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Facies transition and biostratigraphic correlation of the Upper Silurian and Lower Devonian in West Bulgaria

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Upper Silurian and Lower Devonian shelf deposits in West Bulgaria are exposed in three main Alpine tectonic units: the West Balkan Unit, the Lyubash Monocline and the Morava Unit. The West Balkan and Lyubash units consist of siliciclastic deposits: black graptolitic shales, banded pale shales and black siltstones. The Ludlow, Pridoli, Lochkovian, Pragian and Emsian were recognized on the basis of graptolite and tentaculite faunas. In the Morava Unit, the Ludlow black shales are progressively replaced by clayey limestones and nodular and micritic limestones in the Pridoli and Early Devonian. Newly obtained conodonts show the presence of the *siluricus, eosteinhornensis, woschmidti, postwoschmidti, delta-pesavis, sulcatus, dehiscens* and *gronbergi* zones. Petrographic study of the Morava Unit shows an increasing carbonate content and shallowing conditions upwards. The biostratigraphical correlation and facies interpretation reveal the coeval existence of two different depositional environments within the same shelf basin as well as a gradual shift in proximal direction.

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Key words: Bulgaria, Upper Silurian, Lower Devonian, conodonts, graptolites, facies transition.

INTRODUCTION

Sedimentary rocks of the Upper Silurian and Lower Devonian in West Bulgaria crop out in three main Alpine tectonic structural units: the West Balkan Unit, the Lyubash Monocline and the Morava Unit (Fig. 1). In previous publications, the Kraishte area was used in a geomorphological sense and corresponds to the Morava and Lyubash tectonic units (Zagorchev, 2001). During the Late Silurian and Early Devonian chiefly fine siliciclastic distal shelf rocks were deposited in the West Balkan Unit and Lyubash Monocline and carbonate-siliciclastic deposits of the open shelf in the Morava Unit.

The Morava Unit is a system of nappes that overthrust the Struma Unit during the Mid-Cretaceous. The Morava Unit succession comprises Precambrian gneisses and migmatites covered by Ordovician, Silurian, Devonian strata of Rheno-Hercynian affinities (Dabovski *et al*., 2002). The Morava Unit consists of two subunits: the Penkjovci Thrust and Milevski Thrust slices. The area studied is situated in the Penkjovci Thrust subunit.

The purpose of this study is to present a stratigraphical and lithofacies synthesis of the Upper Silurian and Lower Devonian in West Bulgaria including detailed biostratigraphy and correlation based on graptolites, conodonts and tentaculites, sedimentary petrography and basin reconstruction based on facies differentiation.

GEOLOGICAL SETTING

MORAVA UNIT
(CARBONATE-SILICICLASTIC SEDIMENTATION)

The Upper Silurian and Lower Devonian carbonate-siliciclastic deposits occur as isolated and tectonically disturbed outcrops. A characteristic feature of the Late Silurian and Early Devonian sedimentation is the onset and increase of the carbonate component, from limestone lenses among black shales in the Ludlow, through shale-limestone alternation and nodular limestones in the Pridoli and Lochkovian to thin-bed-

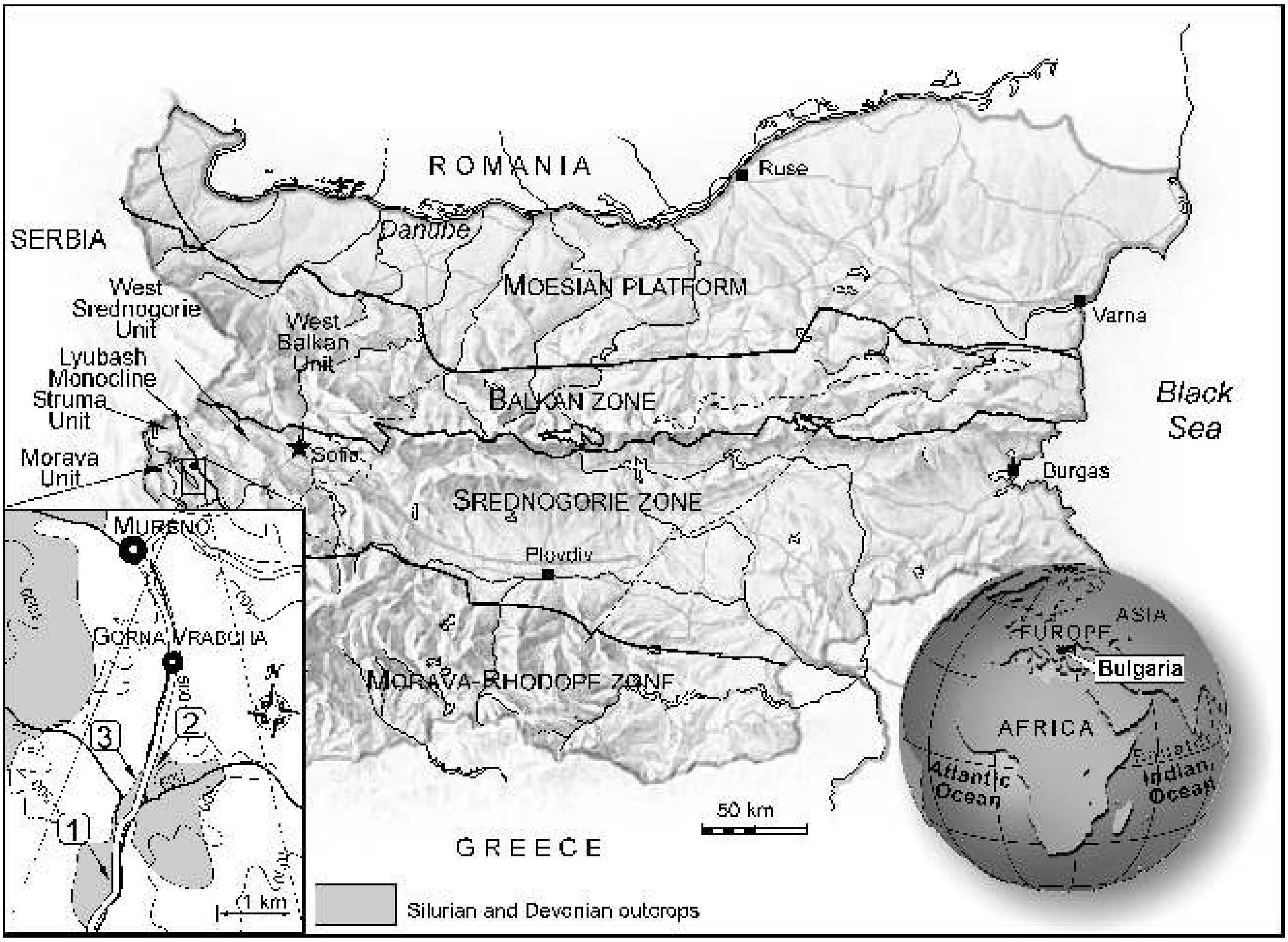

Fig. 1. Tectonic sketch map of Bulgaria showing position of the West Balkan Unit, Lyubash Monocline and Morava Units and geographic position of the Gorna Vrabcha sections 1, 2 and 3

ded limestones in the Pragian and medium-bedded limestones in the Emsian. Spassov (1973) introduced the Vrabcha Formation (185 m thick) for the alternation of thin-bedded or nodular limestones and slightly phyllitized shales and siltstones and lydites dominated by limestones.

In the Gorna Vrabcha 2 section, below the Vrabcha Formation, black Ludlovian shales of Gorstian age assigned to the *nilssoni* graptolite Zone are exposed (Sachanski *et al*., 2005). The Silurian-Devonian transition is related to continuous carbonate-shaly sedimentation considered here as the lower member (shale-limestone member) of the Vrabcha Formation (Fig. 2). The Ludfordian to Lochkovian age of the shale-limestone member is based on conodonts indicating the *siluricus, eosteinhornensis* and *woschmidti* zones and the graptolite *ultimus-parultimus* Zone (Sachanski *et al*., 2005).

The Lower Devonian of the Vrabcha Formation was subdivided biostratigraphicaly on the basis of conodonts by Spassov (1971). He recognized seven conodont zones in the Lochkovian, Pragian and Lowermost Emsian. Boncheva (1987, 1991) gave evidence for the presence of five conodont zones in the Emsian based on the *Polygnathus* species succession. The age of the Vrabcha Formation was first determinated on the basis of conodonts as Late Silurian early Emsian by Spassov (1973) and was later revised by Boncheva (1991) and Sachanski *et al.* (2005) as Ludlow early Eifelian.

BALKAN UNIT AND LYUBASH UNIT
(SILICICLASTIC SEDIMENTATION)

In these tectonic units, the Upper Silurian and Lower Devonian are represented by fine siliciclastic deposits, banded greenish siltstones, black graptolitic shales and green shales with pale spots.

The Upper Silurian-Lower Devonian lithostratigraphic division of the Balkan Unit by Sachanski and Tenchov (1993) includes four units: the Mala Reka Formation black graptolitic shales, the Yabukov Dol Formation, Ludow and Pridoli banded shales and black shales; dark siltstones of the upper Pridoli and Lochkovian, and Pragian black siltstones and shales with graptolites and tentaculites; and green-grey shales of Pragian and Emsian age. The Mala Reka Formation corresponds to the *nilssoni* and *scanicus* graptolite zones; the Yabukov Dol Formation to the *leintwardinensis, bohemicus, tenuis-kozlowski* and *formosus* zones (Ludlow), and the *parultimus-ultimus* and *bouceki-transgrediens* zones (Pridoli); the dark Lochkovian and Pragian siltstones to the *uniformis, hercynicus* and *fanicus*

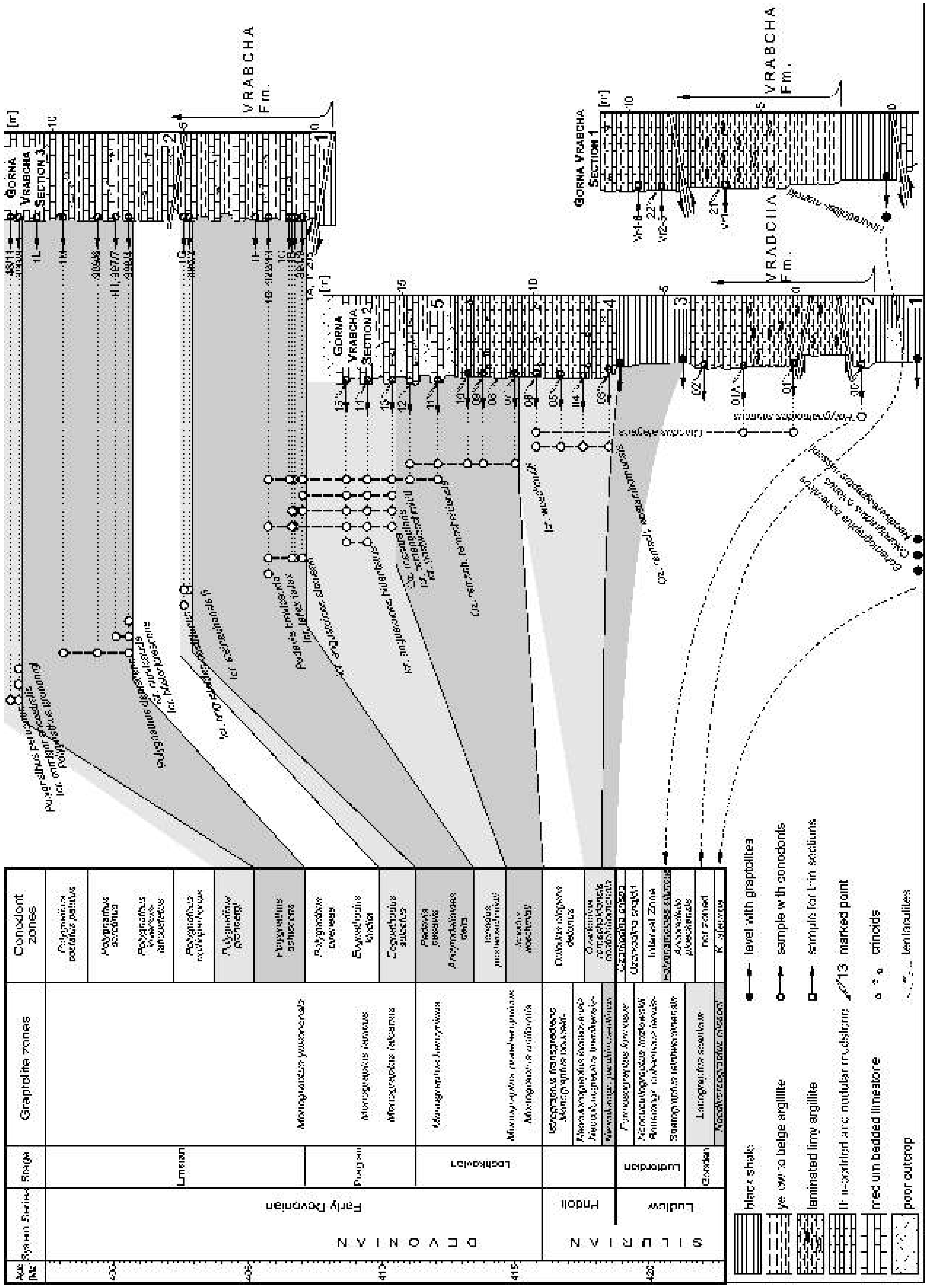

Fig. 2. Lithological columns, sample position and graptolite and conodont zonations with the stratigraphical ranges of selected conodonts in the sections Gorna Vrabcha 1, 2, 3

1 to 5 in the section 2 and 1–2 in section 3 are lithological units described in the text as packets

zones (Sachanski, 1998) and the tentaculite *Homectenowakia bohemica* (Boucek) zone (Sachanski, 1996). The green-grey shales were assigned to the Emsian based on a tentaculite fauna characteristic of the *N. cancellata* Zone (Spassov, 1973, revised by Sachanski, 1996) and on chitinozoans of the *Bursachitina bursa* Zone (data provided by I. Lakova).

Uniform black shales of the Lyubash Unit are assigned to the Upper Silurian and Lower Devonian by Spassov (1963, 1964) on the basis of graptolites. According to recent zonal subdivisions these graptolites provide evidence for the *nilssoni, scanicus* and *formosus* (Ludlow), *ultimus-parultimus* and *branickensis-lochkovensis* zones (Pridoli) (Koren *et al.,* 1996) and for the *uniformis* and *hercynicus* zones (Lochkovian) (House and Gradstein, 2004).

THE GORNA VRABCHA SECTIONS IN THE MORAVA UNIT

The three exposures of the Vrabcha Formation near the village of Gorna Vrabcha (Fig. 2, sections 1, 2, 3) are unique

System	SILURIAN								DEVONIAN																							
Stage	Ludlow				Pridoli				Lochkovian															Prag.		Emsian						
Section	Gorna Vrabcha Section 2																	Gorna Vrabcha Section 3														
Packet	1		2		4				5									1								2						
Sample	00	01	01A	02	03	04	05	06	07	08	09	10	11	12	13	14	15	1A	991/9	1B	1C	1D	1E	986/2	1G	988/4	1H	989/6	1M	1L	990/8	48/11
Polygnathoides siluricus	●																															
Oulodus elegans		●	●					●																								
Oz. excavata excavata	●		●	●	●	●	●	●						●	●	●	●															
Oz. rem. eosteinhornensis					●	●	●	●																								
Icriodus woschmidti									●		●	●	●	●																		
Belodella triangularis									●		●		●	●				●	●	●		●	●	●	●	●	●	●				●
Pseudooneoth. beckmanni									●	●			●					●	●	●						●		●				
Panderodus unicostatus													●					●	●			●				●			●		
Icriodus postwoschmidti														●	●	●	●														
Icriodus rectangularis														●	●	●	●	●	●												
Oz. remsch. remscheidensis												●	●	●	●	●	●	●	●	●	●										
Ozarkodina masara														●	●	●		●	●		●										
Icr. angustoides bidentatus															●	●															
Pelekys. serratus elongatus																	●			●		●		●		●					
Icr. angustoides alcoleae																	●	●	●		●										
Belodella resima																	●	●	●		●	●									●
Belodella devonica																	●	●			●	●									●
Icriodus fallax fallax																				●											
Pedavis brevicauda																					●										
Icriodus steinachensis β																							●	●							
Pandorinellina optima																							●		●	●					
Icr. angustoides castilianus																								●							
Icriodus bilatericrescens																									●						●
Icriodus curvicauda																									●	●					
Oz. steinhornensis telleri																									●	●	●				
Oz. steinhornensis miae																									●						
Pol. dehiscens dehiscens																									●		●	●			
Oz. st. steinhornensis																											●	●			
Icriodus celtibericus																														●	
Polygnathus gronbergi																														●	
Icr. corniger ancestralis																														●	
Polygnathus perbonus																														●	●

Fig. 3. Distribution of conodonts in samples of the Upper Silurian and Lower Devonian of the sections Gorna Vrabcha 2 and 3

1 to 5 in the section 2 and 1–2 in section 3 are lithological units described in the text as packets

for the Morava Unit as they represent the only complete sections through the Upper Silurian and Lower Devonian of this region. There is a need to revise the chronostratigraphy and litholostratigraphy of the Vrabcha Formation. For this reason we study here in detail the succession of the lithological units (packets) and their fossil content (conodonts and graptolites). The stratigraphical distribution of conodont species in the Gorna Vrabcha sections 2 and 3 is given in Figure 3. There are also tentaculites, crinoids, orthocones, bryozoans and scyphocrinoids at some levels, observed both macroscopically and in thin sections. The finer zonation and precise chronostratigraphy serves as a basis for correlations between the West Balkan Unit and the Morava Unit and the reconstruction of the Late Silurian–Early Devonian sedimentary basin evolution.

The Silurian-Devonian boundary is in the lower part of packet 4 within the shale-limestones series. This series passes gradually to the typical clayey and nodular limestones of the Vrabcha Formation but is characterized by presence of shale beds. For this reason the shale-limestone member is regarded rather as a lower member of the Vrabcha Formation than a separate formation. The underlying Black Shale "Series" was described as an informal lithostratigraphic unit by Zagorchev (1993). Its age was defined as Ludlovian (Spassov, 1963) and confirmed herein.

GORNA VRABCHA SECTION 1

The Vrabcha Formation in this section is represented by laminated calcareous shales which grade into gray thin-bedded and nodular limestone. The total thickness is 11 m. The black shales underlying the Vrabcha Formation have yielded the graptolite *Holoretiolites mancki* (Münch). This species is characteristic of the *scanicus* Zone (upper Gorstian), according to Kozłowska-Dawidziuk (2004). Petrographic studies reveal the presence of tentaculites, bryozoans and crinoids in thin sections of mudstone. These fossiliferous beds correspond to similar Pridoli-Lochkovian limestones in the Gorna Vrabcha section 2.

GORNA VRABCHA SECTION 2

The section consists of graptolitic black shales, Shale-Limestone Member of the Vrabcha Formation and the Vrabcha Formation in the sense of Spassov (1973) (Fig. 2). Stratigraphically, this section underlies the Vrabcha Formation type section (Gorna Vrabcha section 3). A continuous transition across the Silurian-Devonian boundary was documented on the basis of graptolites and conodonts (Sachanski *et al*., 2005).

Vrabcha Formation, shale-limestone member (21.5 m)

— Packet 5 (5 m): clayey medium-bedded limestones alternating with shales. Lower Lochkovian, *woschmidti-postwoschmidti* Zone (samples 11–15).

— Packet 4 (6.5 m): thin-bedded laminated clayey nodular limestones with crinoids, samples 03–06, Pridoli, *eosteinhornensis* Zone, and samples 07–10, Lochkovian, *woschmidti* Zone.

— Packet 3 (3 m): black shales with graptolites, early Pridoli, *parultimus-ultimus* Zone.

— Packet 2 (2 m): thin-bedded laminated clayey nodular limestones, Ludlow. Conodonts from samples 01A and 02 are: elements of *Ozarkodina excavata excavata* (Branson and Mehl).

— Packet 1 (5 m): laminated limy shales with limestone lenses Ludlow, Ludfordian, *Polygnathoides siluricus* Zone.

Black Shale "Series"

Black shales with graptolites, 5.3 m, Ludlow, Gorstian, *Neodiversograptus nilssoni* Zone.

GORNA VRABCHA SECTION 3

Two packets of pale clayey medium-bedded limestones alternating with calcareous shales crop out, and are separated by a disconformity. The conodont faunas in the upper packet 2 indicate a lower Emsian age (*dehiscens and gronbergi/perbonus* Zones). In the lower packet 1 two conodont zones are recognized, the *delta-pesavis* Zones (upper Lochkovian) and *sulcatus* Zone (Pragian). The stratigraphical distribution of selected conodonts and zonation is shown in Figure 2, and the occurrence of samples in Figure 3.

— Packet 2 (6.2 m): lower Emsian, *gronbergi/perbonus* Zone, pale clayey limestones, alternating with beige calcareous shales, samples 48/11 and 990/8 (Fig. 3) and *dehiscens* Zone, pale clayey limestones, alternating with beige calcareous shales, samples 1L, 1M, 989/6 and 1H, 988/4.

— Packet 1 (5.6 m): upper Lochkovian and Pragian; *sulcatus* Zone, lower Pragian, pale clayey limestones, alternating with beige calcareous shales, sample 1G, 986/2; *delta/pesavis* Zone, upper Lochkovian, clayey limestones, 1E, 1D, 992/10, 1C, 1B, 991/9, 1A, 1129b.

CONODONT BIOSTRATIGRAPHY

More detailed sampling as well as extending the area studied has allowed us to recognize eight conodont zones in the Gorna Vrabcha 2 and 3 sections (Fig. 3): *siluricus, eosteinhornensis, woschmidti* zones (Walliser, 1964), *postwoschmidti* Zone (Mashkova, 1970) *delta-pesavis* Zones (Klapper, 1977; Klapper and Johnson, 1980), *sulcatus* Zone (Klapper, 1977), *dehiscens* Zone (Fahraeus, 1971), and *gronbergi/perbonus* Zones (Klapper, 1977). In this study, the conodont zones *siluricus* (Ludfordian), *eosteinhornensis* (Pridoli), *delta-pesavis* (upper Lochkovian) and *sulcatus* (Pragian) are recognized and described for the first time in Bulgaria

LUDLOW

SILURICUS ZONE

In the shale-carbonate member, the first carbonate layer in section 2 (sample 00) has yielded a sparse conodont fauna with *Polygnathoides siluricus* and *Ozarkodina excavata excavata*. It permits us to assign the packet 1 of yellow to beige shales with individual carbonate lenses to the *siluricus* Zone (Ludfordian). The underlying Black Shale "Series" is of Gorstian age (*Neodiversograptus nilssoni* graptolite Zone). In samples 01A, 02, scarce conodont elements of *Ozarkodina excavata excavata* (Branson and Mehl) were found. These conodonts occur in the Ludlow and Pridoli. The position of this association, however, between the Ludfordian *siluricus* Zone and the lowermost Pridoli *parultimus-ultimus* graptolite Zone suggests a late Ludfordian age.

PRIDOLI

EOSTEINHORNENSIS ZONE

The conodonts recovered from section 2, packet 4 (samples 03–06) are characteristic of the *eosteinhornensis* Zone: *Ozarkodina remscheidensis eosteinhornensis* (Walliser), *Ozarkodina excavata excavata* (Branson and Mehl) and *Oulodus elegans* (Walliser). Above this level no *O. r. eosteinhornensis* elements have been recovered. It is therefore assumed that the Silurian–Devonian boundary must occur somewhere within packet 4, above sample 06 and 10 m above the base of the measured section Gorna Vrabcha section 2.

We consider the *eosteinhornensis* Zone to be indicated on the presence of the index taxa and that it comprises the uppermost Přídolí Series in the section studied, as used by Carls *et al*., 2007). The presence of the *eosteinhornensis* Zone just below the *woschmidti* Zone in a continuous section suggests assigning the *woschmidti* Zone to the lower Lochkovian.

The *eosteinhornensis* conodont Zone was recognized by Spassov (1973) in the Staniovtsi section (Lyubash Unit) and thus is a tool for correlation in the uppermost Silurian between different facies areas.

LOCHKOVIAN

WOSCHMIDTI ZONE

In 1964 the *woschmidti* Zone was defined by Walliser (1964) and became a useful guide for approximate recognition and correlation of the base of the Devonian. In section 2, packet 4 (sample 07) *Icriodus woschmidti* Ziegler makes its appearance (Fig. 2). There seems to have been no break in sedimentation in packet 4 of the Gorna Vrabcha section 2 and from this continuous sedimentation of thin-bedded laminated clayey nodular limestones with crinoids we recovered many juvenile elements only of *I. woschmidti.* Together with *I. woschmidti* we found *Ozarkodina remscheidensis remscheidensis* in packet 5 (samples 11 and 12) in the Gorna Vrabcha section 2.

Icriodus woschmidti and *Ozarkodina remscheidensis remscheidensis* both have occurrences somewhat later than the graptolites *Monograptus uniformis uniformis* Přibyl and *Monograptus uniformis angustidens* Přibyl at the base of Lochkovian.

This zone occurs in the Gorna Vrabcha section 2 in packet 4 (samples 07, 08, 09, 10) and in packet 5 (samples 11 and 12). Previously, Spassov (1971) indicated the presence of the *woschmidti* Zone in the area studied.

POSTWOSCHMIDTI ZONE

This zone was established by Mashkova (1970) in Podolia. The first appearance of the index species *Icriodus postwoschmidti* Mashkova indicates the lower boundary. Together with the index species from sample 13 occur *Icriodus rectangularis* Carls and Gandl, *Ozarkodina excavata excavata* (Branson and Mehl), *Ozarkodina remscheidensis remscheidensis* (Ziegler) and *Ozarkodina masara* (Schönlaub). The index is also accompanied in samples 14 and 15 by the following species: *Icriodus rectangularis* Carls and Gandl, *Icriodus angustoides bidentatus* Carls and Gandl, *Ozarkodina excavata excavata* (Branson and Mehl), *Ozarkodina remscheidensis remscheidensis* (Ziegler) and *Ozarkodina masara* (Schönlaub). The conodont association of the *postwoschmidti* Zone contains endemic species of *Icriodus* known from Western Europe and Morocco (Bultynck, 2003) such as *Icriodus rectangularis* Carls and Gandl and *Icriodus angustoides bidentatus* Carls and Gandl. These species and the presence of *Ozarkodina masara* (Schönlaub), known from the Barrandian, in the Lochkovian section in Western Bulgaria indicates endemism in conodont faunas during the Late Lochkovian and Pragian (Klapper and Ziegler, 1979).

The *postwoschmidti* Zone corresponds to packet 5 of the Gorna Vrabcha section 2 with thin-bedded and nodular limestones.

DELTA–PESAVIS ZONES

The lower boundary of the *delta* Zone as well as the latest Lochkovian *pesavis* Zone cannot be identified very precisely because of the absence of the index taxa. In this study, the identification of the *delta* Zone is based on the appearance of *Icriodus angustoides alcoleae* Carls and *Pandorinellina optima* (Moskalenko) in samples 1A, 991A and *Icriodus fallax fallax* Carls in sample 1C and accompanying conodonts ranging from the underlying *postwoschmidti* Zone: *Ozarkodina remscheidensis remscheidensis* (Ziegler), *Icriodus rectangularis* Carls and Gandl, *Icriodus postwoschmidti* Mashkova, *Ozarkodina excavata excavata* (Branson and Mehl). In the absence of *Pedavis pesavis* defining the lower boundary of the *pesavis* Zone, we use *Pedavis brevicauda* as an alternative for recognizing the *pesavis* Zone.

The *delta-pesavis* Zones comprises the thin-bedded limestones in section, samples1A, 991/a, 1C, 1D, 992/10, 1E from the base of the Gorna Vrabcha section 3 (packet 1) up to the first appearance of *Icriodus steinachensis* β Al-Rawi in sample 986/2 marking the upper boundary.

The increasing number of *Icriodus* species in the late Lochkovian and Pragian is typical of the endemism of European conodont faunas (Klapper and Ziegler, 1979) also observed here, e.g. *Icriodus rectangularis* Carls and Gandl, *Icriodus angustoides bidentatus* Carls and Gandl, *Icriodus angustoides alcoleae* Carls, *Icriodus fallax fallax* Carls, *Icriodus angustoides castilianus* Carls and *Icriodus steinachensis* β which we use to recognize the upper Lochkovian and Pragian zones in the absence of the zonal index species.

PRAGIAN

SULCATUS ZONE

A specific feature for the Bulgarian Lower Devonian conodont faunas is the absence of zonal index species such as

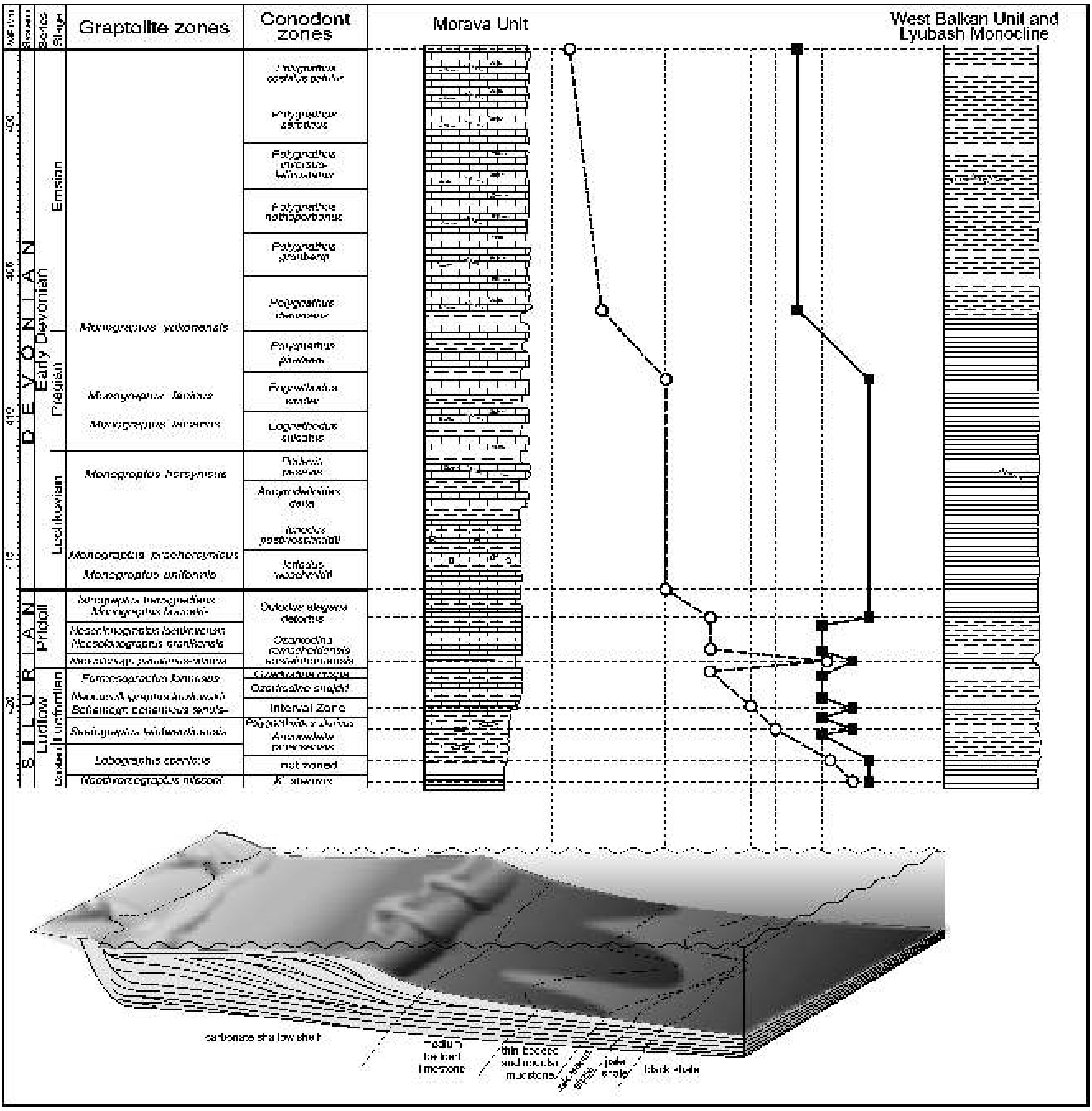

Fig. 4. Biostratigraphic correlation and changes in depositional environment in the two distinct facies zones in West Bulgaria

For other explanations see Figure 2

Eognathodus sulcatus, Eognathodus kindlei and *Polygnathus pireneae* as well as *Ancyrodelloides.*

In regions where specimens of *Eognathodus* do not exist, according to Valenzuela-Rios (1997), correlation with the global conodont biozonation can be effected with the help of *Icriodus steinachensis* β Al-Rawi occurring close to the base of the Pragian (*sulcatus* Zone), and ranging up to the base of the *kindlei* Zone. We assigned the limestones from 4.8–5 m (samples 986/2 and 1G) from the base of the Gorna Vrabcha section 3 (packet 1) and below the fault to the *sulcatus* Zone.

The appearance of *Eognathodus sulcatus* accompanied by *Icriodus steinachensis* β in the Lochkovian-Pragian type sections in Barrandien area was used by Chlupac *et al.* (2000) to define the base of the Pragian. Bultynck (2003) showed that in Europe and Morroco *Icriodus steinachensis* β and *Icriodus angustoides castilianus* Carls appear at the base of the *sulcatus* Zone. Thus, we use the first appearance of *Icriodus stainachensis* β and *Icriodus angustoides castilianus* Carls for determination of the *sulcatus* Zone. The co-occurrence of *Icriodus steinachensis* β and of the index dacryoconaride

Nowakia acuaria in the upper part of packet 1 is reason for setting the Lochkovian-Pragian boundary at 4.8 m above the base of the Gorna Vrabcha section 3.

EMSIAN

Two Emsian conodont zones have been recogized in the Gorna Vrabcha section 3, the *dehiscens* Zone and the *gronbergi/perbonus* Zones, on the presence of the index taxa and of accompanying Emsian conodont species. The Emsian *laticostatus, serotinus* and *costatus patulus* Zones and the lowermost Eifelian *costatus partitus* Zone were recognized by Boncheva (1991) higher in the Vrabcha Formation.

SEDIMENTARY PETROLOGY

Thin-sections were prepared from samples of the Upper Silurian in the Vrabcha Formation. Marls, argillites, mudstones and wackestones were recognized.

GORNA VRABCHA SECTION 1

Strata in this section are represented by buff laminated calcareous argillites (Vr1) which grade into gray thin-bedded fossiliferous mudstones (Vr2, Vr3) and into gray nodular fossiliferous mudstone (Vr4, Vr5, Vr6).

The argillites comprise an alternation of argillite and calcareous argillite laminae with less than 2% silt-sized quartz and feldspar grains. Their composition and sedimentary features are the same as those in section 2. Fossiliferous mudstones are similar to mudstones from section 2, but contain about 2–3% bioclasts (remains of tentaculites).

GORNA VRABCHA SECTION 2

An alternation of thin-bedded to laminar argillites, marls and variously recrystallized thin-bedded to nodular limestones crop out in section 2.

A marl layer with rich barite mineralisation was observed in the lowermost part of the section (01). It is composed chiefly of large (up to 1 cm) platy barite crystals in a argillaceous and limy matrix, strongly impregnated by iron and manganese oxides and hydroxides. The barite is euhedral to subhedral with rhombic cleavage. Besides large grains, some recrystallyzed fine grains occur along fractures. Clay minerals are altered to chlorite and sericite. Primary, calcite was microcrystalline (micrite), part having been recrystallized to larger sparite crystals. Slight dolomitisation (about 5–7%) is observed. Dolomite crystals are rhombic and about 0.03 mm across. Thin veins filled with a clear calcite mosaic cross the sample.

Argillites are yellow to beige in colour, laminated, and containing various amounts of carbonate minerals (02, 04, 08, 10). The thickness of single laminae varies between 0.8 and 2 mm. The lamination comprises alternation of laminae rich in siliciclastic and clayey minerals with those rich in carbonate minerals. Quartz and subordinate feldspars of silt grade (0.008–0.032 mm) represent the clastic minerals. Clay minerals are recrystallized and altered to chlorite and sericite. A few phosphate grains were observed. Microcrystalline calcite makes up about 2–3 to 15–20%, partly recrystallized to sparite. Some of the argillites in the upper part of the section grade into marls with about 50% calcite and without a siliciclastic component (10). These rocks are impregnated with iron and manganese hydroxides too, especially on the lamina surfaces. Dolomitisation here represents between 10 and 12% dolomite crystals in more carbonaceous lamina. Fine quartz veins cross the lamination.

Limestones are thin-bedded to nodular, partly fossiliferous, grayish-beige to yellowish-beige in colour. A transition exists from bodies with discrete nodules to discontinuous limestone beds with wavy upper or lower bounding surfaces. Discrete nodules are elongated and parallel to the bedding surfaces and generally possess mudstone or wackestone structure. They are represented mainly by recrystallized micritic limestones (mudstones), interbedded with calcareous mudstones material in the bottom and middle of the section (03, 07, 05, 09), succeeded by biomicrite limestones (wackestones) in the upper part (12, 14).

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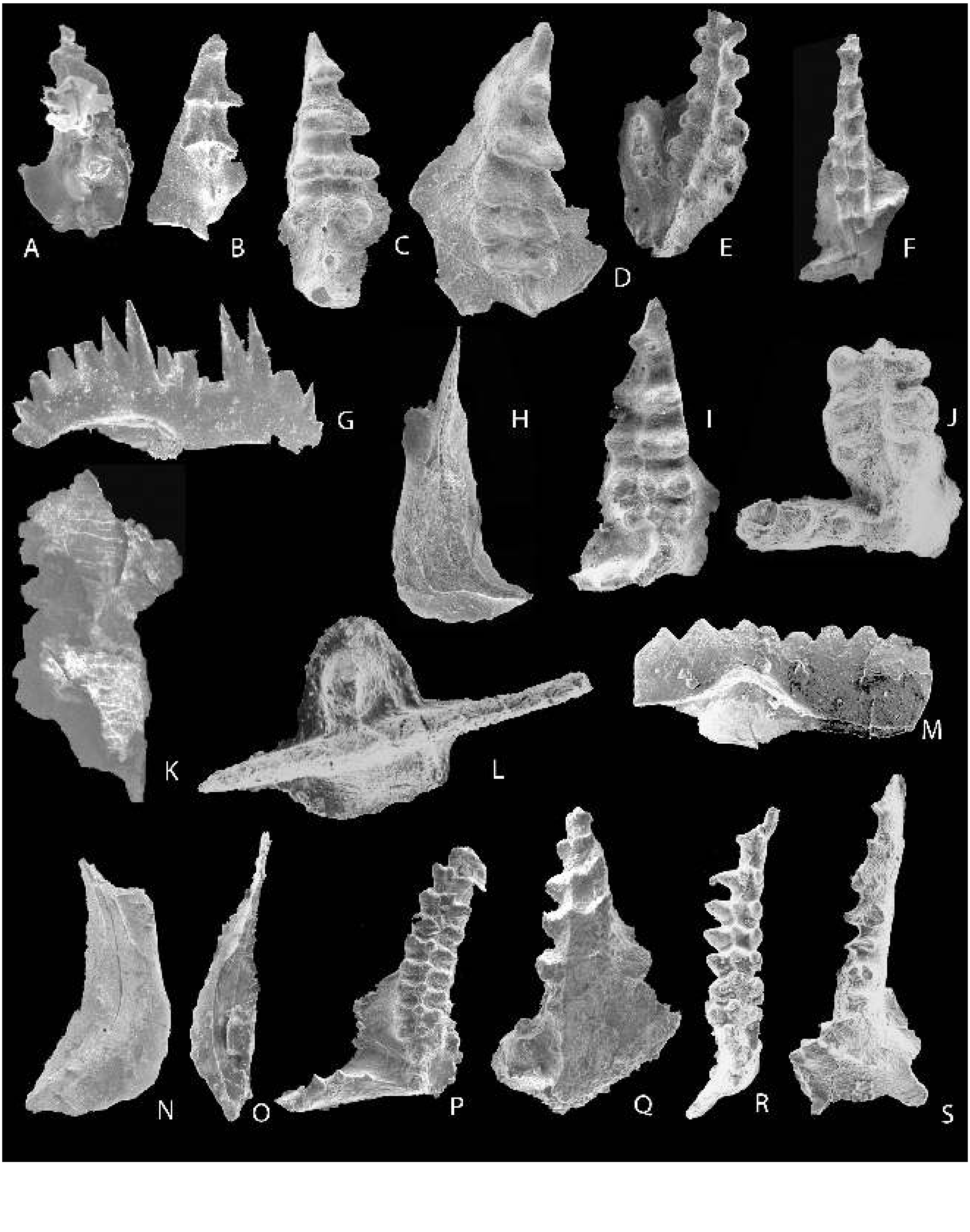
Fig. 5. Selected conodonts from Gorna Vrabcha sections 2 and 3

A — *Polygnathoides siluricus* Branson and Mehl, 1933; Gorna Vrabcha Fm., section 2, packet 1, sample 00; *siluricus* Zone, × 45; **B** — *Icriodus woschmidti* Ziegler, 1960; Gorna Vrabcha Fm., section 2, packet 5, sample 07, *woschmidti* Zone, × 45; **C** — *Icriodus angustoides bidentatus* Carls and Gandl, 1969; Gorna Vrabcha Fm., section 2, packet 5, sample 14, *postwoschmidti* Zone, × 60; **D** — *Icriodus postwoschmidti* Mashkova, 1968; Gorna Vrabcha Fm., section 2, packet 5, sample 13, *postwoschmidti* Zone, × 45; **E** — *Icriodus fallax fallax* Carls, 1975; Gorna Vrabcha Fm., section 3, packet 1, sample 1C, *delta-pesavis* Zone, × 45; **F** — *Icriodus bilatericrescens* Ziegler, 1956; Gorna Vrabcha Fm., section 3, packet 2, sample 988/4, *dehiscens* Zone, × 45; **G** — *Ozarkodina optima* (Moskalenko, 1966); Gorna Vrabcha Fm., section 3, packet 1, sample 986/2, *sulcatus* Zone, × 60; **H** — *Polygnathus dehiscens dehiscens* Philip and Jackson, 1967; Gorna Vrabcha Fm., section 3, packet 2, sample 988/4, *dehiscens* Zone, × 45; **I** — *Icriodus sigmoidalis* Carls and Gandl, 1969; Gorna Vrabcha Fm., section 3, packet 2, sample 990/8, *gronbergi* Zone, × 45; **J** — *Icriodus rectangularis* Carls and Gandl, 1969; Gorna Vrabcha Fm., section 2, packet 5, sample 13, *postwoschmidti* Zone, × 45; **K** — *Pedavis brevicauda* Murphy and Matti, 1982; Gorna Vrabcha Fm., section 3, packet 1, sample1D, *delta-pesavis* Zone, × 45; **L** — *Ozarkodina masara* Schonlaub, 1980; Gorna Vrabcha Fm., packet 5, sample 14, *postwoschmidti* Zone, × 60; **M** — *Ozarkodina remscheidensis eosteinhornensis* (Walliser, 1964); Gorna Vrabcha Fm., section 2, packet 4, sample 06, *eosteinhornensi* Zone, × 45; **N** — *Polygnathus gronbergi* Klapper and Johnson, 1975; Gorna Vrabcha Fm., section 3, packet 2, sample 990/8, *gronbergi* Zone, × 45; **O** — *Polygnathus perbonus* (Philip, 1966); Gorna Vrabcha Fm., section 3, packet 2, sample 990/8, *gronbergi* Zone, × 45; **P** — *Icriodus bilatericrescens multicostatus* Carls and Gandl, 1969; Gorna Vrabcha Fm., section 3, packet 2, sample 990/8, *gronbergi* Zone, × 45; **Q** — *Icriodus steinachensis* β Al-Rawi, 1977; Gorna Vrabcha Fm., section 3, packet 1, sample 986/2, *sulcatus* Zone, × 45; **R** — *Icriodus curvicauda* Carls and Gandl, 1969; Gorna Vrabcha Fm., section 3, packet 2, sample 988/4, *dehiscens* Zone, × 45; **S** — *Icriodus angustoides alcoleae* Carls, 1969; Gorna Vrabcha Fm., section 3, packet 1, sample 991/9, *delta-pesavis* Zone, × 45

Mudstones are composed of very fine grained calcite (micrite) comprising about 80–95% and clay minerals and iron hydroxides at about 5–20%. Some micrite nodules have been recrystallized to larger sparite crystals (0.03–0.08 mm), but recrystallisation is selective and encompasses less than 35% of the bulk rock volume. In some samples more advanced recrystallisation is observed where almost all primary texture is lost and the rocks are very close to marbles (13). Relics of micrite are still present, but idiomorphic calcite crystals with sizes ranging from 0.15 × 0.20 mm to 0.40–0.80 mm are main rock-building component. Clay minerals have recrystallized to chlorite and sericite, oriented in the direction perpendicular to the pressure.

Wackestones are composed of 10–40% bioclasts and 60–80% matrix. Bioclasts chiefly are well-preserved tentaculite



shells and less fragmented shells. Some remnants of Bryozoa are present, too. Micrite with minor clay admixtures represent the matrix (12). In the uppermost sample (14) clay admixtures are more significant. Clay minerals are altered to sericite here.

Both wackestones and mudstones are iron-impregnated and crossed by thin calcite veins. Some tectonized calcite crystals are observed in the limestones.

Later diagenetic and tectonic processes form nodular structures where the clayey component has been squeezed around the nodules, followed by recrystallization which has blur red, to a significant degree, the primary sedimentary features. Recrystallization of micrite and alteration of clay minerals to chlorite and sericite indicate advanced diagenesis, close to low grade metamorphism.

Barite in the lowermost sample from Gorna Vrabcha may have precipitated from hydrothermal solutions with a temperature of about 100–200°C during later volcanic processes in the region.

BIOSTRATIGRAPHIC CORRELATIONS

The Gorstian (Ludlow) black shales underlying the Vrabcha Formation in the Morava Unit correlate with the top of Mala Reka Formation in the West Balkan Unit on the basis of the *nilssoni* and *scanicus* graptolite Zones. The base of the Vrabcha Formation is within the Ludfordian (*siluricus* Zone) which corresponds in the West Balkan Unit to the base of Yabukov Dol Formation, belonging to the *leintwardinensis* graptolite Zone. The lower Pridoli facies is quite similar in both areas, black shales of the graptolite *parultimus-ultimus* Zone. During the middle and upper Pridoli, however, a facies differentiation starts in the Morava Unit with laminated clayey limestones (*eosteinhornensis* conodont Zone) and, in the West Balkan Unit, banded shales and black shales *(bouceki-transgrediens* graptolite Zone).

The Silurian-Devonian boundary interval in both sedimentary facies indicates continuous sedimentation with little change in the lithology and faunas. In the West Balkan and Lyubash Units the index species *Monograptus uniformis* marks the base of the Devonian but it is missing in the Morava Unit, where the first occurrence of *Icriodus woschmidti* Ziegler in the Gorna Vrabcha section 2 defines approximately the boundary between the Silurian and the Devonian. The lower Lochkovian deposits in the two units are correlated on the basis of the tentaculte *H. bohemica–N. acuaria* Interval Zone, corresponding to the *postwoschmidti* conodont Zone in the Morava Unit. The upper part of the Lochkovian and the lower Pragian are represented by black shales with graptolites (*hercynicus* and *fanicus* Zones) in the West Balkan Unit and by thin-bedded limestones (*delta-pesavis* and *sulcatus* Zones) in the Morava Unit. The Emsian in the two units is correlated on the basis of tentaculites (*N. cancellata* Zone) (Sachanski and Boncheva, 1994). The facies differentiation persisted and rich conodont faunas occur only in the Morava Unit.

FACIES TRANSITIONS IN THE SILURIAN-DEVONIAN SEDIMENTARY BASIN

The stratigraphic synthesis of the Ludlow to Emsian deposits in West Bulgaria reveals the existence of two depositional environments during the Late Silurian and Early Devonian, each with specific characters. The Morava Unit corresponds to a proximal open shelf with siliciclastic-carbonate rocks, whereas the Lyubash and Balkan Units represent distal shelf-to-basin environments, an area of fine siliciclastic sedimentation.

During the early Ludlow, in both areas, black graptolitic shales were deposited in a distal shelf-to-basinal environment. In the West Balkan Unit, the overlying Ludfordian and Pridoli banded pale shales with black shale intercalations reflect a slight change to more proximal conditions, though still within the outer shelf. The coeval occurrence of fine laminated calcareous shales and nodular limestones in the Morava Unit are evidence of a significant progressive shift to an inner shelf environment until the end of the Silurian (Fig. 4). During the early Pridoli, a transgressive event resulted in the short-lived deposition of black graptolitic black shales in both the Morava and West Balkan units.

The Lochkovian and Pragian in the West Balkan Unit represent a uniform distal shelf with dark shales and siltstones with scarce graptolites and tentaculites. In the Morava Unit, during the early Lochkovian, the trend towards carbonate sedimentation increases and the proximal migration of the environment which commenced in the late Pridoli is exhibited by the deposition of laminated clayey nodular limestones. In the mid-late Lochkovian and Pragian, characterized by thin-bedded clayey limestones with shales and medium-bedded micritic limestones, sedimentation occurred on a proximal shelf with a shift towards the platform. The Emsian was a time of shallowing conditions with deposition of pale green-grey shales in the Balkan Unit, and micritic limestiones rich in conodonts and tentaculites but also with bryozoans and corals derived from a neighbouring carbonate platform in the Morava Unit.

Textural and structural features of the rocks studied from the Morava Unit indicate that they formed in relatively deep, slightly agitated water with restricted terrigenous influx. The gradual increase, carbonate content and in limestone bed thickness suggest a regression and shallowing of the basin. This corresponds to a transition from a distal shelf zone (shales and nodular limestones) to a proximal shelf (wackestones).

CONCLUSIONS

This stratigraphical and lithofacies synthesis of the Upper Silurian and Lower Devonian in West Bulgaria is based on detailed biostratigraphy and correlations based on graptolites, conodonts and tentaculites. Siliciclastic-carbonate sedimentation characterized the Morava Unit, regarded as formed on a proximal shelf. The uniform fine siliciclastic sediments of the West Balkan and Lyubash units correspond to a distal shelf-to-basin environment. The sedimentary petrography and facies patterns indicate a tendency towards a gradual increase in carbonate content, shallowing conditions and a shift in proximal direction in the Morava Unit. Thus, in West Bulgaria, complete Ludlow to Emsian coeval sedimentary successions have been documented that were deposited under different environmental conditions in the same shelf basin.

The following conodont zones are described: *siluricus* (Ludlow), *eosteinhornensis* (Pridoli)*, woschmidti, postwoschmidti, delta-pesavis* (Lochkovian)*, sulcatus* (Pragian)*, dehiscens* and *gronbergi* (Emsian).

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