GEOLOGICA CARPATHICA, JUNE 2006, 57, 3, 199–210

Sarmatian biostratigraphy of the Mountain Medvednica at Zagreb based on siliceous microfossils (North Croatia, Central Paratethys)

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(Manuscript received October 15, 2004; accepted in revised form October 6, 2005)

Abstract: We proposed a biozonation of the Middle and Upper part of the Sarmatian Stage, based on siliceous microfossils (silicoflagellates *Distephanopsis soljani–Distephanopsis slavnicii* Zone and diatoms *Anaulus simplex–Coscinodiscus doljensis* Zone). The new silicoflagellate and diatom zones have been correlated with other already proposed zonations for the Paratethys Sea and other marine realms. 46 diatom and 3 silicoflagellate taxa have been determined, that were hitherto not known from the Croatian part of the Sarmatian Paratethys. The boundary between Middle and Upper Sarmatian is supposed to be indicated by the change within the diatom assemblages and by the complete disapperance of silicoflagellates. Tuffitic particles, occurring at the boundary, could also be used as a marker. Likewise a drastic decrease of macrofaunal (molluscs) and microfaunal (foraminifers, ostracods) content is observed. The reason for changes in species assemblages could be in gradual disconnections between Central Paratethys and other marine realms (Eastern Paratethys, links through the Mediterranean to the Atlantic and towards the Indopacific) providing more near shore influence and less saline environment during the Late Sarmatian.

Key words: Sarmatian, Central Paratethys, Medvednica Mt, diatoms, silicoflagellates.

Introduction

In a paleogeographical sense the investigated area (SW and S parts of Mt Medvednica comprising the suburbs of Zagreb), represents the SW part of the Pannonian Basin System, which was part of the Central Paratethys Sea. Three sections were systematically sampled. These localities are: Podsused (Dol-I), Kostanjek (Kst-I), and Markuševac (Mar-I). Isolated outcrops in the Susedgrad-Jarek region (Dol-II) have also been sampled (Fig. 1). According to the obtained data, in comparatively deeper areas, far from land influence, the sedimentation of the Sarmatian deposits proceeded continuously (Kst-I; Fig. 3), whereas in the nearshore settings the sedimentation was affected by tectonic and/or eustatic movements recorded as the discontinuities in the successions (Mar-I and Dol-I; Fig. 3). The Sarmatian in the Paratethys is characterized by endemisms, with numerous endemic taxa (genera and

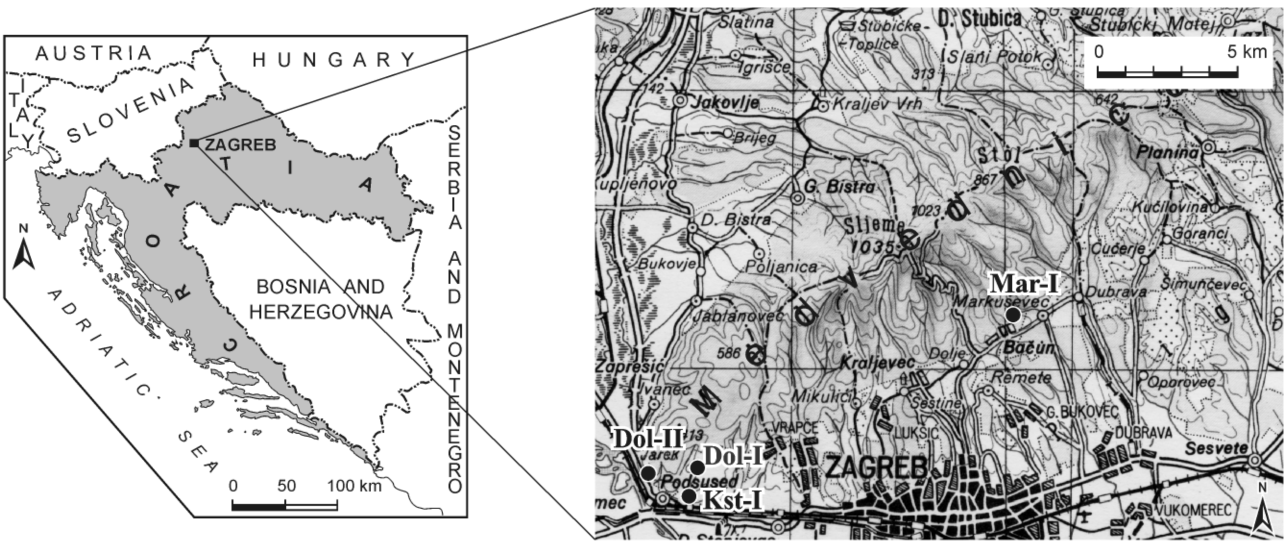

Fig. 1. Topographic map of Mt Medvednica with location of investigated areas.

species) including phytoplankton (Jurilj 1957; Jerković 1963, 1965; Bajraktarević 1983a,b). However, a dense and systematic sampling (Fig. 3), allowed establishment of a reliable diatom and silicoflagellate zonation, which may serve as a base for correlation with other seas (Table 1).

Material and methods

Almost every 1.5–5 cm of particular marly horizons have been sampled (Fig. 3). Total number of samples is 71. From the sample as small as a nut is taken approximately 1/2 cm^3 of sediments, than put into the standard epruvet (16×160 mm) and soaked in distilled water until the sample is completely disaggregated. Samples are treated with 20 ml of 30 % of hydrogen peroxide (H_2O_2) solution in order to remove organic matter from sediments, but some of them are treated with 20 ml of 15 % hydrochloric acid (HCl). Then distilled water is added and decanted to neutral. Some of the samples have been put into an ultrasonic tank for approximately 15 seconds to have better disaggregation. After that we proceed with slide preparation. A few drops of sample are pipetted to smear slide, dried, and mounted with Canada balsam. The slide is than viewed at a magnification of 200 to 500× with emersion oil under the light microscope. Paleodepths are given on the basis of the formula and graph according to Pushkar & Cherepanova (2001).

Geological setting

In a regional geologic sense, Mt Medvednica belongs to the Supradinaricum geotectonic unit (Herak 1986), and represents part of the northern marginal zone of the Inner Dinarides (Šikić 1995). The first geological information regarding the geological structure and paleontological contents of the Neogene deposits of Mt Medvednica come from the second half of the 19th century (Foetterle, Vukotinović, Pilar, Gorjanović-Kramberger, Brusina, Kiseljak, Franzenau and others). The bulk of the central and oldest part of Mt Medvednica, ranging in age from the Paleozoic to the Paleogene, was definitely structurally shaped and placed almost into its present-day position before the sedimentation of the Neogene deposits. Emersion lasted from the Paleocene to the Ottnangian. The Ottnangian is represented by lacustrine sediments, which are topped by marine Karpatian deposits (Avanić 1997). In the Early Badenian, a marine transgression spread over the NE and in the Late Badenian it progressed also over the SW parts of Mt Medvednica. The Paratethys started to become isolated at the end of the Badenian (Šikić 1995). During the Sarmatian, marine sedimentation still existed in the western part of the Central Paratethys but toward the end of the Sarmatian it became progressively brackish due to reduced connection with the Mediterranean (Rögl 1996). The Pannonian Basin became definitely isolated and a lacustrine environment formed (Vrsaljko 1999). In the Early Pontian, the area of Mt Medvednica becomes more brackish. The Late Pontian is characterized by shallowing of environments as a consequence of the basin's closing (Avanić et al. 2003). Due to tectonic movements in the Pliocene and in the Quaternary, Mt Medvednica was uplifted, accompanied by reverse movements with N and NW vergence. Simultaneously, erosional processes became progressively stronger (Šimunić & Šimunić 1987).

Results

Podsused (Dol-I) and Susedgrad-Jarek (Dol-II) localities

The geological column Podsusedsko Dolje (Dol-I) and the outcrop Susedgrad-Jarek (Dol-II) are situated on the southwestern slopes of Mt Medvednica, near the village of Podsused (Fig. 1). The thickness of the Sarmatian deposits amounts to 20 m. They are separated from the underlying Badenian deposits by an erosional and angular unconformity, and from the overlying, Pannonian, deposits, by a fault. In the lower parts of the columns calcitic silts predominate; going upward they pass into a siltose to spongitic microsparite and, further up, parallel laminated marls that form the upper part of the column (Fig. 3). The sequence contains bivalves, small gastropods, imprints of leaves (*Acer* cf. *pseudoplatanus* L.) with other plant and fish remains, foraminifers, ostracods, and calcareous nannofossils (Bajraktarević 1981; Avanić et al. 1995).

Among the siliceous microfossils, most abundant are the diatoms, of which several taxa are unknown from the Paratethys (Table 2). Silicoflagellates are somewhat less abundant, the most frequent being: *Deflandryocha cymbiformis* Jerković, *Def. spathulata* Jerković, *Dictyocha fibula fibula* Ehrenberg, *D. rhombica* (Schulz) Deflandre, *Distephanopsis crux* (Ehr.) Dumitrica, *Dss. crux parvus* (Bachmann) Desikachary et Prema, *Dss. schauinslandii* (Lemmermann) Desik. et Prema, *Dss. slavnicii* (Jerković) Desik. & Prema, *Dss. stradneri* (Jerković) Desik. et Prema, *Dss. soljani* (Jerković) Desik. et Prema, *Mesocena elliptica* (Ehr.) Ehrenberg, *Paramesocena apiculata* (Lemmermann) Locker et Martini and *P. circulus* (Ehr.) Locker et Martini (Plate 1). Rarer are species of the genus *Archaeomonas* (*A. angulosa* Deflandre*, *A. inconspicua* Deflandre*, *A.* cf. *mangini* Deflandre) and the ebriids *Cardiuifolia gracilis* Hovasse*, *Ebria triparita* (Schumann) Lemmermann, *Ebriopsis valida* Deflandre, *Hovassebria ?bravispinosa* (Hovasse) Deflandre*, which were recorded for the first time from this region. These are accompanied by the dinophycean *Actiniscus stella* Ehrenberg and sponge spicules.

Reworking of Mesozoic, Paleogene, Lower Miocene, and Badenian deposits has also been observed. In the Sarmatian deposits of the Podsused locality, 75 diatom species have been recorded that were up to now unknown in the investigated area; among those, 25 species have been recorded for the first time for the Central Paratethys region (marked by an asterisk). Above, we have listed only those diatom species that were not previously mentioned by Jurilj (1957), Table 2.

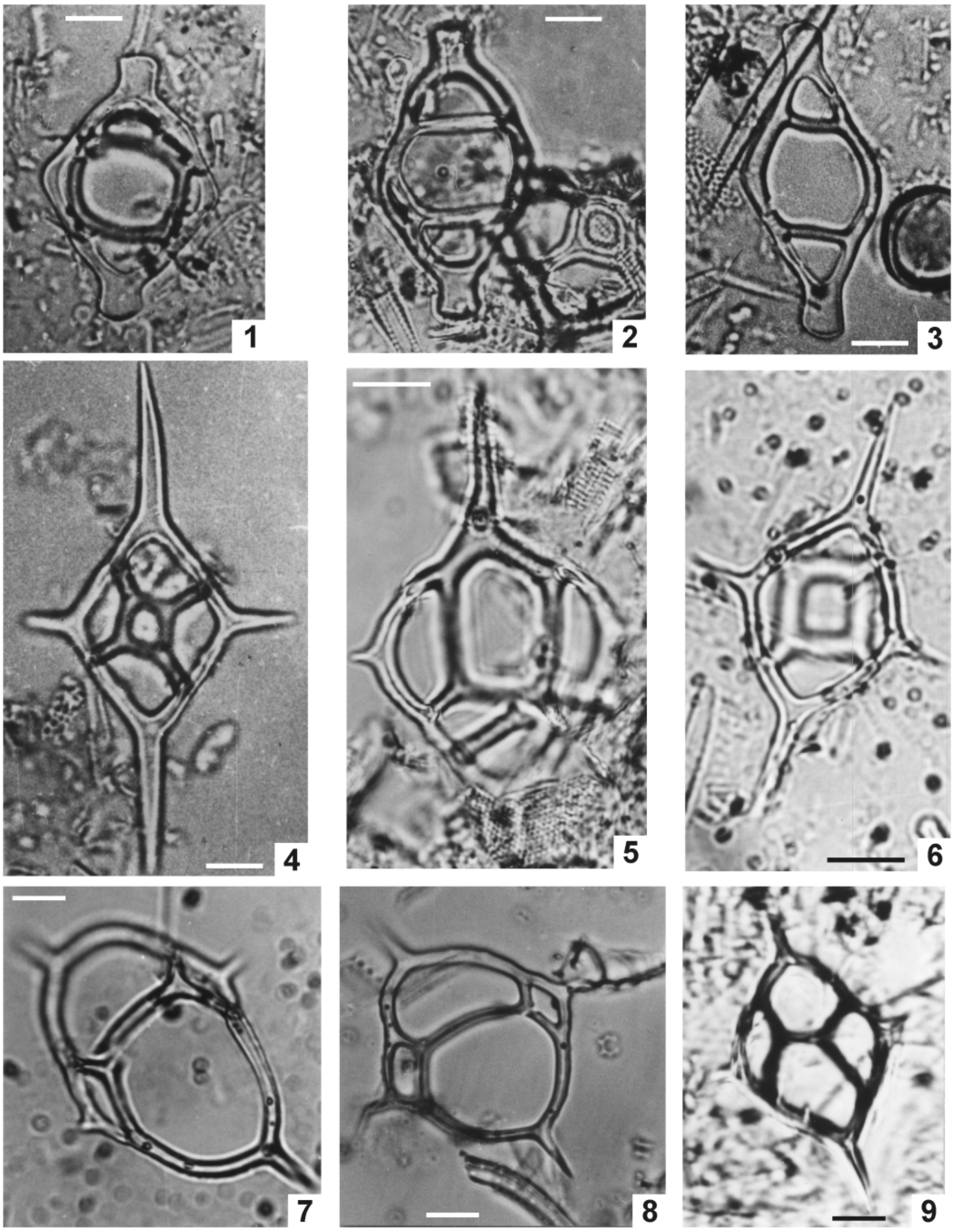

Fig. 2. 1 — *Deflandryocha spatula* Jerković (800×); **2** — *Def. naviculoidea* Jerković (800×); **3** — *Def. cymbiformis* Jerković (800×); **4** — *Distephanopsis soljanii* (Jerković) Prema et Desik. (800×); **5** — *Dss. slavnicii* (Jerković) Prema et Desik. (1100×); **6** — *Dss. longispinus* (Schulz) Desik. et Prema (1100×); **7** — *Dictyocha brevispina brevispina* (Lemmermann) Bukry (750×); **8** — *D. rhombica* (Schulz) Deflandre (750×); **9** — *D. subclinata* Bukry (750×). Scale bar = 10 μm.

Kostanjek (Kst-I) locality

The geological column Kostanjek (Kst-I) is situated on the southwestern slope of Mt Medvednica, within the exploitation grounds of the abandoned cement factory in Podsused, near the Kostanjek village (Fig. 1). At the foot of the deserted clay strip mine the top part of the Sarmatian deposits and the continuous transition into the Pannonian beds is exposed. Only about 1.5 m of parallel laminated marls of varved sediments, typical for the Sarmatian, were sampled. They have a grey-greenish to brown colour and are intercalated with white laminae, mostly 0.5–2 mm thick, reaching a maximum of 4 mm (Fig. 3). Their fossil content includes fish remains, leaves, other macro- (molluscs) and microfauna (ostracods, foraminifers), (Vrsaljko 1999), and calcareous nannofossils.

Diatoms are less abundant and less diverse than at Podsusedsko Dolje (Table 2). Rare species is *Archaeomonas colligera* Hajós*, and even rarer are silicoflagellate fragments and sponge spicules. Reworked phytoplankton of

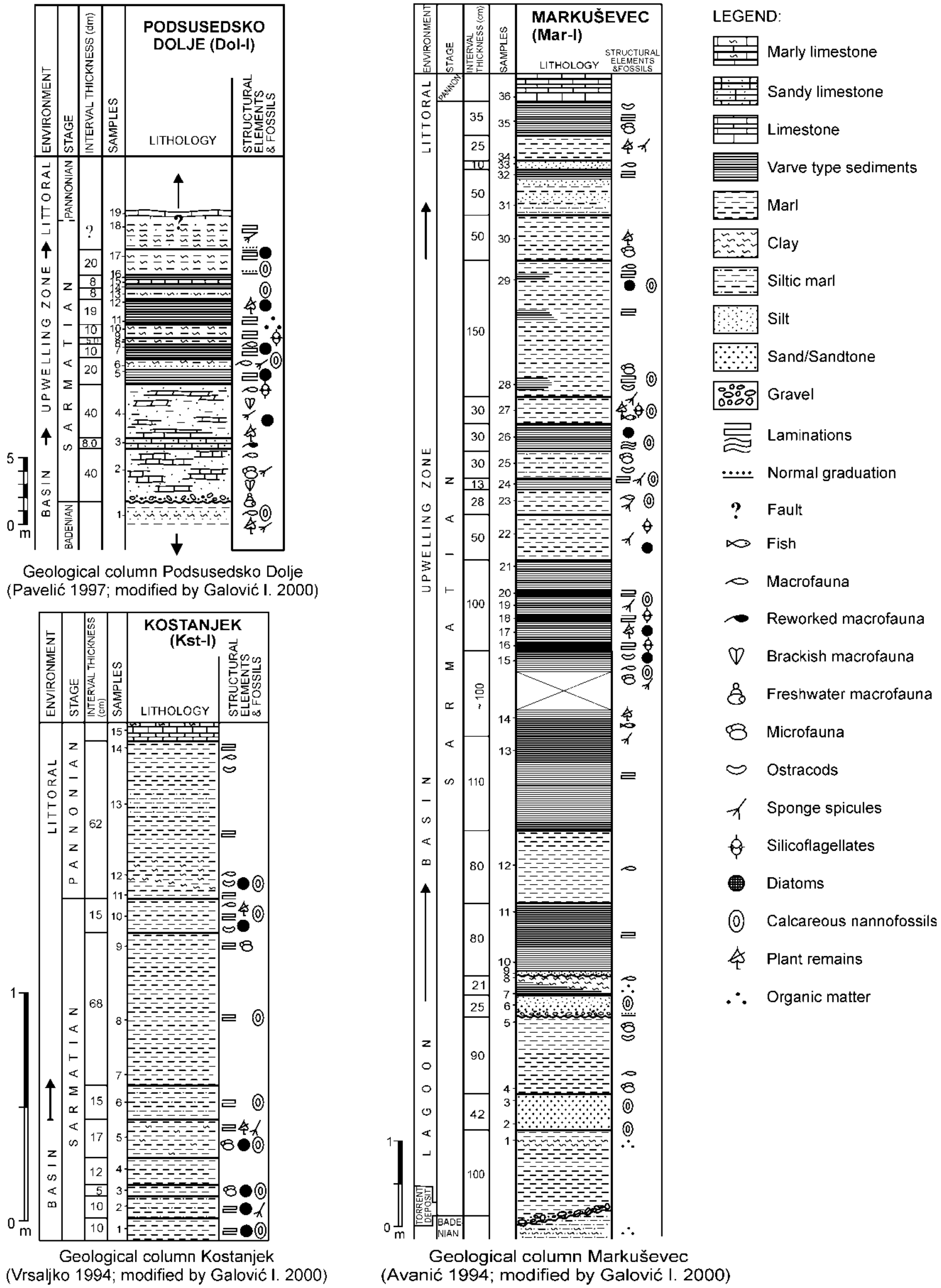

Fig. 3. Geological columns.

Table 1: Correlation table of Sarmatian (eco) biozones according to different authors.

12.2 12.1 12.0 11.9 11.8 11.7 11.6 11.5 11.4 11.3		TIME (Ma)		
SERRAVALIAN		MEDITERRANEAN		STAGE WITH SUBSTAGES
SARMATIAN MIDDLE	UPPER	CENTRAL PARATETHYS		STAGE WITH SUBSTAGES
VOLHYNIAN	LOWER BESSARABIAN	EASTERN PARATETHYS		STAGE WITH SUBSTAGES
NN7	**NN8**	CALCAREOUS NANNOPL. ZONES Martini (1971), Mărunţeanu (1999)		
Elphidium hauerinum Zone	*Porosononion granosum* Zone	Foraminifera Grill (1941)		(ECO)BIOZONES Harzhauser & Piller (2004)
L.-U. *Ervilia* Zone	*Sarmatimactra vitaliana* Zone	Molluscs Papp et al. (1974)		(ECO)BIOZONES Harzhauser & Piller (2004)
Rhaphoneis diamantella		Andrews (1978)		DIATOM ZONATION
Anaulus simplex		Hajós (1986)	CENTRAL PARATETHYS	DIATOM ZONATION
Anaulus simplex	*Coscinodiscus doljensis*	Řeháková (1977)	CENTRAL PARATETHYS	DIATOM ZONATION
Anaulus simplex	*Coscinodiscus doljensis*	(THIS PAPER)	CENTRAL PARATETHYS	DIATOM ZONATION
Mastogloia szontaghii *Cymatosira biharensis*		Olshtynska A. (2001)	EAST	DIATOM ZONATION
Dictyocha brevispina SUBZONE *Dictyocha subclinata*	*Distephanus longispinus* SUBZONE *Distephanus crux stradneri*	Desik. & Prema (1996) Bukry et al. (1973) Mc Cartney et al. (1992, 1995) Amigo (1999)	INDOPACIFIC AND ATLANTIC	SILICOFLAGELLATE ZONATION
Dictyocha rhombica		Bachmann (1971) Martini (1972)	MEDITERR-ANEAN	SILICOFLAGELLATE ZONATION
Distephanus slavnicii		Hajós (1986)	CENTRAL PARATETHYS	SILICOFLAGELLATE ZONATION
Distephanopsis soljanii	*Distephanopsis slavnicii*	(THIS PAPER)	CENTRAL PARATETHYS	SILICOFLAGELLATE ZONATION
Distephanus soljanii	*Distephanus mezopthalmus*	Dumitrica et al. (1975)	EAST PARATETHYS	SILICOFLAGELLATE ZONATION

micro- to nanno-scale belongs to the Paleogene, Lower Miocene, and Badenian. In the investigated area, the diatom *Cymbella* cf. *ventricosa* Kützing was recorded for the first time, and *Nitzschia sinuata* var. *tabellaria* (Grunow) Grunow* for the entire Paratethys area.

Markuševec (Mar-I) locality

The geological column Markuševec (Mar-I) is situated on the southwestern slope of Mt Medvednica, in the bed of Mrzljak creek in the village Markuševec (Fig. 1). In the bottom part of the column, Sarmatian sediments consist of coarse-grained clastic deposits (conglomerates) and normally graded sands. These are overlain by a 13 m thick alternation of light and dark, 3–5 cm thick, parallel laminated marls of varved sediments. The Sarmatian clastics unconformably overlie Badenian biocalcarenites, whereas the transition to the Pannonian is continuous (Fig. 3). They contain macro- (fish remains, molluscs) and microfauna (foraminifers), and sporadically carbonized plant remains and calcareous nannofossils (Galović et al. 2000).

The diatom assemblage is abundant and diverse (Table 2). Less abundant are the following siliceous microfossils like sponge spicules and silicoflagellates *Dictyocha fibula ausonia* (Deflandre) Mc Cartney, Churchill et Woestendiek, *D. brevispina brevispina* (Lemm.) Bukry, *D. pentagona* (Schulz) Bukry et Foster*, *D. rhombica* (Schulz) Deflandre, *D. subclinata* Bukry*, *Distephanopsis crux* (Ehr.) Dumitrica, *Dss. crux parvus* (Bachmann) Desik. et Prema, *Dss. hannai* (Bukry) Desik. et Prema*, *Dss. longispinus* (Schulz) Desik. et Prema, *Dss. schauinslandii* (Lemm.) Desik. et Prema, *Dss. slavnićii* (Jerković) Desik. et Prema, *Dss. staurodon* (Ehr.) Desik. et Prema, *Dss. stradneri* (Jerković) Desik. et Prema, *Dss. šoljani* (Jerković) Desik. et Prema, *Distephanus crux lockerii* Amigo*, *Ds. quinquengellus* Bukry et Foster, *Ds. speculum speculum* (Ehr.) Haeckel, *Ds. speculum elongatus* Bukry, *Mesocena elliptica* (Ehr.) Ehrenberg, *Paramesocena apiculata* (Lemm.) Locker et Martini, *P. circulus* (Ehr.) Locker et Martini. More rare are ebriids *Ammodochium rectangulare* (Schulz) Deflandre, *Cardiufolia gracilis* Hovasse, *Ebria tripartita* (Schum.) Lemmermann, *Ebriopsis valida* Deflandre, *Hermesinum adriaticum* Zacharias*, *Parathranium clathratum* (Ehr.) Deflandre, dinoflagellate endoskeletons *Actiniscus pentasterias* Ehrenberg, *A. stella* Ehrenberg, *Planifolia tribrachiata* Ernissee, archaeomonadaceas *Archaeomonas angulosa* Deflandre, *A. colligera* Hajós, *A. mangini* Deflandre, *A. pseudocompressa* Hajós*, *A. sphaerica* Deflandre, *A. spinosa* Hajós*, and radiolarians. Fifty-six Sarmatian diatom species have been registered for the first time in this region and 18 of them have not been recorded so far from the Paratethys realm (marked by an asterisk). The above mentioned assemblage contains taxa that were not mentioned by Jurilj (1957). Reworked

Table 2: Distribution of diatom species in samples from diferent localities; * — not registrated in the Paratethys during the Sarmatian. *Continued on the next page.*

Diatoms	Localities with samples		
	Dol-I, II	Kst-I	Mar-I
Achnanthes exiqua Grunow*	10	–	16
A. fimbriata (Grun.) Ross*	8–12	–	27
A. hauckiana Grunow var. *elliptica* Schulz*	6–10	–	16–27
A. lanceolata var. *elliptica* Cleve	10	–	–
A. lanceolata var. *lanceolatoides* (Sovereign) C.W.Reimer	–	–	16–28
Actinocyclus karstenii Van Heurck*	–	–	19
Amphora binodis var. *bigibba* Grunow*	9–12	–	–
Am. costata Smith*	8–13	–	27
Am. hidasensis Hajós	7–12	–	–
Am. holsatica Hustedt	13	–	–
Am. laevis var. *A.* Gregory*	8–9	–	–
Anaulus simplex Hajós	6–14	–	16–20
An. minutus Grunow	6–13	–	16–20
Bacteriastrum furcatum Shadbolt*	–	–	16–22
Chaetoceros cinctus Gran	–	–	20
Ch. compressus Lauder	6–13	–	28
Ch. wighamii Brightwell	6–12	–	–
Cocconeis boryana Pantocsek	9–10	–	–
C. pinnata Gregory*	12	–	–
C. placentula var. *euglypta* (Ehrenberg) Grunow	5–12	–	16–28
C. pseudofluminensis Hajós	6–13	–	27
C. sarmatica Pantocsek	8–13	–	–
C. scutellum var. *inequlepunctata* Miss	9–10	–	–
C. scutellum var. *parva* (Grun.) Cleve	6–13	–	14
C. scutellum var. *pulchra* Miss*	10–12	–	16–27
C. scutellum var. *raena* (Pant.) Cleve	6–13	–	–
Coscinodiscus plicatus Grunow*	6–13	1–2	–
C. rothii (Ehr.) Grunow	6–9	–	16–22
C. rugulosus Hajós	–	1–3	–
C. sarmaticus Pantocsek	–	1–3	–
C. stellaris Roper	6–13	–	18–27
Cussia aff. *paleacea* (Grun.) Schrader*	13	–	16
Cymatosira miocaenica Hajós	6–13	–	–
Cymbella cf. *sinuata* (Greg.)*	–	–	28
Cy. cf. *ventricosa* Kützing	–	10	
Delphineis surirella (Ehr.) Andrews*	9–13	–	28
Denticula sp.	8–12	–	–
Denticulopsis hustedtii (Sim. & Kanaya) Simonsen	–	–	16–22
Dimerogramma boryanum Pant.	6–12	–	–
Dimidiata saccula Hajós	8–13	–	20
Diploneis coffaeiformis (Schm.) Cleve	7–15	–	17–20
Dip. ovalis (Hilse) Cleve	6–9	–	18–22
Dip. sejuncta (Schm.) Jørgensen*	10	–	–
Dip. sejuncta f_o. *constricta* Hustedt*	10	–	–

Paleogene, Lower Miocene and Badenian have also been registered.

Biostratigraphy

A more detailed biostratigraphic and paleontological research of the region was done in the second half of the 20th century, with the works of Kochansky-Devidé (1957, 1973), Sokač (1965, 1967, 1972, 1985), Šikić (1966, 1967, 1968, 1975), Bajraktarević (1976), Kochansky-Devidé & Bajraktarević (1981), Polšak et al. (1986), Basch (1990a,b), Basch et al. (1992), Šikić (1995) and Vrsaljko (1999). The stratigraphy of the siliceous phytoplankton was particularly researched by Jurilj (1957), Jerković (1965, 1969, 1974), Bajraktarević (1983a,b, 1984) and Galović (2001).

In the Mt Medvednica environments the transition from the marine Badenian into the Sarmatian basin is presented. The later was characterized by reduced salinity and starvation of sediment supply (Avanić et al. 2003). This corresponds to the uppermost part of the calcareous nannoplankton NN6 Zone (Martini 1971). The southwestern slopes of Mt Medvednica are well known for diatomaceous laminated marls with diatoms, sponge spicules, silicoflagellates, ebriids, radiolarians and archaeomonadaceans (Jurilj 1957; Jerković 1969; Bajraktarević 1983a,b; Galović 2001). The Paratethyan silicoflagellate cenozone *Dictyocha soljani* has been established in the laminated marls of “Dolje type” by Bajraktarević (1984). Also, on the basis of a rare occurrence of *Dictyocha rhombica* the assemblage could belong to *Dictyocha rhombica* Zone (Martini 1977) in a broader geographical context, corresponding to the NN7 Calcareous Nannoplankton Zone (Table 1) (Bajraktarević 1984).

The first occurrence of the diatom species *Rhaphoneis diamantella* in the Parathetys is reported from the Karpatian (Hajós 1986). According to the diatom zonation, *Rhaphoneis diamantella* is a characteristic species of the namesake Partial Range Zone (mid-Atlantic region), ranging in age between 12.25–11.5 Ma (Andrews 1978). The diatom species *Actinocyclus karstenii* was recorded for the first time in the southern part of the Indian Ocean, in deposits of 11.7 Ma (Harwood & Maruyama 1992). In the Markuševac locality it was recorded in deposits belonging to the Middle Sarmatian (NN7 Calcareous Nannoplankton Zone), accompanied by *R. diamantella*, *Grammatophora hungarica*, and *Denticulopsis hustedtii*, which are characteristic for the lower middle Miocene of the Paratethys (Hajós 1986). One reason for their occurrence in younger sediments is perhaps due to reworking, tectonics (Dol-I) and/or eustatics. The beginning of the first Sarmatian transgression in the Paratethys was dated at about 12.5 Ma (Kováč et al. 2001). The maximum transgression of the next cycle (Harzhauser & Piller 2004), at the Marku-ševec and Podsused localities, occurs in the middle part of the Sarmatian (NN7 and/or NN7/NN8 Calcareous Nannoplankton Zone, respectively; Galović 2003). It is recorded in neritic-littoral development. These sediments contain molluscs belonging to the Ervilia-Mactra beds and a foraminiferal assemblage with *Elphidium hauerinum* and *Porosononion granosum* (Fig. 3) (Galović et al. 2000). The following diatom species are indicative

Table 2: *Continued.*

Diatoms	Localities with samples		
	Dol-I, II	Kst-I	Mar-I
Eunotia cf. *tenella* (Grun.) Hustedt*	6–10	–	16–22
Fogedia finmarchica (Cleve et Grun.) Witkowski, Metzeltin et Lange – Bertolt*	–	–	16
Fragilaria brevistriata var. *fossilis* Pantocsek	6–18	–	20–27
Staurosirella leptostauron (Ehr.) Williams et Round	10	–	–
F. martyi (Héribaud) Lange – Bertalot	6–9	–	16–28
Glyphodesmis driveri Hanna et Grant	–	–	14–19
Goniothecium odontella Ehrenberg	–	–	15–24
Grammatophora oceanica var. *macilenta* (Smith) Grunow	5–12	–	16–27
G. hungarica Pantocsek	8–12	–	–
G. oceanica var. *oceanica* Ehrenberg	9–13	–	14–20
G. stricta var. *biharensis* Ehrenberg	10–12	–	14–18
Gyrosigma distortum (W. Smith) Cl. var. *parkeri* Harrison*	8–10	–	–
Hantzschia cf. *virgata* (Roper) Grunow*	–	–	16–28
Lyrella praetexta (Ehrenberg) Mann	7–9	–	17
Mastogloia binotata (Grunow *)* Cleve*		–	–
M. lacustris (Grunow *)* Van Heurck*	–	–	22–27
M. pethöi (Pantocsek) Hajós	8	–	16–19
M. quinqecostata Grunow *	9–12	–	–
Neidium cf. *iridis* var. *A* Ehrenberg*	10	–	27
Nitzschia cf. *didyma* var. *A**	–	–	18–20
Ni. frustulum var. *obtusa* Pantocsek	–	–	28
Ni. frustulum var. *subsalina* Hustedt*	8–13	–	14–27
Ni. imperforata Andrews	–	–	16
Ni. sinuata var. *tabellaria* (Grunow) Grunow*	–	10	–
Opephora marina (Gregory) Petit	6–14	–	–
Perissonoë cruciata (Janisch et Roben.) Andr. et Stoelzel	–	–	16–17
Pinnularia viridis (Nitzsch) Ehrenberg	9	–	27
Podosira robusta Pantocsek	–	–	27
Rhaphoneis diamantella Andrews	–	–	16–23
Rh. gratiosa Hajós	8–13	–	–
Rh. intermedia Hajós	10–12	–	–
Rh. ischaboensis (Grunow) Mertz.	9–12	–	–
Rh. mertzi Hajós	10–12	–	–
Rh. rhombica (Grunow) Andrews	6–15	–	16–22
Rhizosolenia oligocaenica Schrader*	6–15	–	16–22
Rhopalodia gibba (Ehrenberg) Müller	10–12	–	–
Rho. giberula (Ehrenberg) Müller	–	3	–
Staurosira construens (Ehrenberg) Williams et Round	6–13	–	16–27
St. construens var. *venter* (Grunow) Williams et Round	6–13	–	17–27
Stictodiscus hungaricus Pantocsek	6–12	–	–
Surirella biharensis Pantocsek	6–10	–	18–27
Thalassiosira nordenskioldi Cleve	10–13	–	–
Trahineis aspera var. *intermedia* Grunow	12	–	–
Xantiopyxis ovalis Lohmann	6 –13	–	15–27

for the Middle Sarmatian in the Paratethys: *Coscinodiscus doljensis*, *Odontella aurita*, *Achnanthes baldjikii*, *Caloneis liber* var. *zagrebiensis*, *Cocconeis distans*, *C. scutellum* var. *inequlepunctata*, *C. scutellum* var. *pulchra*, *Cymatosira biharensis*, *Dimidiata saccula*, *Grammatophora insignis*, *Mastogloia pethoei*, *M. szontaghii*, *Rhopalodia giberula* and *Thalassionema nitzschioides.* This means, that the conditions suitable for the development of the above mentioned assemblage could be well established, both in some other parts of the Paratethys (partially from Balchik, Bulgaria by Temniskova-Topalova 1982; Mecsek Mt, Hungary by Hajós, 1986; Bremia, Romania by Pantocsek 1886–1905; and Dolje & Rožman, Croatia by Jurilj 1957) and in the investigated area. Silicoflagellates gradually disappear and the abundance of diatoms is drastically reduced toward the end of the Middle Sarmatian (lower part of the NN8 Zone which belongs to the Volhynian, Mărunţeanu 1999). The beginning of the appearance of Upper Sarmatian diatoms in the Mar-I and Kst-I columns (*Cocconeis pediculus*, *Cymatopleura solea*, *Cymbella* cf. *ventricosa*, *Cy.* cf. *sinuata*, *Nitzschia frustulum* var. *obtusa*) characterized the boundary. The changes from the Middle to Upper Sarmatian Paratethyan diatom assemblages (*Achnanthes baldjikii*, *Cocconeis distans*, *Thalassionema nitzschioides*) also could confirm the Middle/Upper Sarmatian boundary. Besides, the Middle/Upper Sarmatian boundary (lower/upper part of the NN8 Zone corresponding to the Volhynian/Early Bessarabian; Papp et al. 1974; Mărunţeanu 1999) may be established, on the basis of both the phytoplankton (silicoflagellate, diatom and coccolithophorid) assemblage and of volcanic particles. Vass (1999) attempted to correlate different and heterogeneous data for the Sarmatian age in particular Paratethys areas, derived from magnetostratigraphy, chronostratigraphy, biostratigraphy, and radiometric dating, focusing particularly on the age of NN8 Calcareous Nannoplankton Zone. In this paper, this zone is correlated with Vass's first datings. This zone is detected in Papp's 'Impoverishment zone' (or *Sarmatimactra vitaliana* Biozone) with rare foraminiferal (*Porosononion granosum*) and ostracod (*Aurila notata*) species (Galović et al. 2000).

The silicoflagellate (*Distephanopsis* (*Distephanus*) *soljani–Distephanopsis* (*Distephanus*) *slavnicii*) and the diatom zonation (*Anaulus simplex–Coscinodiscus doljensis*) have been correlated with other established zonations (Table 1).

The silicoflagellate ***Distephanopsis soljani–Distephanopsis slavnicii* Zone** is characterized by first and last occurrence of these species in the Paratethys. It consists of: *Dictyocha subclinata* Bukry, *Dictyocha brevispina brevispina* (Lemm.) Bukry, *Dictyocha rhombica* (Shulz) Deflandre, *Deflandryocha cymbiformis* Jerković, *Def. spathulata* Jerković, *Distephanopsis crux* (Ehr.) Dumitrica, *Dss. longispinus* (Schulz) Desik. et Prema, *Dss. schauinslandii* (Lemm.) Desik. et Prema, *Dss. stradneri* (Jerković) Desik. et Prema, *Dss. crux parvus* (Backmann) Desik. et Prema and *Distephanus crux lockerii* Amigo.

The diatom ***Anaulus simplex–Coscinodiscus doljensis* Zone** was established by Řeháková (1975, 1977) for the Czech part of Central Paratethys (Table 1). This zone is distinguished by a great species diversity of the genera *Actinocyclus*, *Chaetoceros*, *Coscinodiscus*, *Achnanthes*, *Amphora*, *Cocconeis*, *Diploneis*, *Grammatophora*, *Mastogloia*, *Navicula* and *Nitzschia.* It is characterized by the index species of *Anaulus simplex* Hajós, *Coscinodiscus doljensis* Pant., *C. sarmaticus* Pant., *Dimidiata saccula* Hajós, *Mastogloia szontaghii* Pantocsek, *Cymatosira biharensis* Pant., *Achnanthes baldjikii* (Brightwell) Grunow, *Cocconeis scutellum* f. *birhafidea* Jurilj, *Co. scutellum* var. *raena* (Pantocsek) Cleve, *Grammatophora insignis* var. *doljensis* Grun., *Nitzschia doljensis* Pant., *Rhaphoneis mertzi* Hajós, *Rhopalodia giberula* var. *rosmanniensis* Jurilj. Typical forms in the assemblage are *Actinoptychus splendes* var. *zagrebiensis* Jurilj, *Coscinodiscus rugulosus* Hajós, *C. nitidus var. zagrebiensis* Jurilj, *Melosira distans* var. *imbuta* Jurilj, *Triceratium laetum* f. *quadrata* Hajós, *Achnanthes rara* Jurilj, *Ach. saeptata* var. *doljensis* Jurilj, *Ach. saeptata* var. *sussedana* Jurilj, *Amphora crassa* var. *gemmata* Jurilj, *Am. crassa* var. *punctata* Grun., *Am. domkeana* Jurilj, *Am. proteus* var. *nodosa* Jurilj, *Am. intersecta* var. *sarmatica* Jurilj, *Caloneis liber* var. *zagrebiensis* Jurilj, *Cocconeis andesitica* Jurilj, *Co. canaliculata* Jurilj, *Co. evolvens* Jurilj, *Co. ornata* var. *birhaphidea* Jurilj, *Co. scutellum* var. *parva* (Grun.) Cleve, *Diploneis perforata* Jurilj, *Campylodiscus kuetzingii* Pant., *Cymatosira miocaenica* Hajós, *Dictyoneis lorkovicii* Jurilj, *Dimerogramma minor* (Greg.) Ralfs, *Diploneis vetula* f. *minor* Jurilj, *Mastogloia baltschkiana* Grun., *M. angulata* var. *sarmatica* Jurilj, *M. sarmatica* Jurilj, *Navicula latissima* var. *cuneata* Jurilj, *Opephora gemmata* f. *minor* Jurilj, *Plagiogramma boryanum* Hajós, *P. biharense* Pant., *Rhopalodia giberula* var. *protracta* Grun. and *Surirella subfastuosa* Pant.

In the Middle Miocene of the equatorial Pacific Ocean, silicoflagellate species *Dictyocha subclinata* makes a horizon of the *Dictyocha varia* Interval Zone (Table 1), (McCartney et al. 1995). *Dictyocha subclinata* was also found in Middle Miocene deposits of the northern Atlantic. Its first appearance is within the CN5 Nannoplankton Zone (Okada & Bukry 1980), which would correspond to the beginning of the Sarmatian in the Paratethys. The first occurrence of *D. subclinata* is observed when *Corbisema triacantha* disappears (extinction), which is at the Badenian/Sarmatian boundary in the Central Paratethys, corresponding to the nannoplankton Zone NN7 (Hajós 1986). The equivalent of the silicoflagellate zone *Distephanus slavnicii* (Fig. 2) is the diatom Zone *Anaulus simplex–Coscinodiscus doljensis* (Hajós 1986). The *Anaulus simplex–Coscinodiscus doljensis* Diatom Zone of the Central Paratethys is contemporaneous with the *Cymatosira biharensis–Mastogloia szontaghii* Zone in the Eastern Paratethys (Olshtynska 2001) based on co-occurrence of the species.

Paleoecology and paleogeography concerning biostratigraphy

The above mentioned phytoplankton assemblages occur in the middle to upper part of the Sarmatian deposits. Most first appearances of marine planktonic diatoms, with negligible amount of some benthic organisms in the sediments, are characteristic for warm climatic regions. This is also proved by very rare occurrences of the silicoflagellate *Dictyocha fibula*, which, in the Adriatic Sea, almost disappears during the warmer season (Jerković & Kovačić 1970). Following the gradual global cooling, accompanied by temperature oscillations, marine varved sediments have been deposited (Schrader et al. 1986; Vaniček et al. 2000), with taxa adapted to a more temperate environment (*Distephanopsis crux*, *Dss. longispinus*, *Dss.* schauinslandi, and *Dss. staurodon*, together with mesocoenas and paramesocoenas; Bukry 1981; Desikachary & Prema 1996; Amigo 1999). The morphology of the apical ring in the silicoflagellates is indicative of the temperature conditions in which they developed. The more strongly (massive) skeletons indicate lower temperatures. Below 3 °C, however, the development of the skeletons is reduced (Bohaty & Harwood 1998). Silicoflagellates are sensitive to temperature variations, which could be indicative on the orientation of the skeleton (McCartney & Loper 1989) that is not symmetrical in the assemblage and because of that the broader temperature ranges have been inferred for the Sarmatian. The temperature ranges were obtained also based on the diatoms, giving average temperature ranges of 4–16 °C for cooler and from 15–27 °C for warmer periods. In the varve-type sediment, ecologically tolerant forms, regarding salinity, vary from marine to brackish-freshwater, represented in the assemblage with mostly planktonic diatoms. Most samples contain assemblages, indicative for salinity from 20–40 (Hajós 1986), but during warmer seasons a thermohaline assemblage was formed, containing both mesohaline and oligohaline forms, though their share in the whole assemblage is less than 5 % in the Middle Sarmatian. The ebriid *Hermesium adriaticum*, which occurs in stratified waters in the halocline, i.e. in an intermediate brackish/marine environment, indicates oxic to anoxic conditions with a well-developed chemocline (Fig. 3) (Viličić et al. 1996–97). This species belongs to heterotrophic organisms that feed on dissolved and suspended organic material accumulated around the thermohaline zone (Mantoura 1987). During warmer seasons, rivers bring terrigenous particles and organic material, and due to differences in density and temperature between surface and bottom waters, a pycnocline to thermocline is formed. *H. adriaticum* migrates in winter from the eastern Mediterranean into the Adriatic (Gržetić 1982) and has also been found in the Black Sea in anoxic layers rich in H_2S (Bodeanu 1969), which also contain silicoflagellate skeletons (Cornell 1977). With time, disoxic conditions develop below the thermocline (oxygen being used up by respiration of organisms), whereas on the bottom bacteria decompose the organic matter and also use up oxygen, producing anoxic conditions too. Such conditions allowed the (permanent) preservation of the siliceous phytoplankton taxa (Puškarić et al. 1990) and development of dark, millimeter-thick laminae rich in organic material. In cooler seasons, the temperature below and above the thermocline becomes equal, the thermocline disap-

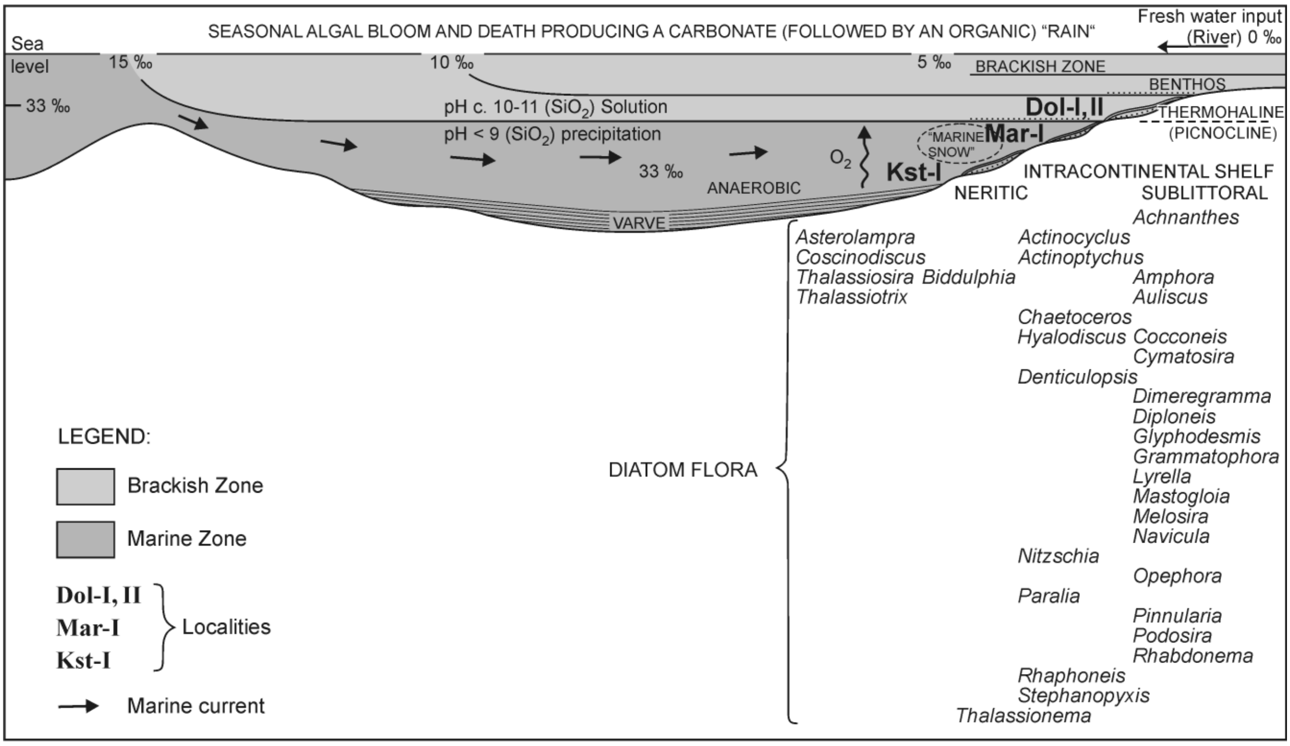

Fig. 4. Schematic paleoecological reconstruction of investigated marginal Paratethys area during the Sarmatian.

pears and upwelling occurs, nutrient rich bottom water mixes with the oxygen-rich surface water. The temperature near the sea bottom is much lower than in the surface layers. The silicoflagellate and diatom skeletons may accumulate because of reduced dissolution in lower temperature conditions (Fig. 4). The seasonality, sedimentation rates and a strong oxygen minimum zone, results in the preservation of annually laminated sediments as in the varved sediment record.

With time, due to diagenetic processes, the BiS (biogenic silica) participate in the formation of varve sediments in the area of Mt Medvednica (Polšak et al. 1986). Also the skeletons may be encrusted by authigenic minerals (ferrous, magnesium and calcium alumosilicates), which additionally affects their preservation potential and may be seen in thin sections of Mar-I and Kst-I (pyrite and/or other opaque minerals). In the Late Sarmatian, the predominance of benthic forms indicates stronger near-shore and meso-oligohalin influence (*Cocconeis pediculus*, *Cymatopleura solea*, *Cymbella* cf. *ventricosa*, *Cy.* cf. *sinuata*, *Nitzschia frustulum* var. *obtusa*). Carbonate content in the sediment of Kst-I increases from 44 % to 55 % at the end of the Sarmatian, because of shallowing and more pronounced near-shore influence. Due to various stress factors (temperature, salinity, water transparency and chemistry) many new species, variations and forms are registrated (Table 2) (Jurilj 1957 and Hajós 1986). Such conditions are indicated in the marginal brackish Paratethys environments, or, locally, in isolated bays (Hajós 1986). The planktonic/benthic diatom ratio varies from min. 0.22 to max. 0.83 corresponding to paleodepth from about 25 to 120 m (Pushkar & Cherepanova 2001) reveals the sea level oscillations during the Middle and Late Sarmatian, with a general regressive trend towards the end of the Sarmatian. The silicoflagellate and diatom assemblages (*Chaetoceros* spp., *Thalassionema nitzschiodes*) point to a marginal Paratethys area and upwelling zone such as coastal regions or epicontinental seas (Puškarić et al. 1990; Trepke et al. 1996). Because of the upwelling, the surface water became enriched with nutrients (nitrates, nitrites, ammonium salts, phosphates, and silica) that were used up by the phytoplankton community during assimilation. A part of the dissolved H_4SiO_4 (silica, orthoslilicate) was brought in by rivers (Fig. 4). Fresh water input is also evident by diatom assemblage, brought by streams into the sedimentary environment (*Aulacoseira islandica*, *Cocconeis placentula* var. *euglypta*, *Diploneis ovalis*, *Gyrosigma distortum* var. *parkeri*). There is an indirect way to find out whether the nutrient concentration was high or low. The complexity of the structure of the skeleton increases with the nutrient concentration. In contrast to that, simpler forms develop in the conditions of low nutrient concentrations. The presence of particular genera and species are evidence of a connection with the Mediterranean (*Dictyocha brevispina*, *D. fibula ausonia*, *D. rhombica*, *Distephanopsis crux*, *Dss. staurodon*, *Distephanus quinquangellus*, *Mesocena elliptica*, *Paramesocena circulus*, *Achnanthes hauckiana* var. *eliptica*, *Actinoptychus senarius*, *Amphora costata*, *Biddulphia biddulphiana*, *Chaetoceros holsaticus*, *Chaetoceros lorenzianus*, *Climacosphenia moniligera*, *Cocconeis cruciata*, *C. distans*, *C. fluminensis*, *C. ornata* var. *birhaphide*, *C. quarnerensis* var.

lanceolata, *Cymatosira lorenziana*, *Diploneis vetula* f. *minor*, *Fragilaria brevistriata* var. *fossilis*, *Grammatophora marina*, *Mastogloia quinquecostata*, *Paralia debyi*, *Plagiogramma staurophorum*, *Planothidium quarnerensis*, *Rhabdonema hamuliferum*, *Thalassionema nitzschoides)* and the Indopacific (*Cannopilus hemisphaericus*, *Dictyocha fibula ausonia*, *D. pentagona*, *D. subclinata*, *Distephanopsis crux*, *Dss. hannai*, *Dss. longispinus*, *Distephanus speculum*, *Paramesocena circulus*, *Actinocyclus karstenii*; Bukry & Foster 1973; Harwood & Maruyama 1992; McCartney et al. 1995*)* during the Middle Sarmatian. In the Markuševec locality, the connection with other marine areas (Eastern Paratethys, Mediterranean, and the Indopacific) can be inferred to have existed only above the middle part of the column in laminated marls, when favourable conditions for the development and preservation of siliceous microfossils have been established (Fig. 4). The first input of siliceous microfossils can be seen with the beginning of the deposition of the Middle Sarmatian deposits when the connection with other marine areas was established. At the end of the Middle Sarmatian (s.str.) connection is reduced, oscillated, and interrupted (*Dictyocha brevispina brevispina*, *D. fibula ausonia*, *D. fibula fibula*, *D. rhombica*, *Distephanopsis crux*, *Dss. staurodon*, *Distephanus speculum*, *Ds. quinquengellus*, *Mesocena elliptica elliptica*, *Paramesocena circulus*). However, aberrant silicoflagellate forms that accompany these changes are also present, though very rare. It is well known that silicoflagellates, under stress conditions, loose their symmetry, such as their apical ring, and develop simpler forms (Guex 1993). All this speaks in favour of specific conditions characterized by a semi-restricted marine environment, like in a bay or the Black Sea. In addition to the upwelling and the connections with other marine areas, occurrence of volcanic glass (Šimunić 1993, pers. com.) may have also contributed to locally favourable conditions for the preservation of silicoflagellate skeletons (Mar-I, Kst-I). In the marine environment, volcanic glass is unstable and subject to hydrolysis, releasing silica that is used by siliceous phytoplankton for the construction of their tests (Zen 1959). Beside the volcanic activity, the region was also affected by tectonics, which is revealed, in addition to sedimentologic indicators (angular unconformity in Podsusedsko Dolje, Fig. 3), by the presence of the dinoflagellate *Actiniscus pentasterias*, an indirect indicator of tectonically turbulent regions (Orr & Conley 1976).

Conclusion

According to the presented results, the middle part of the Sarmatian of the Central Paratethys begins with a transgression. At the beginning of the Middle Sarmatian, in the investigated area, conditions favourable for the development and preservation of siliceous phytoplankton have been established. A large concentration of biogenic silica in the sediment is indicative of marginal marine environments with pronounced continental upwelling (diatom species of *Chaetoceros*, *Coscinodiscus curvatulus*, *Thalassionema nitzschoides* and silicoflagellates). The alternations of dark, organic rich, mm laminae and light laminae rich in carbonate are probably a consequence of sedimentation changes due to the seasonal variations in more temperate climate. At Mt Medvednica, such areas were suitable for the development of marine varved sediments. The interconnectedness of marine realms has also been established. The Sarmatian phytoplankton assemblages that developed in the Mediterranean and Indopacific region have been found in the investigated area, which proves connections between these seas. They have been established during the Middle Sarmatian, when species migrated, by means of currents, into our regions and were deposited in the upwelling areas. The proofs for that may be also found in other parts of the Central Paratethys (Hungary, Slovakia), where the connections with these marine areas have also been established on the basis of diatoms. Towards the end of the Middle Sarmatian, these connections were gradually interrupted. At the end of the Sarmatian the basin was isolated. This could be shown by a sharp decrease of biodiversity (both on the genus and species levels), complete disappearance of silicoflagellates, also changed assemblages and predominance of benthic diatoms (*Cocconeis pediculus*, *Cymatopleura solea*, *Cymbella* cf. *ventricosa*, *Cy.* cf. *sinuata*, *Nitzschia frustulum* var. *obtusa*), which indicate the conditions of reduced salinity and more near shore influence.

Acknowledgments: This paper resulted from the work done within the project “Neogene clastic-carbonate complexes of Mt Medvednica”, under the leadership of Dr. I. Hećimović. We thank him for his expert leadership. Special thanks to Prof. Ivan Gušić for his useful suggestions. We also thank our colleagues Dr. M. Kovačić and Al. Šimunić for their results of sedimentary-petrographic analyses, as well as M. Drušković for calcimetry, all in the Croatian Geological Survey, Zagreb.

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