ABHANDLUNGEN DER GEOLOGISCHEN BUNDESANSTALT

Abh. Geol. B.-A. | ISSN 0016–7800 | ISBN 3-85316-02-6 | Band 54 | S. 377–384 | Wien, Oktober 1999

North Gondwana: Mid-Paleozoic Terranes, Stratigraphy and Biota | Editors: R. Feist, J.A. Talent & A. Daurer

Silurian Bivalvia – Evolution, Palaeoecology, Palaeogeography, Importance for Biostratigraphy and Correlation

JIŘÍ KŘÍZ*)

2 Text-Figure and 1Table

Silurian
Bivalvia
Evolution
Paleoecology
Paleogeography
Biostratigraphy

Contents

Silurische Bivalven – Evolution, Paläoökologie, Palaeogeograpie, Bedeutung für Biostratigraphie und Korrelation

Zusammenfassung

Die zur Kenntnis der Entwicklungsgeschichte, Palökologie und Paläogeographie silurischer Bivalvia im 20. Jahrhundert errungenen Fortschritte werden überblickt. Am Beispiel des Obersilurs des Europäischen Gondwana und Perunica wird die bedeutung der Bivalvia zur Biostratigraphie und Korrelation hervorgehoben.

Abstract

20th century progress in knowledge of evolutionary history, palaeoecology and palaeogeography of the Silurian bivalves is reviewed. Importance of Bivalvia for biostratigraphy and correlation is demonstrated with examples of the upper Silurian of Gondwanan Europe and Perunica.

1. Introduction

Most of the knowledge on the systematics of the Silurian Bivalvia is still concentrated in classic monographs written in the 19th and during the first decades of the 20th century e. g. GOLDFUSS (1837), MURCHISON (1839), MÜNSTER (1840), BARRANDE (1881), HALL (1884, 1885), CLARKE (1899), CHAPMAN (19O8), HEDE (1915), JANIŠEVSKIJ (1918), MCLEARN (1918, 1924), HELLER (1925), HERITSCH (1929) and CHAUBET (1937). Little new information has appeared since these publication. KŘÍZ (1979a) wrote:

*) Author's address: RNDr. Ph.D. Jiří Kříz: Division of Regional Geology of Sedimentary Formations, Czech Geological Survey, P.O.B. 85, Praha 011, 11821, Czech Republic.

"Bivalves are a somewhat neglected group when compared with other fossils such as trilobites, brachiopods and graptolites that are widely used for biostratigraphical, and palaeogeographical studies of Devonian rocks. It is surprising that so little attention is paid to the group, which is highly diversified and distributed in many various environments, and which retains the same various modes of life from Ordovician times onwards. Modern studies of relationships between shell form and life habits (e.g. STANLEY, 1970) make possible well-supported paleoecological interpretations of fossil bivalves to a degree that is hardly possible with extinct groups. Bivalves may also be used for biostratigraphical purposes in the same way as any other group when their phylogeny and stratigraphical ranges are sufficiently known."

However, it became apparent that revisions of the classic works were needed and new systematic studies of Bivalvia necessary. Since 1984 only 22 new genera of bivalves have been most probably described from the Silurian, and at the end of the 20th century only a limited number of modern studies are available for a review on the evolution, palaeogeography and palaeoecology of Silurian Bivalvia.

A number of systematic revisions and studies of Silurian bivalves are available from the Gondwanan region, Perunica (as of HAVLÍČEK et al., 1994) and China, e.g. BABIN (1966), BABIN & ROBARDET 1974, BRANISA (1965), CASTELLARO (1966), FREITAS et al. (1993), IORDAN (1981), JOHNSTON (1991), KEGEL (1953), KŘÍŽ (1966, 1967, 1969, 1979b, 1984, 1985, 1996a, 1996b, 1998a, in press), KŘÍŽ & IORDAN (1975), KŘÍŽ & PARIS (1982), KŘÍŽ & SERPAGLI (1993), KŘÍŽ & VESELINOVIČ (1975), POJETA, KŘÍŽ & BERDAN (1976), SÁNCHEZ (1991, 1992), SÁNCHEZ et al. (1995), SHERRARD (1959), TALENT & PHILIP (1956), TERMIER & TERMIER (1950), and ZHANG (1984).

Silurian bivalves of the Baltica region were mainly studied by KOREJWO & TELLER (1964), LILJEDAHL (1984, 1985, 1989a, 1989b, 1989c, 1992a, 1992b, 1992c, 1994), SALADŽJUS (1966), SINICYNA (1964, 1968), SOOT-RYEN (1964), and TOMCZYKOVA (1958).

Laurentian bivalves of Silurian age have been studied during the last few decades especially by BOLTON (1972), FISCHER (1957), HARRISON and HARRISON (1975) and POJETA & NORFORD (1987).

English and Scottish Silurian bivalves have been studied by REED (1931), WATKINS (1978, 1979), and WATKINS & BERRY (1977).

The Silurian bivalves of Siberia and Kazakhstania were studied during the last half of the century especially by BOGOLEPOVA & KŘÍŽ (1995), SINICYNA (1986, 1993), KULIKOVA (1973, 1983), KRASILOVA (1963), and KŘÍŽ & BOGOLEPOVA (1995).

2. Evolution of Silurian Bivalves

During the Silurian the Bivalvia underwent their second major radiation following abrupt changes in the Earth's environment with accompanying extinctions in the uppermost Ordovician and lowermost Silurian (KŘÍŽ, 1984). Only 26 genera of Bivalvia (35 % of which were free-burrowing and 65 % endobyssate infaunal and semi-infaunal) survived this mass extinction. At present 111 genera and 25 families of Silurian bivalves are known. Adaptation to unique Silurian environments led to the development of 86 new genera and 13 new families.

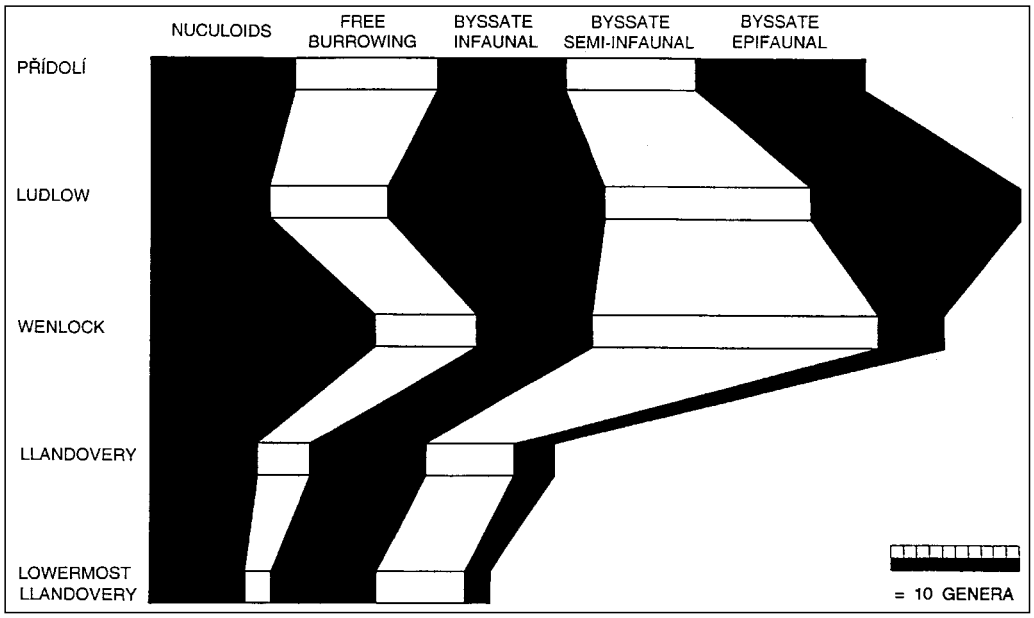
3. Palaeoecology of Silurian Bivalves

The Silurian is characterized by the development of suspension-feeding, free-burrowing, and epibyssate bivalves in particular, from endobyssate forms through rapid evolutionary transitions (KŘÍŽ, 1984). During the Silurian, bivalves employed all major life styles, except for cementation of the shell to the substrate (KŘÍŽ, 1984, 1996a, LILJEDAHL, 1992c).

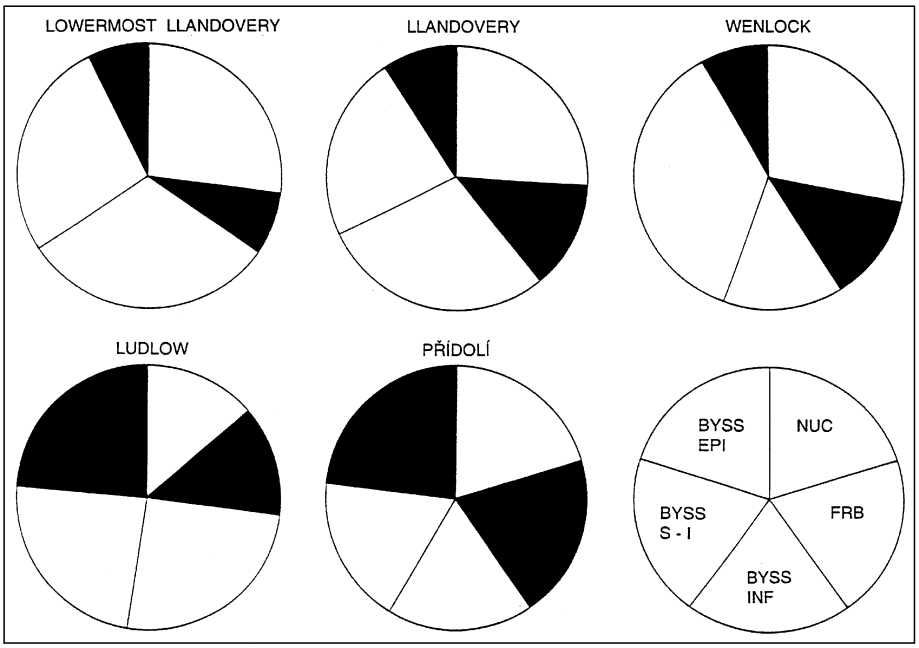
The majority of Silurian nuculoids., most of were shallow burrowers (WALKER & BAMBACH, 1974a, b) are included in infaunal deposit feeders. As in Recent nuculoids, Silurian nuculoids appear to have been adapted to living in soft muds (LILJEDAHL, 1984). They represent an ecologically conservative group without prominent radiation during the Period. The number of genera increases from the lowermost Llandovery up into the Přídolí. Seventeen genera are known from the Wenlock, most of them from Gotland (Text-Figs. 1 and 2).

Free burrowing genera also increased during the Silurian. Two are known in the lowermost Llandovery, four in the Llandovery, eight in the Wenlock, nine in the Ludlow, and 11 in the Přídolí (Text-Figs. 1 and 2).

A maximum of 17 infaunal byssate genera are recorded from the Ludlow and also show a continuous increase in



Text-Fig. 1.
Changes in life habit spectrum of the Bivalvia during the Silurian.
Figures based on the number of genera known per stratigraphic interval.
Modified after KRÍZ (1984).



Text-Fig. 2.
Changes in percentages of bivalve life habits during the Silurian.
NUC = "nuculoids" – free-burrowing deposit feeders; FRB = free burrowing suspension feeders; BYSS INF = byssate infaunal suspension feeders; BYSS S-I = byssate semi-infaunal suspension feeders; BYSS EPI = byssate epifaunal suspension feeders.
Figures based on percentage of genera per stratigraphic interval (modified after KŘÍZ, 1984).

number. From the lowermost Llandovery eight genera are recorded, in the Llandovery nine, in the Wenlock nine and in the Přídolí 10 genera (Text-Figs. 1 and 2).

A maximum number of byssate semi-infaunal genera (22) is described from the Wenlock, but a small decrease is recorded later in the Silurian (16 in the Ludlow and 10 in the Přídolí).

Especially interesting is the distinct increase in the number of byssate epifaunal bivalves during the Silurian. From two genera in the lowermost Llandovery, to three in the Llandovery, five genera in the Wenlock, 16 in the Ludlow and 13 in the Přídolí (Text-Figs. 1 and 2).

The number of epibyssate bivalves in the lowermost Llandovery represents about 7 % of all Llandoverian bivalves (Text-Fig. 2). During the Silurian this number increases and by the Přídolí represents about 23 % of all bivalves (nuculoids – 20 %, free burrowing bivalves – 20 %, byssate infaunal – 18.2, and byssate semi-infaunal – 18.2 %).

4. Palaeogeography of Silurian Bivalves

Three main climate regions may be distinguished in the Silurian on the basis of bivalve distribution. These are a tropical region in the equatorial zone, temperate zones north and south of the Silurian equator and a cold zone known only from the Gondwana region (South American Precordillera, northwestern Argentina basins and Bolivia).

A clearly tropical reef-associated habitat is known in the Silurian represented by "giant clams" megalodonts in the Canadian Arctic, west-central New York, Michigan Basin and Australia (FREITAS et al., 1993) and from Gotland (LINDSTRÖM, 1885). It agrees with the most recent reconstructions of the Silurian and Early Devonian palaeogeography published by Cocks & SCOTESE (1991) and with the reconstructions of the Silurian oceanic and atmospheric circulation by WILDE, BERRY & QUINBY-HUNT (1991).

LILJEDAHL (1984 and 1985) described mainly a deposit-feeder dominated community of bivalves (e.g. *Nuculoidea, Nuculodonta, Palaeostraba* and *Caesariella*) from the Silurian (Wenlock, Homerian) tropical region of Gotland. Rare representatives of the mainly epibyssate genera (*Maminka, Mytilarca, Kenzieana* and *Procarinaria*) were also described from the same region (LILJEDAHL, 1984, 1989c). These genera are also known from the temperate zone communities of the Bohemian type fauna of Gondwanan Europe (KŘÍZ & SERPAGLI, 1993 and KŘÍZ, 1996b) and from the Perunica - Prague Basin (BARRANDE, 1881).

A littoral zone tropical association of bivalves was described by FISCHER (1957) from the west-central New York Vernon Shales (late Silurian). This low diversity community is dominated by an epibyssate pterineid described as "*Pterinea*" (most probably congeneric with *Joachymia* RŮŽIČKA, 1949) which is homologous and analogous with the upper Přídolí age *Joachymia falcata* Community of the temperate zones of Gondwana (Sardinia) and Perunica.

Another Silurian tropical bivalve community of the Silurian bivalves was described by WATKINS (1997) from the reefs of the Racine Formation (Wenlock) of the Michigan Basin. Bivalves form less than 1 % of skeletal material in the reef and are mostly represented by byssate epifaunal and semi-infaunal suspension-feeders. One species was a recliner on the surface and another was a shallow-burrower. It is interesting that rare representatives of some mainly epibyssate genera of the Bohemian type of fauna of Gondwanan Europe (*Cardiola, Mytilarca, Actinopteria, Cypricardinia, Rhombopteria* and *Modiolopsis*) are also found in this community.

A nearshore, warm, carbonate mud bottom bivalve community was described from the lower Silurian of Ohio (Brassfield Formation) by HARRISON & HARRISON (1975). An interesting diminutive fauna is composed of the deposit-feeders *Palaeoneilo, Nuculites, Praenucula, Palaeoconcha* and *Deceptrix*, and by the infaunal suspension-feeder *Lyrodesma*.

The Silurian Malvinokaffric faunas are considered to represent the coldest water associations of Silurian Bivalvia. They were described and listed recently by SÁNCHEZ et al. (1995) from the Silurian South American Precordillera, northwestern Argentina basins and Bolivia. These associations are characterized by a rich occurrence of deposit-feeders (e.g. *Nuculites* and *Palaeoneilo*). Occurring more rarely are representatives of some genera known from the Bohemian type of fauna of Gondwanan Europe (*Actinopteria* and *Dualina*).

The highest diversity of the Silurian bivalves is known in the carbonate facies of the temperate zone in Gondwanan Europe. The facies is characterized by the development of the "Bohemian type" fauna (KŘÍZ, 1984, 1991, in press), best known from the Prague Basin of Bohemia described by KŘÍZ (1979, 1996b), KŘÍZ & PARIS (1982), KŘÍZ & SER-

PAGLI (1993), and also from other European basins (Sardinia, Montagne Noire, Massif Mouthoumet, Massif Armoricain, and the Carnic Alps).

The Bohemian type of fauna is characterized especially by epibyssate representatives of the families Cardiolidae, Lunulacardiidae, Butovicellidae, Praeostreidae, Pterineidae, and Pterinopectinidae. Reclining, endobyssate and free burrowing forms are represented by the family Antipleuridae and Praecardiidae. About 22 Silurian and Devonian "Bohemian type" communities that are dominated by Bivalvia and described from Bohemia, North Africa, Sardinia, France, Italy, Austria, Turkey and related regions (eastern Serbia, Poland, Florida), are grouped into five community groups on the basis of homology and analogy (KŘÍZ, in press, BOUCOT & KŘÍZ, in press). The *Cardiola* Community group (Wenlock to lowermost Přídolí) is characterized by 10 recurring communities formed by mostly epibyssate forms living in the cephalopod limestone biofacies environment (FERRETI & KŘÍZ, 1993, KŘÍZ, in press). The *Snoopyia* Community Group (upper Přídolí) is characterized by mostly infaunal forms living in micritic limestone – cephalopod limestone biofacies. The *Patrocardia* Community Group (upper Přídolí to Upper Devonian) is dominated by epibyssate forms living in the facies represented by biodetrital limestones – micritic limestones and shales. In the Lower Devonian the *Antipleura-Hercynella* Community Group is dominated by burrowing and reclining Antipleuridae and Praecardiidae. The *Cheiopteria* Community Group (Ludlow to Upper Devonian) is characterized by mass occurrences of semi-infaunal forms in the deeper facies of micritic limestones – claystones.

The Silurian non-carbonate facies, represented mainly by shales with graptolites, cephalopods and bivalves, is especially developed in England (Welsh Borderland – WATKINS, 1979), Sweden (Gotland and Skane – LAUFELD, BERGSTRÖM & WARREN, 1975), France (Normandie, Massif Armoricain, Montagne Noire, and Massif Mouthoumet – BABIN & ROBARDET, 1974, KŘÍZ, 1996b), Czech Republic (Prague Basin and Brunovistulicum – KŘÍZ, 1991, BOUČEK, 1935), Poland (Góry Swietokrzyskie, eastern Poland – TOMCZYKOVA, 1958, KOREJWO & TELLER, 1964), Romania (Moesian Platform – IORDAN, 1981), Guinea, Africa (KŘÍZ, 1985), Nova Scotia (LEVINTON & BAMBACH, 1975) and Arctic Canada (POJETA & NORFORD, 1987). The facies was in general described by BERRY & BOUCOT (1967) as having a pelecypod – graptolite association from North Africa northward into Scandinavia and from the Atlantic Coast of Europe to the Caucasus.

WATKINS (1978, 1979) and WATKINS & BERRY (1977) studied in detail communities of bivalves from the muddy shelf Wenlockian and Ludlovian sediments of the Welsh Borderland and Wales. These are mostly composed of suspension feeders living together with deposit feeders at shallow depth. They consider the muddy substrate to be a high-stress environment where bivalves are the most numerous invertebrates.

Similar conclusions for soft muddy substrates were made by LEVINTON & BAMBACH (1975) based on three communities from the McAdam Brook Formation, Arisaig Group, Nova Scotia. These are dominated by deposit feeding bivalves which comprise 60–90 % of the total bivalve fauna of the formation. Suspension feeders are never dominant.

The expansion of bivalve dominated communities from shallow environments to deeper environments during the Silurian and Lower Devonian was well documented by KŘÍZ (in press). The trend which began in the Upper Ordovician, when bivalve dominated communities were restricted to the inner-shelf shallow water environments (JABLONSKI et al., 1983), continued during the Silurian.

5. Importance of Silurian Bivalves for Biostratigraphy and Correlation

Detailed study of the Silurian family Cardiolidae from the Prague Basin, Bohemia and other world regions (KŘÍZ, 1979b), extensive collections and systematic study of the Silurian and Lower Devonian Bivalvia from the Prague Basin, Perunica (KŘÍZ, 1966, 1967, 1969, 1979b, 1985, 1996a, 1998, in press), and from Gondwana, e.g. Armoricain Massif, Bolivia, Carnic Alps, Eastern Serbia, Florida and Georgia, Montagne Noire, Moesian Platform, Mouthoumet Massif, Sardinia and Turkey (KŘÍZ, 1979, 1996b, KŘÍZ & PARIS, 1982, KŘÍZ & SERPAGLI, 1993, KŘÍZ & VESELINOVIČ, 1975, KŘÍZ & IORDAN, 1975, POJETA, KŘÍZ & BERDAN, 1976), provided sufficient material to define bivalve dominated communities of the Bohemian type (KŘÍZ, in press).

In the upper Silurian (Ludlow and Prídolí) sequences of Gondwanan Europe, bivalve-rich horizons occur in the cephalopod limestones and represent stratigraphical markers. Each of these horizons contains a characteristic bivalve-dominated community of the *Cardiola* Community Group which consists of about 11 recurrent communities dominated by different species of the genus *Cardiola*. These levels correspond to one, or at the most, two graptolite zones in Gondwanan Europe. Their exact stratigraphic position is controlled by the occurrence of graptolites, conodonts and chitinozoans in the Prague Basin (KŘÍZ et al., 1986, KŘÍZ et al., 1993, KŘÍZ in KALJO et al., 1996, KŘÍZ, 1998), conodonts, graptolites and chitinozoa in Sardinia (DUFKA & GNOLI, 1996, KŘÍZ & SERPAGLI, 1993), the Armoricain Massif (KŘÍZ & PARIS, 1982), and in the Carnic Alps (SCHÖNLAUB, 1980). Cardiolidae and the recurring communities dominated by *Cardiola* species may have stratigraphic significance in Gondwanan areas where graptolites are scarce and where the cephalopod limestones are developed. Species of *Cardiola* are easy to recognize because of their characteristic ontogeny, which concerns the swollen band in the umbonal part (KŘÍZ, 1979b). The proposed biostratigraphy of the Wenlock, Ludlow and Prídolí based on bivalve dominated communities characteristic of different levels of the cephalopod limestones (KŘÍZ, in press) is shown on Table 1.

KŘÍZ (1998) and KŘÍZ et al. (in press) demonstrated that Silurian bivalves are also valuable for interbasinal correlations (Prague Basin, Montagne Noire, the Armoricain Massif, Spain, Guinea, Morocco, Carnic Alps, Sardinia, Eastern Serbia and Western Macedonia) within Gondwanan Europe and Africa. Bivalve dominated communities studied in the South Armoricain Domain, Sardinia, Prague Basin, the Carnic Alps, Mouthoumet Massif and the Montagne Noire by KŘÍZ & PARIS (1982), KŘÍZ & SERPAGLI (1993), and KŘÍZ (1991, 1996b, 1998, in press) show closer relationships between the northern margin of the Gondwana regions than with the communities described from the Prague Basin on the Perunica microcontinent. Bivalve dominated communities on Perunica show higher diversity than the same communities known from the other Gondwana basins (KŘÍZ et al., in press).

Biostratigraphy of the subsurface Silurian rocks of Florida (POJETA, KŘÍZ & BERDAN, 1976) and their correlation with Gondwanan Europe is based mainly on the Bohemian type

Table 1.
Biostratigraphy of the Silurian and Lower Devonian based on the Bivalvia dominated communities.

CHRONO-STRATIGRAPHY			BIOSTRATIGRAPHY BASED ON GRAPTOLITES		BIOSTRATIGRAPHY BASED ON BIVALVE DOMINATED COMMUNITIES
DEVONIAN	LOWER DEVONIAN	PRAGIAN			*Panenka* Community
		LOCHKOVIAN			*Hercynella-Neklania* Community
			M. uniformis Zone		*Antipleura bohemica* Community
SILURIAN	PŘÍDOLÍ		*M. transgrediens* Zone		*Snoopyia insolita* Community *Joachymia - Cardiolinka - Pygolfia* Community *Pterinopecten (P.) cybele cybele* Community *Patrocadia - Dualina* Community
			M. perneri Zone		
			M. bouceki Zone		
			M. lochkovensis Zone		
			M. ultimus Zone		*Cardiolinka sardiniana* Community
			M. parultimus Zone		*Cardiolinka bohemica* Community
	LUDLOW	LUDFORDIAN	*M. fragmentalis* Zone		*Cardiola conformis* Community
			M. latilobus Zone		
			N. kozlowskii Zone		*Cardiola alata* Community
			N. inexpectatus Zone		
			B. bohemicus tenuis Zone		
			S. linearis Zone		*Cardiola docens* Community
		GORSTIAN	*S. chimaera* Zone		*Cardiola signata* Community *Cardiola consaguis* Community *Cardiola donigala* Community
			C. colonus Zone		*Cardiola gibbosa* Community
	WENLOCK	HOMERIAN	*P. ludensis* Zone		
			P. praedeubeli - P. deubeli z.		
			G. nassa Zone		
			P. parvus Zone		
			C. lundgreni Z.	*T. testis* Subz.	*Cardiola figusi* Community *Cardiola agna* Community
				C. radians Subz.	
		SHEINWOODIAN	*C. perneri / C. ramosus* z.		
			C. rigidus Zone		*Carnalpia nivosa* Community
			M. belophorus Zone		
			P. dubius Zone		
			M. riccartonensis Zone		

The Wenlock and Ludlow are indicated by the characteristic Gondwanan bivalve *Butovicella migrans*, and the Přídolí by the *Cheiopteria bridgei* Community and the *Lunulacardium excellens* Community first described from the Prague Basin, Bohemia (Kríz, in press). The Silurian (Přídolí)/Devonian (Lochkovian) boundary community of bivalves is characterized by *Prothyris, Arisaigia, Pleurodapis* and *Nuculites* and shows close relationships to the bivalve community described by KOREJWO & TELLER (1964) from the East European Platform of Baltica and also to the community of bivalves known from Arisaig, Nova Scotia (MCLEARN, 1924).

Acknowledgments

The author thanks Claude BABIN, Margaret A. BRADSHAW, Raimund FEIST and Kathleen HISTON for critical readings of the manuscript and for language corrections. A special thanks is given R. HORČÍKOVÁ for assistance in the graphic work.

References

BABIN, C.: Mollusques Bivalves et Céphalopodes du Paléozoique armoricain. Étude systématique. Essai sur la phylogénie des Bivalves. Esquisse paléoécologique. – Imprimerie Commerciale et Administrative, 1–471, Brest 1966.

BABIN, C. & ROBARDET, M.: Mollusques Bivalves du Silurien supérieur et de l'extreme base du Dévonien en Normandie. – Ann. Soc. géol. Nord, **94** (1), 19–45, Lille 1974.

BARRANDE, J.: Systeme silurien du centre de la Boheme. Iere partie: Recherches paléontologiques, **6**, 1–342, Prague, Paris 1881.

BERRY, W.B.N. & BOUCOT, A.J.: Pelecypod-graptolite association in the Old World Silurian. – Geol. Soc. Amer. Bull., **79**, 1515–1522, New York 1967.

BOGOLEPOVA, O.K. & KŘÍZ, J.: Ancestral forms of Bohemian type Bivalvia from the lower Silurian of Siberia (Tungusskaja Syneclise, Russia). – Geobios, **28** (6), 691–99, Lyon 1995.

BOLTON, T.E.: Illustrations of Canadian fossils. Silurian faunas of Ontario. – Pap. Geol. Surv. Canada, **66** (5), 1–46, Ottawa 1966.

BOLTON, T.E.: Geological map (22 H, 12 E, F) and notes on the Ordovician and Silurian litho- and biostratigraphy, Anticosti Island, Québec. – Pap. Geol. Surv. Canada, **71** (19), 1–44, Ottawa 1972.

BOUCOT, A.J. & KŘÍZ, J.: Definition of the terms "homologous" and "analogous" community. – Cambridge University Press, **6**, p. 32, Cambridge, in press.

BOUČEK, B.: O silurské faune od Stínavy (západne od Plumlova) na Drahanské vysocine. – Cas. Vlast. Spol. mus., **48** (3–4), 1–10, Olomouc 1935.

BRANISA, L.: Los fósiles guias de Bolivia. I. Paleozoico. – Serv. Geol. Bolivia, Bol., **6**, 1–282, La Paz 1965.

CASTELLARO, H.A.: Guía Paleontológica Argentina. Parte I: Paleozoico. Faunas Silúricas y Devónicas. – Publ. Cons. Nac. Invest. Cient. Técn., 164 p., Buenos Aires 1966.

CHAPMAN, F.: A monograph of the Silurian bivalved Mollusca of Victoria. – Mem. Nat. Mus. Victoria, **2**, 1–62, Melbourne 1908.

CHAUBET, M.-Ch.: Contribution a l'Étude géologique du Gothlandien du versant méridional de la Montagne Noire. – Travaux du Laboratoire de Géologie de la Faculté des Sciences de Montpellier, Mém., **1**, 1–233, Montpellier 1937. CLARKE, J.M.: The Paleozoic faunas of Pará, Brazil. – Arch. Mus. Nac. Rio de Janeiro, 1899, **10**, 127 p., Rio de Janeiro 1899.

COCKS, L.R.M. & SCOTESE, C.R.: The global biogeography of the Silurian Period, 109–122. – In: M.G. BASSETT, LANE, P.D. & EDWARDS, D. (eds.): The Murchison Symposium: proceedings of an international conference on The Silurian System. – Spec. Pap. Palaeont., **44**, 397 p. London, 1991.

DUFKA, P. & GNOLI, M.: A report on Silurian and lowermost Devonian chitinozoans from South-western Sardinia. – Boll. Soc. pal. ital., **34** (3), 263–269, Modena 1996.

FERRETI, A. & KŘÍZ, J.: 1995. Cephalopod limestone biofacies in the Silurian of the Prague Basin, Bohemia. – Palaios, **10** (3), 240–253, Tulsa 1995.

FISCHER, D.W.: Lithology, paleoecology and paleontology of the Vernon Shale (late Silurian) in the type area. – Bull. N. Y. St. Mus. Sc. Serv., **364**, 1–31, Albany 1957.

FREITAS, T.A., BRUNTON, F. & BERNECKER, T.: Silurian megalodont bivalves of the Canadian Arctic and Australia: Paleoecology and evolutionary significance. – Palaios, **5** (8), 450–464, Tulsa 1993.

GOLDFUSS, A.: Petrefacta Germaniae. 2, 141–244, Düsseldorf 1837.

HALL, J.: Paleontology, Lamellibranchiata I, Monomyaria of the upper Helderberg, Hamilton and Chemung Groups, 1–268. – Geol. Surv. of the State of New York, Albany 1884.

HALL, J.: Lamellibranchiata II, Dimyaria of the upper Helderberg, Hamilton, Portage and Chemung Groups. – 1–561, Geol. Surv. of the State of New York, Albany 1885.

HARRISON, W.B.III. & HARRISON, L.K.: A Maqueta-like molluscan community in the Brassfield Formation (early Silurian) of Adams County, Ohio. – Bull. Amer. Pal., **67** (287), 193–234, Ithaca 1975.

HAVLÍČEK, V., VANEK, J. & FATKA, O.: Perunica microcontinent in the Ordovician (its position within the Mediterranean Province, series division, benthic and pelagic associations). – Sbor. geol. Ved, Geol., **46**, 23–56, Praha 1994.

HEDE, J.E.: Skanes Colonusskiffer I. – Lunds Univ. Arsskr., N. F., A. 2, **11**, 6, 1–65, Lund, Leipzig 1915.

HELLER, T.: Die Fauna des obersilurischen Orthocerenkalks von Elbersreuth. – Geogn. Jh., **38**, 197–277, München 1925.

HERITSCH, F.: Faunen aus dem Silur der Ostalpen. – Abh. Geol. Bundesanst., **23** (2), 1–183, Wien 1929.

IORDAN, M.: Study of Silurian and Devonian faunas from the eastern part of the Moesian Platform. – Mém., Inst. Géol. Géoph., **30**, 115–222, Bucarest 1981.

JABLONSKI, D., SEPKOSKI, J.J.,Jr., BOTTJER, D.J. & SHEEHAN, M.P.: Onshore-offshore patterns in the evolution of Phanerozoic shelf communities. – Science, **222**, 1123–1125, Washington 1983.

JANIŠEVSKIJ, M.: O trilobitach i molljuskach verchnovo silura Kavkaza. – Ezegod. Russ. Paleont. Obsc., **2** (1917), 48–63, Petrograd 1918.

JOHNSTON, P.A.: Systematics and ontogeny of a new bivalve, Umburra cinefacta, from the Silurian of Australia: implications for pteriomorphian evolution. – Alcheringa **15**, 293–319, Sydney 1991.

KALJO, D., BOUCOT, A.J., CORFIELD, M., LE HÉRRISÉ, A., KOREN, T., KŘÍZ, J., MÄNNIK, P., MÄRSS, T., NESTOR, V., SHAVER, R.H., SIVETER, D.J. & VIIRA, V.: Silurian bio-events 173–224. – In: O.H. WALLISER, (ed.): Global events and event stratigraphy in the Phanerozoic: results of international interdisciplinary cooperation in the IGCP Project 216 "Global Biological Events in Earth History", Springer-Verlag, 1–333, Berlin, Heidelberg 1996.

KEGEL, W.: Das Paläozoikum der Lindener Mark bei Giessen. – Abh. Hess. Landesam. Bodenforsch., **7**, 1–55, Wiesbaden 1953.

KOREJWO, K. & TELLER, L.: Upper Silurian non-graptolite fauna from the Chelm borehole (eastern Poland). – Acta geol. pol., **14** (2), 233–301, Warszawa 1964.

KRASILOVA, I.N.: Stratigrafija i pelecypody verchov silura i niznevo devona severo-vostocnovo Pribalchasija. – Trudy Geol. Inst., Akad. Nauk SSSR, **75**, 1–200, Moskva 1963.

KŘÍZ, J.: Praeostrea Barrande, 1881 from the Lower Paleozoic of Central Europe (Bivalvia). – Cas. Nár. Mus., odd. prír., **135** (1), 25–32, Praha 1966.

KŘÍZ, J.: The genus *Manulicula* gen. n. from the Silurian of Bohemia (Bivalvia). – Vest. str. st. geol., **42** (2), 123–126, Praha 1967.

KŘÍZ, J.: Genus *Butovicella* Kříz, 1965 in the Silurian of Bohemia (Bivalvia). – Sbor. geol. Ved, R. P, Paleont., **10**, 105–139, Praha 1969.

KŘÍZ, J.: Devonian Bivalvia. – Spec. Pap. in Paleont., **23**, 255–257, London 1979a.
KŘÍZ, J.: Silurian Cardiolidae (Bivalvia). – Sbor. geol. Ved, R. P, Palaeont., **22**, 5–157, Praha 1979b.
KŘÍZ, J.: Autecology and ecogeny of Silurian Bivalvia. – Spec. Pap. Paleont., **32**, 183–195, London 1984.
KŘÍZ, J.: Silurian Slavidae (Bivalvia). – Sbor. geol. Ved, R. P, Palaeont., **27**, 47–111, Praha 1985.
KŘÍZ, J.: The Silurian of the Prague Basin (Bohemia) – tectonic, eustatic and volcanic controls on facies and faunal development, 179–203. – In: M.G. BASSETT, LANE, P.D. & EDWARDS, D. (eds.): The Murchison Symposium: proceedings of an international conference on The Silurian System, Spec. Pap. Palaeont., **44**, 397p., London 1991.
KŘÍZ, J.: *Maida* nov. gen., the oldest known nektoplanktic bivalve from the Přídolí (Silurian) of Europe. – Geobios, **29** (5), 529–535, Lyon 1996a.
KŘÍZ, J.: Silurian Bivalvia of Bohemian type from the Montagne Noire and Mouthoumet Massif, France. – Palaeontolographica, Abt. A, **240**, 29–63, Stuttgart 1996b.
KŘÍZ, J.: Recurrent Silurian-lowest Devonian cephalopod limestones of Gondwanan Europe and Perunica. – In: LANDING, E. & JOHNSON, M.E. (eds.): Silurian cycles: Linkages of dynamic stratigraphy with atmospheric, oceanic, and tectonic changes, N.Y. St. Mus. Bull., **491**, 183–198, Albany 1998a.
KŘÍZ, J.: Taxonomy, functional morphology and autecology of sinistrally twisted bivalve Vlasta (Vlastinae, Antipleuridae) from the Lower Devonian of Bohemia, Morocco and Central Asia. – Geobios, **31**, 4, Lyon 1998b.
KŘÍZ, J.: Bivalvia dominated communities of Bohemian type from the Silurian and Lower Devonian carbonate facies. – Cambridge University Press, **16**, 225–248, Cambridge, in press.
KŘÍZ, J. & BOGOLEPOVA, O.K.: *Cardiola* signata Community (Bivalvia) in cephalopod limestones from Tajmyr (Gorstian, Silurian, Russia). – Geobios, **28** (5), 573–583, Lyon 1995.
KŘÍZ, J., DEGARDIN, J.-M., FERRETTI, A., HANSCH, W., GUTIÉRREZ MARCO, J.C., PARIS, F., PIÇARRA D-ALMEIDA, J.M., ROBARDET, M., SCHÖNLAUB, H.P. & SERPAGLI, E.: Silurian stratigraphy and paleogeography of Western, Southern and Central Europe (north Gondwana and Perunica). – N. Y. St. Mus. Bull. **493**, Albany, in press.
KŘÍZ, J., DUFKA, P., JAEGER, H. & SCHÖNLAUB, H.-P.: The Wenlock/Ludlow boundary in the Prague Basin (Bohemia). – Jb. Geol. Bundesanst., **136** (4), 809–839, Wien 1993.
KŘÍZ, J. & IORDAN, M.: Silurian bivalves of Bohemian type from the deep boreholes on the Moesian Platform (Romania). – Vest. Ústř. Úst. geol., **50** (2), 109–113, Praha 1975.
KŘÍZ, J., JAEGER, H., PARIS, F. & SCHÖNLAUB, H.-P.: Prídolí – the fourth subdivision of the Silurian. – Jb. Geol. Bundesanst., **129** (2), 291–360, Wien 1986.
KŘÍZ, J. & PARIS, F.: Ludlovian, Pridolian and Lochkovian in La Meignanne (Massif Armoricain): Biostratigraphy and correlations based on Bivalvia and Chitinozoa. – Geobios, **15**, 391–421, Lyon 1982.
KŘÍZ, J. & SERPAGLI, E.: Upper Silurian and lowermost Devonian Bivalvia of Bohemian type from South-Western Sardinia. – Boll. Soc. paleont. ital., **32** (3), 289–347, Modena 1993.
KŘÍZ, J. & VESELINOVIČ, M.: Ludlovian, Prídolian and Lochkovian bivalves from the Suva Planina Mountains (Eastern Serbia, Yugoslavia). – Vest. Ústř. Úst. geol., **50** (6), 365–369, Praha 1975.
KULIKOVA, V.F.: Granica silura-devona i niznevo-srednevo devona po dannym izucenija pelecypod Kuzneckovo bassejna. – Trudy III Mezdunarodnovo sympozyuma po granice silura i devona i stratigrafii noznmevo i srednevo devona. Stratigrafia niznevo i srednevo devona, **2**, 148–152, 289–290, Leningrad 1973.
KULIKOVA, V.F.: Silurijskije i rannedevonskije dvustvorcatyje molljuski podnatija Cernova (Poljarnyj Ural). – Ezegod. Vsesojuz. paleont. Obsc., **24**, 148–162, Leningrad 1983.

LAUFELD, S., BERGSTRÖM, J. & WARREN, P.T.: The boundary between the Silurian Cyrtograptus and Colonus Shales in Skane, southern Sweden. – Geol. Fören. Förh., **97**, 207–222, Stockholm 1975.
LEVINTON, J.S. & BAMBACH, R.K.: A comparative study of Silurian and recent deposit-feeding bivalve communities. – Paleobiology **1**, 97–124, Chicago 1975.
LILJEDAHL, L.: Silurian silicified bivalves from Gotland. – Sver. geol. Unders., Ser. C NR 804, **78** (2), 1– 82, Stockholm 1984.
LILJEDAHL, L.: Ecological aspects of a silicified bivalve fauna from the Silurian of Gotland. – Lethaia, **18**, 53–66, Oslo 1985.
LILJEDAHL, L.: Fylgia baltica gen. et sp. nov. (Bivalvia, Mollusca) from the Silurian of Gotland. – Geol. Fören. Förh., **111** (4), 339–345, Stockholm 1989a.
LILJEDAHL, L.: Identity of the bivalve Modiolodonta gothlandica (Hisinger) from the Silurian of Gotland. – Geol. Fören. Förh., **111** (4), 313–318, Stockholm 1989b.
LILJEDAHL, L.: Two micromorphic bivalves from the Silurian of Gotland. – Paläontol. Z., **63** (3/4), 229–240, Stuttgart 1989c.
LILJEDAHL, L.: Yonginella, a new bivalve (Mollusca) from the Silurian of Gotland. – J. Paleont., **66** (2), 211–214, Tulsa 1992a.
LILJEDAHL, L.: Silurozodus, new genus, the oldest known member of the Trigonioida (Bivalvia, Mollusca). – Paläont. Z., **66** (1/2), 51–65, Stuttgart 1992b.
LILJEDAHL, L.: The Silurian *Ilionia prisca*, oldest known deep burrowing suspension-feeding bivalve. – J. Paleont., **66** (2), 206–210, Tulsa 1992c.
LILJEDAHL, L.: Silurian nuculoid and modiomorphid bivalves from Sweden. – Fossils and Strata, **33**, 1–89, Oslo 1994.
LINDSTRÖM G.: List of the fossils of the upper Silurian Formation of Gotland. – P.A. Norstedt & Söner, 1–20, Stockholm 1885.

MCLEARN, F.H.: The Silurian Arisaig Series of Arisaig, Nova Scotia. – Amer. J. Sci., **45** (10), 126–140, New Haven 1918.
MCLEARN, F.H.: Palaeontology of the Silurian rocks of Arisaig, Nova Scotia. – Geol. Surv. Canada, Geol. Ser., Mem., **137** (118), 1–179, Ottawa 1924.
MURCHISON, R.I.: The Silurian system. Part 1. – 1–768, London 1839.
MÜNSTER, G.G.: Beiträge zur Petrefacten-Kunde, **3**, 1–129, Bayreuth 1840.

POJETA, J.Jr., KŘÍZ, J. & BERDAN, J.M.: Silurian-Devonian pelecypods and Paleozoic stratigraphy of subsurface rocks in Florida and Georgia and related Silurian pelecypods from Bolivia and Turkey. – U. S. Geol. Surv. profess. Pap., **879**, 1–32, Washington, D.C. 1976.
POJETA, J.Jr. & NORFORD, B.S.: A Bohemian-type Silurian (Wenlockian) pelecypod faunule from Arctic Canada. – J. Pal., **61** (3), 508–520, Tulsa 1987.

REED, F.R.C.: Some new lamellibranchs from the Silurian of the Ludlow District. – Ann. Mag. Nat. Hist., Ser. 10, **8** (46), 289–304, London 1931.
RŮŽIČKA, B.: Pteriidae Thiele ceského siluru a devonu. – Sbor. Vys. Sk. báns. Ostrava, Prír. Sbor. ostrav. Kraje, **1949**, (3), 97–118, Praha 1949.

SALADŽJUS, V.J.: Fauna molljuskov silurijskich otlozenij Juznoj Pribaltiki. – Paleontologija i stratigrafija Pribaltiki i Belorusii, **1** (6), 31–73, Vilnius 1966.
SÁNCHEZ, T.M.: El género *Dualina* (Bivalvia, Praecardioida) en la Formación Lipeon (Silúrico), Sierra de Zapla, Provincia de Jujuy, Argentina. – Ameghiniana, **28** (1–2), 31–34, Buenos Aires 1991.
SÁNCHEZ, T.M.: Functional morphology and autecology of Silurian and Devonian nuculoid bivalves from western Argentina. – Zbl. Geol. Paläont., **1**, 1991, 6, 1815–1839, Stuttgart 1992.
SÁNCHEZ, T.M., WAISFELD, B.G. & TORO, B.A.: Silurian and Devonian molluscan bivalves from Precordillera Region, Western Argentina. – J. Paleont., **69** (5), 869–886, Tulsa 1995.
SCHÖNLAUB, H.-P.: Field Trip A: Carnic Alps. – In: SCHÖNLAUB, H.-P. (ed.): Second European Conodont Symposium (ECOS II), Guidebook and Abstracts, Abh. Geol. Bundesanst., **35**, 5–57, Wien 1980.
SHERRARD, K.: Some Silurian lamellibranchs from New South Wales. – Proc. Linn. Soc. New South Wales, **84** (3), 356–372, Sydney 1959.
SÍNICYNA, I.N.: Predstaviteli semejstva Modiolopsidae Fischer iz silurijskich otlozenij Podolii. – Vest. Leningrad. Univ., **24**, 44–50, Leningrad 1964.

SÍNICYNA, I.N.: Dvustvorcatyje molljuski skalskovo, borsovskovo i cortkovskovo gorizontov Podolii. – In: Silurijsko-Devonskaja fauna Podolii, Leningrad. Univ., 72–94, Leningrad 1968.

SÍNICYNA, I.N.: Nekotoryje novyje dvustvorcatyje molljuski isfarinskovo gorizonta (verchnyj silur) juznoj Fergany. – Vopr. Paleont., **9**, 60–73, Leningrad 1986.

SÍNICYNA, I.N.: Klas Bivalvia – dvustvorcatyje molljuski. – In: KISELEV, G.N. (ed.): Atlas molljuskov i brachiopod silura i devona juznovo Tjan-Sanja, Sankt-Petersburskij Gosudarstvennyj Universitet, 10–25, 104–106, Petrograd 1993.

SOOT-RYEN, H.: Nuculoid pelecypods from the Silurian of Gotland. – Ark. Mineral. Geol., **3**, 489–519, Stockholm 1964.

STANLEY S.M.: Relation of shell form to life habits of the Bivalvia (Mollusca). – Memoir of the Geological Society of America, Inc., 125, 1–296, Boulder 1970.

TALENT, J.A. & PHILIP, G.M.: Siluro-Devonian Mollusca from Marble Creek, Thomson River, Victoria. – Proc. Roy. Soc. Victoria, **68** (2), 57–71, Melbourne 1956.

TERMIER, G. & TERMIER, H.: Paléontologie Marocaine II, Invertébrés de l'Ere primaire. – Not. Mém. Serv. Geol., **78**, 1–246, Paris 1950.

TOMCZIKOWA, E.: Fauna z lupków graptolitowych syluru niecki bardzianskiej Gór Swietokrzyskich. – Kwart. geol., **2** (2), 321–345, Warszawa 1958.

WALKER, K.R. & BAMBACH, R.K.: Analysis of communities. – In: ZIEGLER, A.M. et al.: Principles of benthic community analysis (Notes for a short course), Sedimenta, **4**, 2.1–2.19, Miami 1974a.

WALKER, K.R. & BAMBACH, R.K.: Feeding by benthic invertebrates classification and terminology for paleoekological analysis. – Lethaia, **7**, 67–78, Oslo 1974b.

WATKINS, R.: Bivalve ecology in a Silurian shelf environment. – Lethaia **11**, 41–56, Oslo 1978.

WATKINS, R.: Benthic community organization in the Ludlow Series of the Welsh Borderland. – Bull. Brit. Mus. (Nat. Hist.), Ser. Geol., **31** (3), 175–280, London 1979.

WATKINS, R.: Paleoecology of Silurian reef bivalves, Racine Formation, North America. – Lethaia, **29**, 171–180, Oslo 1997.

WATKINS, R. & BERRY, B.N.: Ecology of a late Silurian fauna of graptolites and associated organisms. – Lethaia **10**, 267–286, Oslo 1977.

WILDE, P., BERRY, W.B.N. & QUINBY-HUNT, M.S.: Silurian oceanic and atmospheric circulation and chemistry. – Spec. Pap. Palaeont., **44**, 123–143, London 1991.

ZHANG, R.: Early Silurian bivalves and rostroconchs in northwest Hunan, China. – Acta paleont. sin., **23** (5), 586–596, Beijing 1984.

Manuskript bei der Schriftleitung eingelangt am 2. Oktober 1998