriodus woschmidti* Ziegler (Maslov *et al.* 1985). The thickness of the lower Lochkovian Siyak Horizon varies from 45 to 70 m. The upper part of the Lochkovian succession is represented by the Sherlubai Horizon, which is correlated by *Favosites intricatus, Pseudamplexus subbrevis* and *Karpinskia vagranensis* regional biozones (*cf.* Antsygin *et al*. 1993; see Fig. 3). The late Lochkovian–early Pragian time is characterized by formation of reef complexes with up to 1000 m thickness of clear carbonate succession (Maslov *et al.* 1985, Artyushkova & Maslov 2008). The Lochkovian strata are overlain by shallow-water carbonates of the early Pragian Kulamat Horizon. The transition between Lochkovian and Pragian strata is also gradual. The Early Emsian time characterizes rapid change in sedimentation patterns with increased facies diversification both in near-shore and off-shore environments and complete transformation of faunal assemblages (for more information on the Emsian see Artyushkova & Maslov 2008).

As for the western slope of the South Urals, the most representative and uninterrupted successions of Lochkovian and Pragian carbonate rocks are located within the West Zilair structural Zone (see Fig. 1). These correspond to near-shore facies. This paper is focused on the Lochkovian strata because these enabled a detailed study due to relatively abundant and higly diversified conodont faunas.

The Lochkovian of the West Zilair Zone and conodont distribution

There are two main lithotypes in the Lochkovian deposits developed in the West Zilair Zone: The carbonate-dominated lithotype characterized by grey organogenic limestones with abundance of benthic faunas (mostly brachiopods and corals); it prevails in the south-western part of the Zone. The carbonate-terrigenous lithotype is represented by thin-layered mixed carbonate-terrigenous rocks containing abundant nektonic and planktonic faunal elements: conodonts, fish remains (thelodonts) and dacryoconarid tentaculites. The outcrops representing this lithotype can be found on the banks of the Belaya River (see Fig. 1C); these have been the subjects of the study presented in this paper.

For the conodont zonation is used herein the binomial system in the sense of Murphy (1977). This nomenclatorial system was originally used in the conodont zonation of the middle and upper Lochkovian by Valenzuela-Ríos & Murphy (1997); please note it is not an ancestor-descendant sequence (see Figs 2 and 3).

The carbonate-dominated lithotype

The sections of this rock-type have been studied in detail along the Irgizly River and its tributaries. They are considered to be the type sections for the established regional horizons. Their basic biostratigraphical characteristics are adopted from Tyazheva *et al.* (1976) and Antsygin *et al.* (1993).

The Ust-Irgizly beds occur stratigraphically below the Siyak deposits of the Lochkovian age and correspond to the Přídolí (upper Silurian). They are represented by grey layered and selectively dolomitized organogenic limestones with scarce intercalations of siltstones. The Přídolí strata are characterized by corals *Entelophyllum lossenifformis* (Zheltonogova), *Microplasma gotlandica* Dybowski, *Riphaeolites priscus* Yanet and brachiopods: *Uralotoechia kuschvensis* (Tschernyschew), *Tectatrypa*

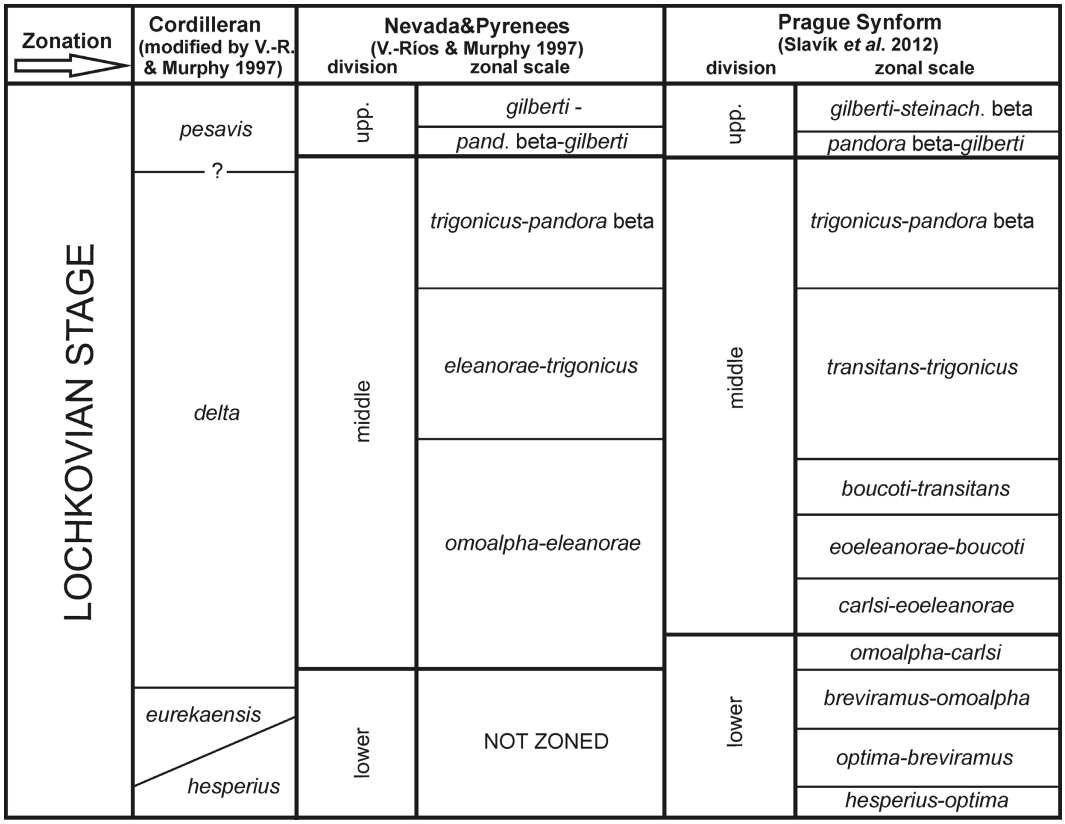


Figure 2. Comparison of different concepts of conodont subdivision of the Lochkovian Stage with the most recent concept based on data from the Prague Synform.

tectiformis (Tschernyschew), *Atrypoidea (Atrypoidea) camelina* (Buch), *Atrypoidea* (*Lingatrypa) linguata* (Buch), *Lissatrypinella kuschvensis* (Tschernyschew). The thickness of the horizon ranges from 20 to 40 m.

As in other parts of the South Urals, the Siyak Horizon is not characterized by a prominent change in lithology from the underlying Ust-Irgizly beds. The boundary between the two units is precisely determined by an abrupt change in the brachiopod and coral assemblages. In the Siyak Horizon, the typical coral species include *Cladopora actuosa* Yanet, *Favosites clarus* Yanet, *Neomphyma originata* (Soshkina), *Pachyfavosites kozlowskii* (Sokolov) and *Riphaeolites ramosus* Yanet. The most important among brachiopods are *Gipidula pelagica* (Barrande), *Lanceomyonia borealiformis* (Siemiradzki), *Protathyris praecursor* Kozlowski, *Rhynchospirina siemiradzkii* Kozlowski and *Spirigerina supramarginalis* Khalfin. The thickness of the Siyak deposits ranges here from 55 to 70 m.

The Sherlubai Horizon includes grey and light-grey thick-layered, indistinctly bedded to massive limestones with diversified coral, brachiopod, bivalve and crinoid faunas. The macrofaunal assemblages that characterize the deposits are rich in taxa that are characteristic only for the Sherlubai Horizon. Among these are typical corals *Favosites admirabilis* Dubatolov, *Favosites shiriktensis* Chekhovich, *Favosites intricatus* Barrande, *Pseudamplexus subbrevis* Shurygina and *Pseudamplexus quadripartitus* Soshkina. Brachiopod fauna is characterized by a significant renovation: *Atrypinella losvensis* Khodalevich, *Karpinskia vagranensis* Khodalevich appear and blossom out together with *Atripopsis thetis* (Barrande), *Clorindina vijaica* Khodalevich, *Protathyris praecursor* Kozlowski, *P. celsus* Tjazheva and others. The thickness of the Sherlubai Horizon in the West Zilair Zone ranges from 60 to 73 m.

The shallow-water clear carbonate facies that occur along the Irgizly River contain only scarce conodonts of the Přídolí and the Lochkovian age. They are represented mostly by elements of long-ranging taxa, *e.g.*, *Delotaxis* Klapper & Philip (= *Oulodus*), *Ozarkodina typica* Branson & Mehl, *Wurmiella excavata* (Branson & Mehl) and *W. wurmi* (Bischoff & Sannemann). This faunal association does not allow a biozonal subdivision due to lack of diagnostic taxa.

The carbonate-terrigenous lithotype

The deposits of this type are developed on the banks of the Belaya River in the south-western part of the West Zilair

SYSTEM	SUBDIVISION	SERIES/STAGE	Former standard conodont zonation (compiled)	Recent conodont zonation (Prague Synform)	South Urals, Western Slope		
					Stratigraphical schemes of Urals, Antsygin *et al.* 1993		Established conodont zones (this paper)
					Horizon	Regional biozones (brachiopod & coral)	
DEVONIAN	Lower	Pragian (part)	*sulcatus*	*steinach.* beta-*brunsvicensis*	Kulamat	*Coenites puberulus* *Columnaria kuallomatensis* *Ivdelinia lahuseni*	*sulcatus* eta/ *steinachensis*
		Lochkovian upp.	*pesavis*	*gilberti-steinach.* beta *pandora* beta-*gilberti*	Sherlubai	*Favosites intricatus* *Pseudamplexus subbrevis* *Karpinskia vagranensis*	*pand.* beta-*sulc.* eta
		Lochkovian middle	*delta*	*trigonicus-pandora* beta *transitans-trigonicus* *boucoti-transitans* *eoeleanorae-boucoti* *carlsi-eoeleanorae*			*trigonicus-pand.* beta *eleanor.-trigonicus* *eoeleanor.-eleanor.*
		Lochkovian lower	*eurekaensis* / *postwoschmidti-woschmidti/hesp.*	*omoalpha-carlsi* *breviramus-omoalpha* *optima-breviramus* *hesperius-optima*	Siyak	*Cladopora actuosa* *Neomphyma originata* *Lanceomyonia borealiformis*	*omoalpha-eoelean.* *optima-omoalpha* *hesperius-optima*
SILURIAN	Upper	Přídolí	*eosteinhornensis*	*eosteinhornensis* s.s. *detorta* *eosteinhornensis* s.l.	Ust-Irgizly beds	*Favosites favositiformis* *Collarothyris canaliculata*	*eosteinhornensis* s.l. not zoned

Figure 3. Stratigraphic scheme of the Lochkovian Stage with the lower and upper boundary intervals of the Western Slope of the South Urals matched with former and recent concepts of conodont zonation. Note the difference in conodont subdivision between the Prague Synform and the South Urals: The proposed regional conodont subdivision respects the absence of some stratigraphically significant taxa known from peri-Gondwana.

Zone. The sections are composed by medium to thin-layered fine-grained marlstones with interbeds and lenses of bioclastic limestones and siltstones. The best exposed Lochkovian rocks including lower and upper boundary strata of the Lochkovian have been studied in the vicinities of the village of Mindigulovo. The Paleozoic rocks are exposed in several cliff outcrops with Ordovician, Silurian and Lower Devonian rock units along the Belaya River. Three described outcrops form a composite section that provides almost complete succession of the Lochkovian including the upper Silurian and lower Pragian boundary intervals.

Outcrop 1 is located on the right bank of the Belaya River, 0.7 km upstream from the village of Mindigulovo (see Figs 1 and 4). It uncovers boundary strata of the upper Přídolí (Ust-Irgizly beds) and lower Lochkovian (Siyak Horizon). Similarly to the sections along the Irgizly River, the Ust-Irgizly beds and Siyak Horizons on the banks of the Belaya River do not differ significantly by their lithologies. The boundary interval is represented by grey fine-grained medium-layered limestones with crinoid limestone interbeds. The total thickness of the uncovered interval in the Outcrop 1 is 15 m.

Scarce conodonts of mostly incomplete preservation represented by *W. eosteinhornensis* (Walliser) *sensu lato* were found 0.3 m above the base. The "*sensu lato*" designation is used in order to differentiate from the "ornamented" taxon *W. eosteinhornensis* according to emended diagnosis by Murphy *et al.* (2004). The overlying interval (14 m approximately) is characterized only by elements of *Wurmiella* (Murphy *et al.*) and *Panderodus* Ethington. Tentative age of the interval is the *eosteinhornensis s.l.* Zone. At the upper part of Outcrop 1, close to the top, enters a clear Devonian conodont indicator – *Icriodus* cf. *hesperius* (Klapper & Murphy). The specimen figured (Fig. 6T) is small and the main posterior process is long as in *I. hesperius*. The development of the posterior area is, however, not decisive for clear taxonomic classification due to immature stage of ontogeny. The typical early Lochkovian taxon *Zieglerodina remscheidensis remscheidensis* (Ziegler) co-enters with the early *Icriodus* mentioned above. The global origin of the genus *Icriodus* is at the base of the Devonian and *I. hesperius* represents one of the oldest icriodontids (*cf.* Carls *et al.* 2007). The age of the upper part of the Outcrop 1 can be correlated, *e.g.*, with the *hesperius-optima* Zone of the Prague Synform (Slavík *et al.* 2012) and *C. hesperius* Zone of Podolia (Drygant & Szaniawski 2012).

Outcrop 2 is located 2 km upstream from the Outcrop 1 and includes the strata of the Sherlubai Horizon (middle and upper Lochkovian) with abundance of stratigraphically significant conodonts (*cf.* Fig. 4). The basal

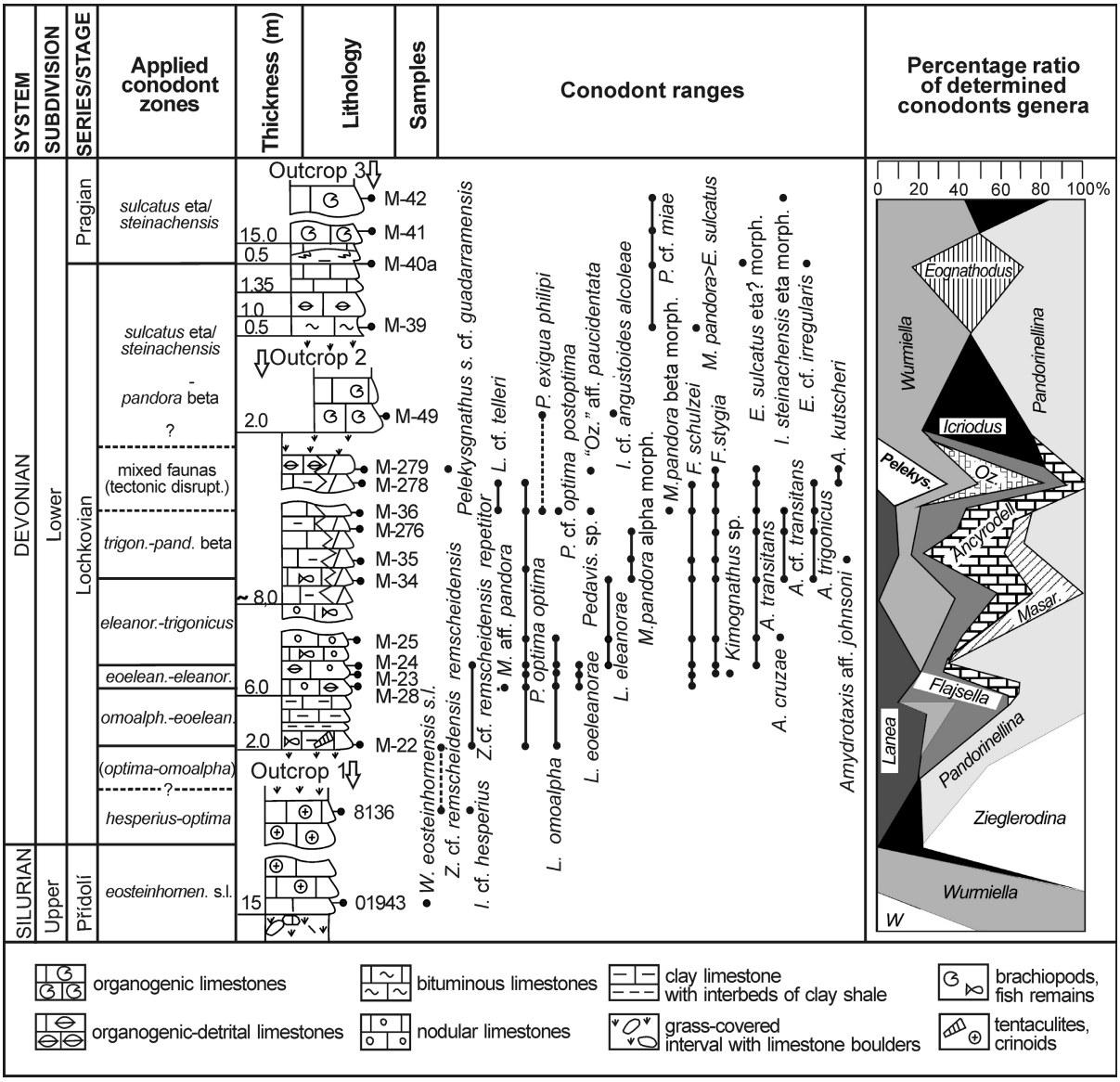
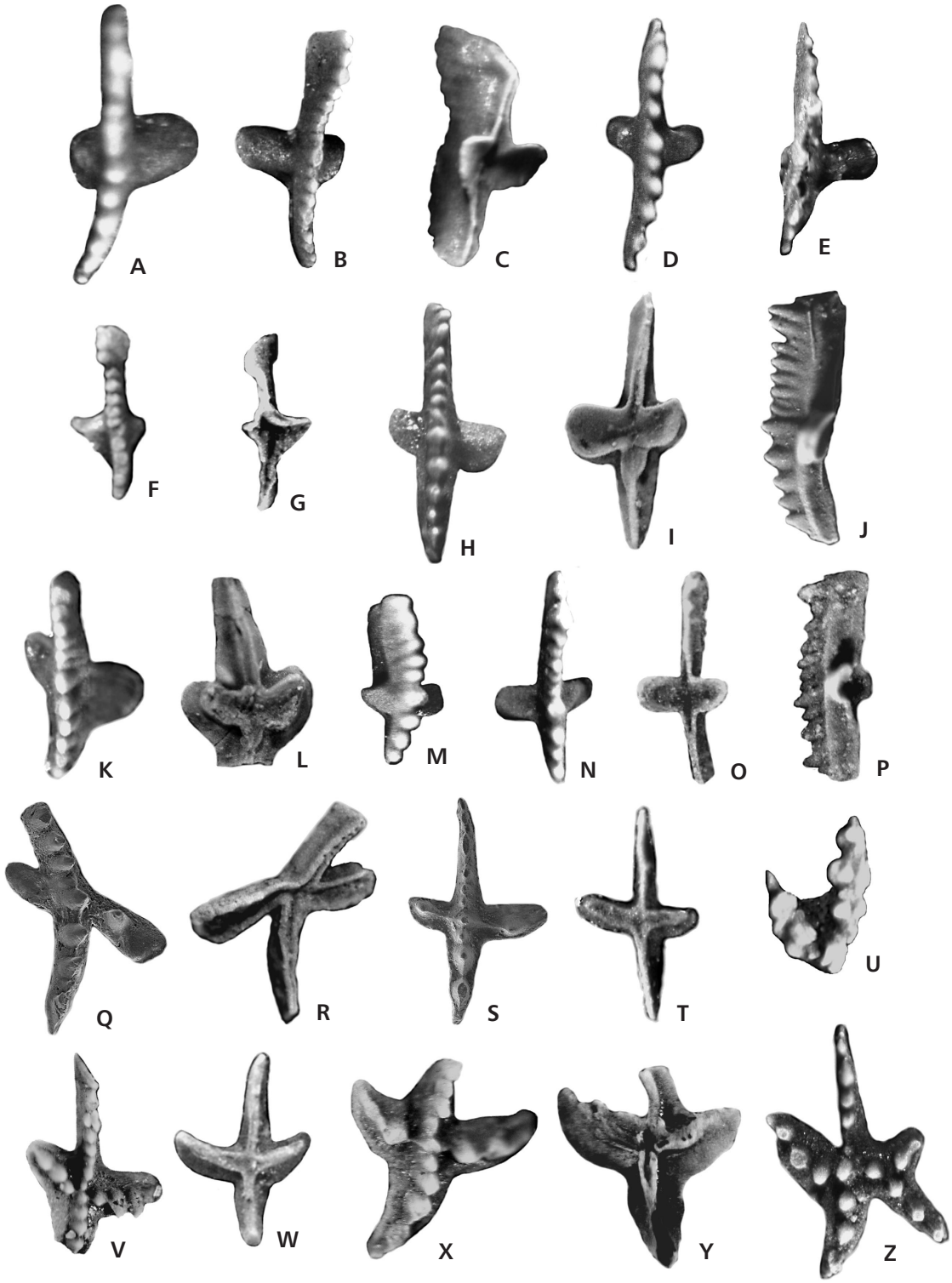


Figure 4. Detailed distribution of the most relevant conodont taxa from the latest Silurian to the early Pragian in outcrops of the composite Mindigulovo section. Applied conodont zones on the left are those from the recent zonal schemes used in peri-Gondwana that can be directly or indirectly delimited in the Lower Devonian of the South Urals. The right column shows a percentage ratio of all determined conodont genera. Abbreviations: *Ancyrodell.* – *Ancyrodelloides*, *Masar.* – *Masaraella*, *Oz.* – *Ozarkodina*, *Pelekys.* – *Pelekysgnathus*.

interval (2 m thick) is characterized by dark grey medium to thin-layered marlstones inter-bedded with clayey shales. The thickness of these siltstone beds varies from 1 to 15–20 cm. Intercalated limestone beds contain abundant tentaculites, fish remains and conodonts. The conodont association includes *Z. remscheidensis remscheidensis* (Ziegler), *Z. r. repetitor* (Carls & Gandl), *Lanea omoalpha* Murphy & Valenzuela-Ríos and *Pandorinellina optima optima* (Moskalenko). The age of the interval is *omoalpha-eoeleanorae* Zone that represents a transition between

Figure 5. Selected specimens of Lochkovian conodonts from the Mindigulovo section. All figures × 32 with the exception of F, G × 60, X, Y × 25. • A–C – *Lanea omoalpha* Murphy & Valenzuela-Ríos, 1999; A, B – upper view of Pa-element, sample M-28, C – lower-lateral view of Pa-element, sample M-22. • D – *Lanea* aff. *eleanorae* (Lane & Ormiston, 1979), upper view of Pa-element, sample M-34. • E – *Amydrotaxis* aff. *johnsoni* Klapper & Murphy, 1980, upper view of Pa-element, sample M-35. • F, G – *Kimognathus* sp.; F – upper view, G – lower view of Pa-element, sample M-23. • H–J – *Lanea eoeleanorae* Murphy & Valenzuela-Ríos, 1999; H – upper view of Pa-element, I – lower view of Pa-element, J – lateral view of Pa-element: sample M-28. • K–M – *Lanea eleanorae* (Lane & Ormiston, 1979); K – upper view, L – lower view of Pa-element, sample M25, M – lower-lateral



view of Pa-element, sample M-24. • N–P – *Lanea* cf. *telleri* (Schulze, 1968); N – upper view, O – lower view, P – lateral view of Pa-element: sample M-36. • Q, R – *Ancyrodelloides cruzae* Valenzuela-Ríos, 1994; Q – upper view of Pa-element, sample M-25, R – lower view of Pa-element, sample M-25. • S, T – *Ancyrodelloides transitans* (Bischoff & Sannemann, 1958); S – upper view of Pa-element, sample M-34, T – lower view of Pa-element, sample M12-276. • U – *Pedavis* sp., upper view of I-element (broken), sample M-36. • V, W – *Ancyrodelloides* cf. *transitans* (Bischoff & Sannemann, 1958) [transitional specimen to *Ancyrodelloides trigonicus* (Bischoff & Sannemann, 1958)]: V – upper view of Pa-element, sample M-36, W – lower view of Pa-element, sample M-36. • X, Y – *Ancyrodelloides trigonicus* (Bischoff & Sannemann, 1958); X – upper view of Pa-element, sample M-36, Y – lower view of Pa-element, sample M-36. • Z – *Ancyrodelloides kutscheri* (Bischoff & Sannemann, 1958), upper view of Pa-element, sample M12-278.

the lower and the middle Lochkovian (*cf.* Valenzuela-Ríos & Murphy 1997, Slavík 2011). The above-mentioned taxa are mostly widespread. They are common not only in peri-Gondwana and Euramerica (Laurussia): a regional conodont zonal scale based on the spathognathodontids including *Zieglerodina remscheidensis* and species of *Pandorinellina* has been established also in the South Tien-Shan (Bardashev & Ziegler 1992), or alternatively also in Podolia (Drygant & Szaniawski 2012).

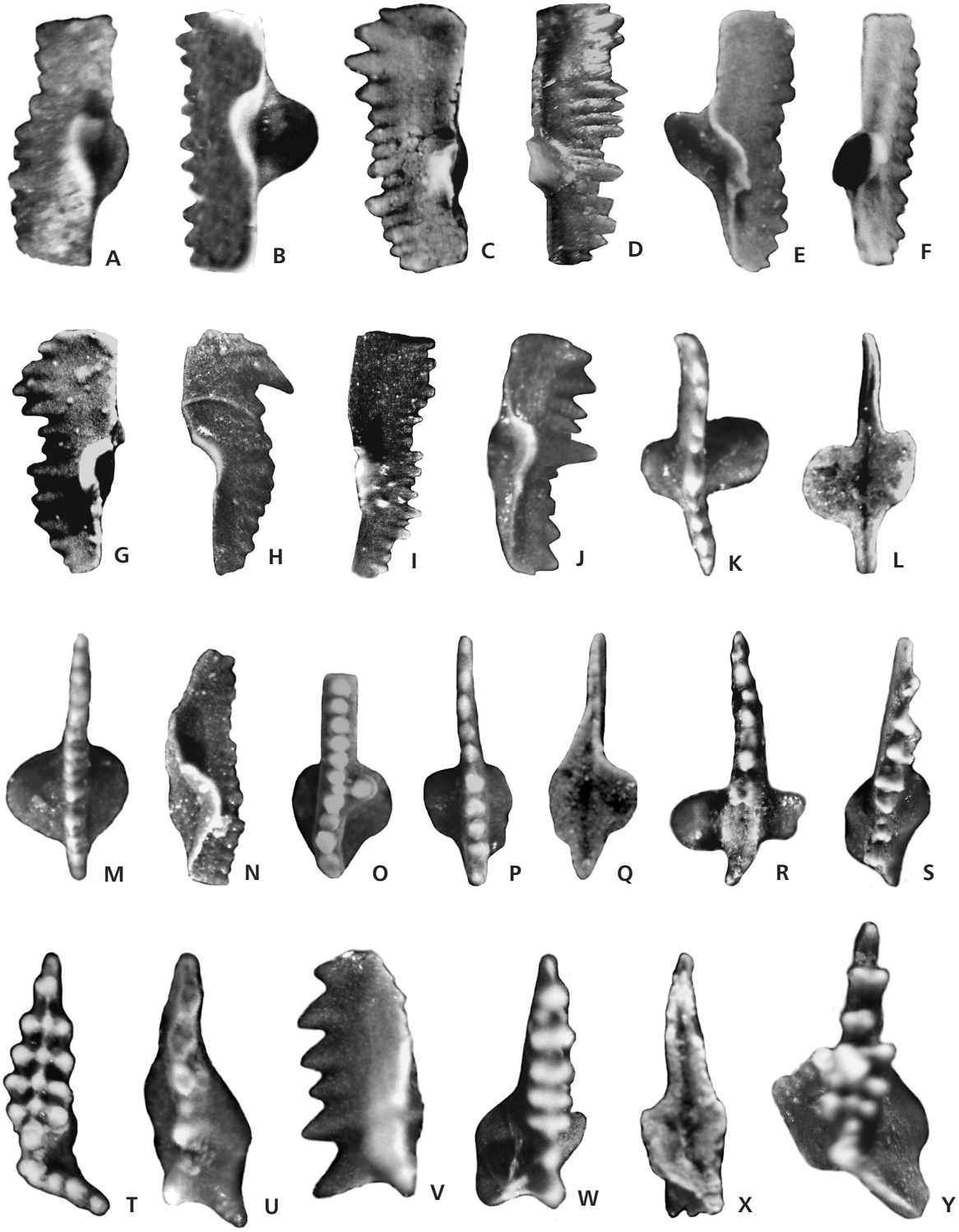
Overlying 6 m thick interval forms alternation of yellowish-grey and grey micritic and nodular limestones. The uppermost part is formed by grey thin-layered calcilutites and calcisiltites with lenses of bioclastic limestones. The interval contains fish remains, algal fragments and rich and diverse conodont faunas: *e.g.*, *L. omoalpha*, *L. eoeleanorae* Murphy & Valenzuela-Ríos, *L. eleanorae* (Lane & Ormiston), *P. o. optima*, *Z. r. repetitor* (Carls & Gandl), *Flajsella schulzei* (Bardashev), *F. stygia* (Flajs), *Kimognathus* sp., *Ancyrodelloides cruzae* Valenzuela-Ríos, *A. transitans* (Bischoff & Sannemann) and transitional "slender" spathognathodontid morphologies – *e.g.*, *Masaraella* aff. *pandora* (Murphy *et al.*). Especially, the presence of cosmopolitan phylogenetic lineage of *Lanea* and the entries of *Flajsella* and *Ancyrodelloides* indicate clearly the middle Lochkovian age with corresponding regional biozones (*eoeleanorae-eleanorae* and *eleanorae-trigonicus*).

Approximately 8 m thick interval of interbedded clayey dark-grey marlstones, organodetrital limestones and calcisiltites follows. In this interval the conodont fauna contains stratigraphically important late middle Lochkovian marker – *Ancyrodelloides trigonicus* (Bischoff & Sannemann) with entries of some associated specimens which are morphologically very close to cosmopolitan taxa: *Lanea* cf. *telleri* and *Amydrotaxis* aff. *johnsoni* (see Figs 4 and 5E, N–P). The sample M-36 in the middle part of the interval is exceptional as regards the faunal content. It contains mixed conodont elements including *A. trigonicus* and *Masaraella pandora* beta. The latter taxon with an ornament on the lateral lobe, *cf.* Fig. 6O) is a marker for the upper Lochkovian in the sense of global subdivision of the Lochkovian by Valenzuela-Ríos & Murphy (1997). *A. trigonicus* and *M. pandora* beta never occur jointly elsewhere; their co-occurrence in the Mindigulovo section is a result of tectonic disruption in this part of outcrop and reworking. Due to the presence of tectonics, the zonal boundaries are marked only approximately in this part of the outcrop (*cf.* Fig. 4). This 8 m thick interval is characterized by terminal ranges of principal middle Lochkovian lineages – *Lanea* and *Ancyrodelloides*, and, by presence of the global *eleanorae-trigonicus*, *trigonicus-pandora* beta and *pandora* beta–*sulcatus* eta/*steinachensis* Zones. As mentioned above, the last zone marks, however, only one specimen of *M. pandora* beta from a sample with mixed conodonts. Therefore the exact position of the zone is not known.

After an interval covered by vegetation, 2 m thick interval of thick-layered organogenic limestones with abundance of corals, crinoids, brachiopods and orthoceratid cephalopods follows. The coral faunas (*e.g.*, *Favosites* cf. *interstinctus* Regnell) and brachiopod faunas (*e.g.*, *Clorindina vijaica* Khodalevich, *Gipidula* sp. and *Karpinskia vagranensis* Khodalevich) are characteristic for the Sherlubai Horizon (Tyazheva *et al.* 1976). Conodont faunas in the shallow-water environment are scarce, represented by few elements of icriodontids – *Icriodus* cf. *angustoides alcoleae* (Carls) and spathognathodontids – *Wurmiella excavata* (Branson & Mehl) and *Pandorinellina exigua philipi* (Klapper). The age of this interval is not certain and is tentatively correlated with *pandora* beta–*sulcatus* eta/*steinachensis* Zone.

Outcrop 3 represents a transition from the Lochkovian Sherlubai Horizon and the Pragian Kulamat Horizon. It starts with 0.5 m thick interval of grey bituminous limestones. The basal bed contains only few but stratigraphically important conodonts including the transitional form *Masaraella pandora* (Murphy *et al.*) → *Eognathodus sulcatus* (Philip) (see Figs 4 and 6P, Q); it is in association with the last recorded *M. pandora* and with the entry of taxon morphologically close to *Pandorinellina miae* (Bultynck). The latter is treated herein in open nomenclature because the *P. miae* displays very common spathognathodontid morphology, and, thus possible morphological convergence cannot be excluded. *P. miae* dominated in the Pragian and early Emsian in many paleogeographic areas (*e.g.*, Bultynck 1971, Klapper & Johnson 1980, Slavík 2004); the entry of this morphology, together with appearance of transitional eognathodontid forms indicate proximity of the lower Pragian boundary. Following 1.0 m thick interval of grey

Figure 6. Selected specimens from the Lower Devonian interval from the Mindigulovo section. All figures × 32. • A, B – *W. eosteinhornensis* (Walliser, 1964) *sensu lato*: lateral view of Pa-element, sample 01943. • C – *Zieglerodina* cf. *remscheidensis remscheidensis* (Ziegler, 1960), lateral view of Pa-element, sample 8136. • D – *Z.* cf. *remscheidensis repetitor* (Carls & Gandl, 1969), lateral view of Pa-element, sample M-22. • E – *Masaraella pandora* morphotype alpha? (Murphy *et al.*, 1981), lateral view of Pa-element, sample M-39. • F – *Pandorinellina* cf. *miae* (Bultynck, 1971), lateral view of Pa-element, sample M-41. • G – *Pandorinellina optima optima* (Moskalenko, 1966), lateral view of Pa-element, sample M-36. • H – *Pandorinellina exigua philipi* (Klapper, 1969), lateral view of Pa-element, sample M-49. • I – *Pandorinellina* cf. *optima postoptima* Farrell, 2003, lateral view of Pa-element, sample M-36. • J–L – "*Ozarkodina*" aff. *paucidentata* (Murphy & Matti, 1982); J – lateral view, K – upper view, L – lower view of Pa-element,



sample M12-279. • M, N – *Masaraella pandora* morphotype alpha (Murphy *et al.*, 1981); M – upper view, N – lateral view of Pa-element, sample M-34. • O – *Masaraella pandora* morphotype beta (Murphy *et al.*, 1981), upper view of Pa-element, sample M-49. • P, Q – *Masaraella pandora* (Murphy, Matti & Walliser, 1981) → *Eognathodus sulcatus* (Philip, 1965): P – upper view, Q – lower view of Pa-element, sample M-39. • R– *Eognathodus sulcatus* morphotype eta (?) Murphy *et al.*, 1981, upper view of Pa-element, sample M-40a. • S – *Eognathodus* cf. *irregularis* Murphy, 2005, upper view of Pa-element, sample M-40a. • T – *Icriodus* cf. *hesperius* (Klapper & Murphy, 1974), upper view of I-element, sample 8136. • U, V – *Pelekysgnathus serratus* cf. *guadarramensis* Valenzuela-Ríos, 1994; U – upper view, V – lateral view of Pa-element, sample M12-279. • W, X – *Icriodus* cf. *angustoides alcoleae* Carls, 1969: W – upper view, X – lower view of I-element, sample M-49. • Y – *Icriodus steinachensis* (Al-Rawi, 1977) morphotype eta Klapper & Johnson, 1980, upper view of I-element, sample M-42.

organogenic limestones is overlain by dark-grey siltstones (1.35 m). The upper bedding surfaces resemble "hardgrounds" with remains of clay and biodetrital material (shell and crinoid fragments). The sample at the top of this bed (M-40a) contains characteristic early Pragian conodonts including eognathodontid faunas that are globally diagnostic for the lower Pragian boundary [*i.e.*, *Eognathodus sulcatus* eta morphotype Murphy *et al.*, 1981 = *Eognathodus sulcatus eosulcatus* (Murphy, 1989) and *Eognatodus* cf. *irregularis* Murphy, 2005]. The taxonomy and phylogenetic interpretation of the early Pragian eognathodontids is very complicated (*cf.* reconstructions and discussions in Murphy *et al.* 1981, Murphy 1989, Slavík & Hladil 2004, Murphy 2005 and Slavík *et al.* 2007). Irrespective of this, the biostratigraphic boundary of the Lochkovian/Pragian is placed to the level of the sample M-40a with content of the zonally diagnostic taxa. The lithostratigraphic boundary between Sherlubai and Kulamat is directly above and is marked by the onset of thick layered dolomitized limestones with relicts of bioclasts. At the base of dolomitized limestones is a thin layer of black folded shale (0.05–0.5 m). The lower part of the Kulamat Horizon (here it is 15 m thick) contains only few I-elements of the typical Lochkovian/Pragian boundary taxon *Latericriodus steinachensis* (Al-Rawi) eta morphotype Klapper & Johnson, 1980 and a few elements of *Wurmiella* and *Pandorinellina* cf. *miae*.

Correlation of the conodont faunas of the South Urals

The number of conodont elements obtained from the section of Mindigulovo and the diversity of conodont faunas vary significantly at different stratigraphic levels. They largely depend on local facies development as well as on global diversity and abundance of Lower Devonian conodonts influenced by the degree of provincialism and global eustacy. In general, the highest diversity and abundance were found in thin-bedded fine-grained marlstones and condensed carbonate beds from pelagic environments. These are typical for the middle Lochkovian, containing off-shore conodont genera, such as *Lanea*, *Ancyrodelloides* and *Kimognathus*. As is the case elsewhere, conodont assemblages in the Devonian shallow-water clear organogenic (reefal) limestones are poor. In the Lower Devonian, shallower environments are characterized by a slightly elevated abundance and higher diversity of icriodontid faunas, which are very sensitive to fluctuations in water depth. Therefore, the inter-regional conodont correlation of Lower Devonian shallow-water environments is mostly based on icriodontids – genera *Icriodus*, *Pelekysgnathus* or *Pedavis* (*cf.* Slavík *et al.* 2007, Drygant & Szaniawski 2012).

Shallow-water crinoidal debris of Ust-Irgizly and Siyak deposits are expectedly poor as regards conodont elements. The average number of specimens does not exceed 10–15 elements per 1 kg of rock. The correlation of the upper Přídolí is complicated due to only one stratigraphically important conodont (*W. eostenhornensis s.l.*). The *eosteinhornensis sensu lato* Zone, however, covers almost the entire Přídolí Series (see discussion in Carls *et al.* 2007). The development of the conodont zonation of the Přídolí has been summarized in Corradini & Corriga (2012) and, in spite of some progress in the past years it still urgently needs a refinement.

The presence of early icriodontids indicates the proximity of the base of the Devonian. The specimen obtained from the Mindigulovo section (Fig. 6T) is very close to *I. hesperius*. Although the specimen is treated in open nomenclature, it can be correlated with the global *hesperius* Zone, originally established in Nevada by Klapper & Murphy (1974). The zone is also present in Sardinia and Carnic Alps (Corradini & Corriga 2012). The oldest Lochkovian zonal equivalent in the Prague Synform (Barrandian area) is the "*hesperius-optima* Zone" (Slavík *et al.* 2012). The associated *Z. r. remscheidensis* is typically an early Lochkovian taxon (*cf.* Murphy *et al.* 2004, Carls *et al.* 2007) and provides a good correlation with peri-Gondwanan regions. The missing interval between Outcrops 1 and 2 is probably stratigraphically very short and is tentatively assigned to the *optima-omoalpha* Zone. Both nominal taxa are present above (in the Sherlubai Horizon): the succession of entries of the nominal taxa of the zone has been described, *e.g.*, in the Prague Synform (Slavík *et al.* 2012).

The most important is the succession of the middle Lochkovian conodonts found in the South Urals. The base of the middle Lochkovian cannot be traced precisely because of the discontinuity between Outcrops 1 and 2. The middle Lochkovian marker – *Lanea carlsi* (Boersma) has not been found in the Mindigulovo section yet. According to the correlation with peri-Gondwanan regions, the base of the middle Lochkovian can be expected between the entries of *Lanea omoalpha* and *L. eoeleanorae*, because *L. carlsi* enters in-between. The entry of *L. omoalpha* can be, however, somewhat below the base of Outcrop 2. Accordingly, the base of the *omoalpha-eleanorae* Zone is herein delimited by the recorded entry of *L. omoalpha* but it may enter earlier – *i.e.*, within the missing interval. The conodont association, however, indicates that the base of the middle Lochkovian should be very close to the base of Outcrop 2.

This is followed by the characteristic and globally dispersed middle Lochkovian conodont succession. The *Lanea* lineage including the taxa *eoeleanorae* and *eleanorae* together with associated cosmopolitan genera of middle Lochkovian origin (*Flajsella*, *Kimognathus* and

Amydrotaxis) allow an excellent global correlation. The late middle Lochkovian (in the sense of Valenzuela-Ríos & Murphy 1997) is confirmed by occurrence of the late forms of the cosmopolitan genus *Ancyrodelloides* here. The *Ancyrodelloides* lineage completely disappears soon after the radiation toward the end of the middle Lochkovian. This radiation gave rise to several morphologies worldwide and took place in the short stratigraphic interval corresponding to the range of the short-lived taxon *A. kutscheri* (Bischoff & Sannemann, 1958).

In the studied section, the middle Lochkovian interval allows a very fine subdivision that can be correlated in detail in a global scale. Four small-scale chronostratigraphic units (*omoalpha-eoeleanorae*, *eoeleanorae-eleanorae*, *eleanorae-trigonicus* and *trigonicus-pandora* beta) are characterized by the presence of widely distributed (actually cosmopolitan) taxa.

Although, the upper Lochkovian is documented here by the presence of the global biozonal marker *M. pandora* beta, the position of the upper Lochkovian boundary is only tentative due to tectonic disruption and resulting mixing of conodont elements. The assumed thickness of the upper Lochkovian interval is small (only few meters), much like in many other regions of the world. The end Lochkovian time is characterized by a sea-level drop that culminated around the Lochkovian-Pragian boundary. The sea-level change is pronounced in areas around peri-Gondwana. In the Prague Synform, the earliest Pragian time was interpreted as a "hot lowstand" (Hladil *et al.* 2008, Koptíková *et al.* 2010), with a very low accumulation rate (Slavík *et al.* 2012). The trend of a gradual increase in energy and shallowing at the base of the Pragian is known as the Basal Pragian Event (Chlupáč & Kukal 1986, 1988; House 2002) (also = the Lochkovian/Pragian Boundary Event, Walliser 1996). The general shallowing is accompanied by the subsequent occurrence of icriodontid taxa that tend to occur towards the late Lochkovian. In the Mindigulovo section, this trend starts with the single occurrence of *Pedavis*, followed by *Pelekysgnathus serratus* cf. *guadarramensis* Valenzuela-Ríos and *Icriodus* cf. *angustoides alcolae* Carls in the upper Lochkovian. The icriodontid lineage is then represented by the *Icriodus steinachensis* stock in the earliest Pragian, which serves as the alternative basal Pragian marker in shallow-water environments. *I. steinachensis* eta morphotype is older then beta morphotype; the latter is known to enter together with the earliest *E. sulcatus* (eta morph) in peri-Gondwana (Slavík *et al.* 2007). The ranges of both morphotypes, however, largely overlap. Some of the above listed taxa equally have a wide regional distribution. The upper Lochkovian time in the Mindigulovo section is represented by the *pandora* beta–*sulcatus* eta/*steinachensis* Zone.

As already mentioned above, the upper Lochkovian time (according to the present global subdivision) is globally represented by sedimentary intervals of small thickness due to low accumulation rate in shallow-water environments in carbonate successions. In contrast to other regions (*e.g.*, Pyrenees, Nevada, Carnic Alps and Prague Synform), the late Lochkovian *Pedavis* taxa are lacking in the South Urals. Therefore, the upper Lochkovian cannot be subdivided in more detail yet. Also, the presence of a tectonic disruption is a serious constraint for a refined subdivision in the Mindigulovo section. The concept of the global Lochkovian subdivision, however, needs a revision due to the proportional discrepancies between individual parts of the three-fold subdivision. According to the present global subdivision, the age of the Sherlubai Horizon is middle and upper Lochkovian. The early Pragian age of the Kulamat Horizon presented in Outcrop 3 is confirmed by the presence of parts of both cosmopolitan eognathodontid and *Icriodus steinachensis* stocks.

Conclusions

For the first time, the study presents conodont biostratigraphic data from the early part of the Lower Devonian from the western slope of the South Urals. The latest Přídolí to earliest Pragian sedimentary succession of the Mindigulovo section is almost complete with only insignificant interruptions. The section provides information on the ranges of many widely distributed or cosmopolitan taxa. Conodont data allowed a refined zonal subdivision that can be mostly directly correlated with global conodont biozones. The highest diversity of conodont faunas can be seen in deeper-water strata of the middle Lochkovian; it provides the best correlation on the basis of the *Lanea* and *Ancyrodelloides* lineages. The presence of many cosmopolitan taxa and the recorded single occurrences of representatives of widespread lineages (*e.g.*, *Pelekysgnathus* and *Pedavis*) are promising for a future detailed study and prospective refinement of the regional biozonation. The abundance of conodonts in shallow-water reefal carbonate rocks is very low but the correlation of the Lochkovian-Pragian boundary interval is relatively precise. The age of the studied upper Silurian strata (Ust Irgizly beds) is established only tentatively – *eosteinhornensis sensu lato* Zone of the Přídolí. According to the global subdivision of the Lochkovian, the age of the Siyak Horizon is lower Lochkovian, and the Sherlubai Horizon includes the middle and upper Lochkovian.

The character of sedimentation in the early Lower Devonian (Lochkovian–early Pragian) on the western slope of the South Urals corresponds with the general trends of eustatic sea-level fluctuations in other peri-Gondwanan regions (*e.g.*, the Prague Synform). The documented ranges of widespread conodont faunas point to a good paleooceanic communication of the Urals region with peri-Gondwana and Euramerica.

Acknowledgements

The authors would like to express thanks to Olga V. Artyushkova and Victor A. Maslov for their critical comments and helpful advices in preparing the paper. The authors would also like to thank Larisa I. Mizens for information on modern brachiopod systematics. The review by Carlo Corradini significantly helped in improvement and correction of the early draft of the manuscript. Daniel Drygant kindly provided valuable review of the final version of the manuscript. The study was supported by the Russian Foundation for Basic Research through Grant No. 11-05-00737-a and by the AS CR, International Cooperation Project No. M100131201. The paper is a contribution to the project UNESCO/IGCP 596.

References

Abramova, A.N. 1999. *Frasnian stage at the western slope of the South Urals.* 54 pp. Institute of Geology, Ufa Scientific Center, Russian Academy of Sciences, Ufa. [in Russian]

Abramova, A.N. & Artyushkova, O.V. 2004a. The Frasnian-Famennian boundary in the South Urals. *Geological Quarterly 48(3)*, 217–232.

Abramova, A.N. & Artyushkova, O.V. 2004b. New data on the position of the Emsian and Eifelian stages boundary in the South Urals, 70–77. *In* Ivanov, A.V. & Musatov, V.A. (eds) *Questions of the Phanerozoic stratigraphy of the Volga and the Caspian area. Collected articles.* Publishing of the Saratov University. [in Russian]

Al-Rawi, D. 1977. Biostratigraphische Gliederung der Tentaculiten-Schichten des Frankenwaldes mit Conodonten und Tentaculiten (Unter- und Mittel-Devon; Bayern, Deutschland). *Senckenbergiana lethaea 58*, 25–79.

Antsygin, N.Y., Popov, B.A. & Chuvashov, B.I. (eds) 1993. *Stratigraphic schemes of the Urals.* 151 pp. Ural Branch Russian Academy of Sciences, Yekaterinburg. [in Russian].

Artyushkova, O.V. 2009. *Biostratigraphy on conodonts volcanic-sedimentary Devonian of the Magnitogorsk Megazone of the Southern Urals.* 40 pp. Abstract of doctoral dissertation (Stratigraphy and correlation of the Devonian deposits of the Magnitogorsk Megazone of the Southern Urals), Novosibirsk. [in Russian]

Artyushkova, O.V. & Maslov, V.A. 2008. Detailed correlation of the Devonian deposits in the South Urals and some aspects of their formation. *Bulletin of Geosciences 83(4)*, 391–399. DOI 10.3140/bull.geosci.2008.04.391

Bardashev, I.A. & Ziegler, W. 1992. Conodont biostratigraphy of Lower Devonian Deposits of the Shihskat section (Southern Tian-Shan, Middle Asia). *Courier Forschungsinstitut Senckenberg 154*, 1–29.

Baryshev, V.N. & Abramova, A.N. 1996. Conodont zonal subdivision of the Upper Devonian deposits on the western slope of the South Urals. *Annual Report 1996*, 26–30. Institute of Geology, Ufa Scientific Center, Russian Academy of Sciences, Ufa. [in Russian]

Bischoff, G.C.O. & Sannemann, D. 1958. Unterdevonische Conodonten aus dem Frankenwald. *Notizblatt des Hessischen Landesamtes für Bodenforschung 86*, 87–110.

Bultynck, P. 1971. Le Silurien Supérieur et le Dévonien Inférieur de la Sierra de Guadarrama (Espagne Centrale); Deuxième partie: Assemblages de Conodontes a Spathognathodus (1). *Bulletin de l'Institut royal des Sciences naturelles de Belgique 47*, 1–43.

Carls, P. 1969. Die Conodonten des tieferen Unterdevons der Guadarrama (Mittel-Spanien) und die Stellung des Grenzbereiches Lochkovium/Pragium nach der rheinischen Gliederung. *Senckenbergiana lethaea 50*, 303–355.

Carls, P. & Gandl, J. 1969. Stratigraphie und Conodonten des Unter-Devons der östlichen Iberischen Ketten (NE Spanien). *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen 132*, 155–218.

Carls, P., Slavík, L. & Valenzuela-Ríos, J.I. 2007. Revisions of conodont biostratigraphy across the Silurian–Devonian boundary. *Bulletin of Geosciences 82(2)*, 145–164. DOI 10.3140/bull.geosci.2007.02.145

Chlupáč, I. & Kukal, Z. 1986. Reflection of possible global Devonian events in the Barrandian area, C.S.S.R., 169–179. *In* Walliser, O.H. (ed.) *Global Bio-events. Lecture Notes in Earth Sciences 8*.

Chlupáč, I. & Kukal, Z. 1988. Possible global events and the stratigraphy of the Paleozoic of the Barrandian (Cambrian-Middle Devonian, Czechoslovakia). *Sborník geologických věd, Geologie 43*, 83–146.

Corradini, C. & Corriga, M.G. 2012. A Přídolí–Lochkovian conodont zonation in Sardinia and the Carnic Alps: implications for a global zonation scheme. *Bulletin of Geosciences 87(4)*, 635–650. DOI 10.3140/bull.geosci.1304

Drygant, D. & Szaniawski, H. 2012. Lochkovian conodonts from Podolia, Ukraine and their stratigraphic significance. *Acta Palaeontologica Polonica 57(4)*, 833–861.

Farrell, J.R. 2003. Late Pridoli, Lochkovian and early Pragian conodonts from the Gap area between Larras Lee and Eurimbla, central western NSW, Australia. *Courier Forschungsinstitut Senckenberg 245*, 107–181.

Hladil, J., Slavík, L., Schnabl, P., Koptíková, L., Fráña, J., Vacek, F. & Bábek, O. 2008. The gross environmental phenomenon of the classical Pragian stage ("hot lowstand"), p. 1343454. *In* Bjorlykke, A. (ed.) *X-CD Technologies, 33rd International Geological Congress, International Union of Geological Sciences. Abstract CD-ROM, HPF-01 General contributions to paleontology and historical geology, Part 1.* Oslo.

House, M.R. 2002. Strength, timing, setting and cause of mid-Palaeozoic extinctions. *Palaeogeography, Palaeoclimatology, Palaeoecology 181*, 5–25. DOI 10.1016/S0031-0182(01)00471-0

Khalymbadzha, V.G., Chernysheva, N.G. & Baryshev, V.N. 1985. Biostratigraphy of the Middle Devonian of the Western Slope of the Urals on conodonts, 69–74. *In* Kamaletdinov, M.A. & Rzhosnitskaya, M.A. (eds) *Middle Devonian of the USSR its boundaries and stage subdivision*. Nauka, Moscow. [in Russian]

Klapper, G. 1969. Lower Devonian conodont sequence, Royal

Creek, Yukon Territory and Devon Island. *Journal of Paleontology 43*, 1–27.

Klapper, G. 1977. Lower and Middle Devonian conodont sequence in central Nevada; with contributions by Johnson, D.B., 33–54. *In* Murphy, M.A., Berry, W.B.N. & Sandberg, C.A. (eds) *Western North America Devonian University of California, Riverside Campus Museum Contributions: Riverside 4*.

Klapper, G. & Johnson, J.G. 1980. Endemism and dispersal of Devonian conodonts. *Journal of Paleontology 54*, 400–455.

Klapper, G. & Murphy, M.A. 1974. Silurian-Lower Devonian conodont sequences in the Roberts Mountains Formation of central Nevada. *University of California Publications in Geological Sciences 111*, 1–62.

Klapper, G. & Murphy, M.A. 1980. Conodont zonal species from the *delta* and *pesavis* Zones (Lower Devonian in central Nevada). *Neues Jahrbuch für Geologie und Paläontologie, Monatshefte 8*, 490–504.

Knyazev, Y.G. (ed.) 2008. *Work Performance Report on Additional Site Appraisal GDP-200, Sheet N-40-XXVIII (Burzyan Area)* (unpublished). 354 pp. Ufa [in Russian].

Koptíková, L., Hladil, J., Slavík, L., Bábek, O. & Čejchan, P. 2010. Fine-grained non-carbonate particulates embedded in neritic to pelagic limestones (Lochkovian to Emsian, Prague Synform, Czech Republic): Composition, provenance and links to magnetic susceptibility and gamma-ray logs. *Geologica Belgica 13(4)*, 407–430.

Krauze, S.M. & Maslov, V.A. 1961. *Ordovician, Silurian and Lower Devonian at the western slope of the Bashkirian Urals.* 95 pp. Bashkir Branch, Academy of Sciences of the USSR, Ufa. [in Russian]

Lane, H.R. & Ormiston, A.R. 1979. Siluro-Devonian biostratigraphy of the Salmontrout River area, east-central Alaska. *Geologica et Palaeontologica 13*, 39–96.

Maslov, V.A., Abramova, A.N. & Baryshev, V.N. 1983. New data on the distribution of conodonts in the Middle Devonian sediments on the western slope of the Southern Urals and Pre-Urals, 58–63. *In Stratigraphy and lithology of the Upper Precambrian and Paleozoic of the Southern Urals and Pre-Urals*. Ufa, BB USSR AS. [in Russian]

Maslov, V.A. & Artyushkova, O.V. 2010. *Stratigraphy and correlation of the Devonian deposits in Magnitogorsk Megazone of the Southern Urals.* 288 pp. DesignPolygraphServis, Ufa. [in Russian]

Maslov, V.A., Tchibrikova, E.V., Abramova, A.N., Baryshev, V.N., Zhavoronkova, R.A. & Garifulina, A.A. 1985. Stratigraphy of the Lower and Middle Devonian of the Western Slope of the Southern Urals, 69–74. *In* Kamaletdinov, M.A. & Rzhosnitskaya, M.A. (eds) *Middle Devonian of the USSR its boundaries and stage subdivision.* Nauka, Moscow. [in Russian].

Moskalenko, T.A. 1966. First find of Late Silurian conodonts from the Zeravshan Range. *Paleontologicheskiy Journal 2*, 81–92. [in Russian].

Murphy, M.A. 1977. On time stratigraphic units. *Journal of Paleontology 51*, 213–219.

Murphy, M.A. 1989. Lower Pragian boundary (Lower Devonian) and its application in Nevada. *Courier Forschungsinstitut Senckenberg 117*, 61–70.

Murphy, M.A. 2005. Pragian conodont zonal classification in Nevada, Western North America. *Revista Española de Paleontología 20*, 177–206.

Murphy, M.A. & Matti, J.C. 1982. Lower Devonian conodonts (*hesperius-kindlei* zones), central Nevada. *University of California Publications, Geological Sciences 123*, 1–83.

Murphy, M.A., Matti, J.C. & Walliser, O.H. 1981. Biostratigraphy and evolution of the *Ozarkodina remscheidensis–Eognathodus sulcatus* lineage (Lower Devonian) in Germany and central Nevada. *Journal of Paleontology 55*, 747–772.

Murphy, M.A. & Valenzuela-Ríos, J.I. 1999. *Lanea* new genus, lineage of Early Devonian conodonts. *Bolletino della Società Paleontologica Italiana 37*, 321–334.

Murphy, M.A., Valenzuela-Ríos, J.I. & Carls, P. 2004. On classification of Pridoli (Silurian)-Lochkovian (Devonian) Spathognathodontidae (conodonts). *University of California, Riverside Campus Museum Contribution 6*, 1–25.

Philip, G.M. 1965. Lower Devonian conodonts from the Tyers area, Gippsland, Victoria. *Proceedings of the Royal Society of Victoria 79*, 95–117.

Schulze, R. 1968. Die Conodonten aus dem Paläozoicum der mittleren Karawanken (Seebergebiet). *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen 130*, 133–245.

Shefer, V.A. (ed.) 2001. *Geological additional appraisal of 1:50,000 scale survey with general prospecting in the Kana area within the sheets N-40-103-A-a, б, г; N-40-103-Б; N-40-103-B-б, г; N-40-103-Г* (unpublished). 298 pp. Ufa. [in Russian]

Slavík, L. 2004. The Pragian–Emsian conodont successions of the Barrandian area: search of an alternative to the GSSP polygnathid-based correlation concept. *Geobios 37*, 454–470. DOI 10.1016/j.geobios.2003.05.002

Slavík, L. 2011. *Lanea carlsi* conodont apparatus reconstruction and its significance for subdivision of the Lochkovian. *Acta Palaeontologica Polonica 56*, 313–327. DOI 10.4202/app.2009.0046.

Slavík, L., Carls, P., Hladil, J. & Koptíková, L. 2012. Subdivision of the Lochkovian Stage based on conodont faunas from the stratotype area (Prague Synform, Czech Republic). *Geological Journal 47*, 616–631. DOI 10.1002/gj.2420

Slavík, L. & Hladil, J. 2004. Lochkovian/Pragian GSSP revisited: evidence about conodont taxa and their stratigraphic distribution. *Newsletters on Stratigraphy 40(3)*, 137–153. DOI 10.1127/0078-0421/2004/0040-0137

Slavík, L., Valenzuela-Ríos, J.I., Hladil, J. & Carls, P. 2007. Early Pragian conodont-based correlations between the Barrandian area and the Spanish Central Pyrenees. *Geological Journal 42*, 499–512. DOI 10.1002/gj.1087

Suttner, T.J. 2007. Conodont stratigraphy, facies-related distribution patterns and stable isotopes (carbon and oxygen) of the uppermost Silurian to lower Devonian Seewarte section (Carnic Alps, Carinthia, Austria). *Abhandlungen der Geologischen Bundesanstalt Band 59*, 1–111.

Tyazheva, A.P. & Zhavoronkova, R.A. 1972. *Corals and*

brachiopods of the Silurian and Lower Devonian boundary deposits of the Southern Urals. 183 pp. Nauka, Moscow. [in Russian]

Tyazheva, A.P., Zshavoronkova, R.A. & Garifullina, A.A. 1976. *The Lower Devonian corals and brachiopods in the South Urals.* 228 pp. Nauka, Moscow. [in Russian]

Valenzuela-Ríos, J.I. 1994a. The Lower Devonian conodont *Pedavis pesavis* and the *pesavis* Zone. *Lethaia 27*, 199–207. DOI 10.1111/j.1502-3931.1994.tb01409.x

Valenzuela-Ríos, J.I. 1994b. Conodontos Lochkoviense y Praguiense (Devónico Inferior) del Pirineo Central español. *Memorias del Museo Paleontológico de la Universidad de Zaragoza 5*, 1–142.

Valenzuela-Ríos, J.I. & Murphy, M.A. 1997. A new zonation of middle Lochkovian (Lower Devonian) conodonts and evolution of *Flajsella* n. gen. (Conodonta), 131–144. *In* Klapper, G., Murphy, M.A. & Talent, J.A. (eds) *Paleozoic Sequence Stratigraphy, Biostratigrphy and Biogeography, Studies in Honor of J. Granville ("Jess") Johnson. Geological Society of America Special Paper 321.*

Walliser, O.H. 1996. *Global events and event stratigraphy in the Phanerozoic. First edition*. 333 pp. Springer, Berlin, Heidelberg & New York. DOI 10.1007/978-3-642-79634-0

Walliser, O.H. 1964. Conodonten des Silurs. *Abhandlungen des Hessischen Landesamtes für Bodenforschung, Heft 41*, 1–106.

Yakupov, R.R., Mavrinskaya, T.M. & Abramova, A.N. 2002. *Paleontological justification of the Paleozoic stratigraphical scheme in northern Zilair Megasynclinorium*. 158 pp. Yekaterinburg. [in Russian]

Ziegler, W. 1960. Conodonten aus dem Rheinischen Unterdevon (Gedinnium) des Remscheider Sattels (Rheinisches Schiefergebirge). *Paläontologische Zeitschrift 34*, 169–201.