GEOLOGICA CARPATHICA, AUGUST 2005, 56, 4, 347–358

Upper Neogene siliceous microfossils from Pelagonia Basin (Balkan Peninsula)

NADJA OGNJANOVA-RUMENOVA

Department of Paleontology and Stratigraphy, Institute of Geology, Bulgarian Academy of Sciences, Acad. G. Bonchev Street 24,
1113 Sofia, Bulgaria; nognjan@geology.bas.bg

(Manuscript received March 15, 2004; accepted in revised form December 9, 2004)

Abstract: This paper presents data from an investigation of the Late Miocene-Pliocene siliceous microfossils (diatoms and chrysophycean stomatocysts) from borehole V-466, east of the city of Bitola, southern Macedonia. The diatom flora consists of 127 species, varieties, and forms of diatoms of thirty genera, eighteen families, five orders, and two classes. Four associations are distinguished in the development of the diatomaceous flora, as confirmed by cluster analysis. Ecological data for the diatom taxa and the frustule/chrysophycean stomatocysts ratio are used in an attempt to reconstruct in detail the paleoecological conditions at the time of sediment deposition in detail.

Key words: Late Neogene, Balkan Peninsula, Pelagonia Basin, paleoenvironment, biostratigraphy, continental sediments, diatoms, chrysophycean stomatocysts.

Introduction and geology of the study area

The Pelagonia Basin, measuring 1500 km^2 is a part of the tectonic basins created after the Savian orogeny and the Early Miocene intense peneplenization in the Balkan Peninsula (Dumurdzanov et al. 1997). This led to the formation of a set of sub-grabens within the Pelagonia Basin and the faults running from NW to SE. The Neogene sediments of the basin are in direct contact with the basement, consisting of metamorphic rock, limestones, dolomites, flysh and ophiolites (Dermitzakis & Papanikolaou 1981). Several major sub-basins can be distinguished: the Bitola and Prilep areas (Republic of Macedonia) and the areas of Florina, Ptolemais and Servia parts (Greece) (Fig. 1). Three lithostratigraphic units are recognized only within sub-basins in the territory of Greece (Koufos & Pavlides 1986), namely: **1** — a lower, unnamed formation composed of basal conglomerates; **2** — a middle unit, the Vegora Formation composed of marls, sandy marls, sands, and lignite (xylite type) (Upper Miocene, according to its macroflora and palynomorphs: Van de Weerd 1983; Knobloch & Velitzelos 1986; Velitzelos & Gregor 1986, 1990; Riegel et al. 1993; Velitzelos & Kvaček 1999); **3** — the upper, Ptolemais Formation composed of argillaceous layers, marls, sands, lignite beds, and lacustrine calcareous muds in alternating sequence (Lower Pliocene, according to its macroflora, palynomorphs and small mammalia: Van de Weerd 1979; Velitzelos & Gregor 1986, 1990; Riegel et al. 1993; Bosch et al. 1996). The Ptolemais Formation is composed of two members: the lower Kardia Member (lower group of lignite beds), and the upper Anagiri Member (upper set of lignite beds).

The Neogene sediments from the Macedonian area can be subdivided into the following informal lithostratigraphic units:

— sandy-gravel-clay series with maximum thickness of 400–500 m, discordantly covering the pre-Neogene formation.
— terrigeneous coal-bearing series with sandy-silty unit, which in the Prilep part has a maximum thickness of 100 m.
— gravel-sandy-silty series, which in the Macedonian area has a thickness of 150 m.
— sandy-silty coal-bearing series, which in the Bitola part of the basin has a thickness of more than 200 m (Suvodol mine, near Bitola).

These sediments correspond to two sedimentary cycles (Dumurdzanov 1997). The first sedimentary cycle (Middle–Upper Miocene/Sarmatian–Meotian) included the first two series. During the second sedimentary cycle (Miocene–Pliocene) the second two series were formed. The upper part of the second sedimentary cycle in the Macedonian part is referred to the Upper Pontian on the basis of correlation by vertebrate fossils. The mammalian fauna in the lignite bed corresponds to zones MN12–13 (Dumurdzanov 1997). Recent paleobotanical studies (Kitanov 1996; Mihajlovic & Lazarevic 2004) have confirmed the age of the second sedimentary cycle as Late Miocene–Pliocene. During the third sedimentary cycle (Pleistocene) the basin was in its final phase of disappearance and this stage is presented by coarse molasses (Dumurdzanov 1997).

Until now, diatom-bearing sediments from the Pelagonia Basin have been studied only from the Ptolemais sub-basin (Gersonde & Velitzelos 1977) and the Servia sub-basin (Economou-Amilli 1991). Here I present the first study of the diatom flora from the sediments in the Bitola sub-basin (Macedonia). The aim of this research is to trace the development of the siliceous microfossils (diatom and chrysophycean stomatocysts), to define the corresponding chronostratigraphy and to reconstruct the paleoecological conditions in the basin during the sediment deposition.

Fig. 1. Schematic map of the Pelagonia Basin with location of the borehole V-466, Bitola. The map is redrawn from outlay maps by Van de Weerd (1983) and Dumurdzanov (1997).

Material and methods

Borehole V-466 in the village of Vranjevci, east of the city of Bitola, is located on the far eastern margin of the Pelagonia Basin (Fig. 1). In an unpublished report of 1986 (Suvodol Coal Mine documentation) N. Krstić (Geoinstitute, Belgrade) described the sedimentation sequence in V-466 as follows:

— 0.70 to 7.05 m: Diluvial bed (from the top downward): red sand-gravelly detritus; white silty sand with gravel at the base.

— 7.05 to 11.85 m: Lacustrine siltstone with a sand interbed (8.85–8.90 m).

— 11.85 to 78.00 m: Light grey diatomite, silty at some levels; an interbed of micaceous sand (24.55–24.70 m); vivianite pellets, particularly abundant in interval 14.05–14.85 m.

— 78.00 to 104.00 m: Lignite.

— 104.00 to 175.00 m: Whitish coarse silty sand with yellowish sand bed (115.00–119.00 m).

— 175.00 to 178.00 m: Paleorelief and/or paleorelief blocks (gneiss–granite).

The present diatom analysis was carried out on 17 samples taken from borehole V-466, Bitola area, Pelagonia Basin. Fourteen samples contained siliceous microfossils.

The diatoms were cleaned by the procedure described by Ognjanova-Rumenova (1991). The relative abundance of diatoms was estimated according to Schrader's scale (Schrader 1973). An amplival microscope was used for the light microscopy. Photographs were taken on ORWO films, 15 DIN. Preparation for scanning electron microscopy was as described in Hasle & Fryxell (1970) and samples were examined with a Jeol Superprobe 733 and Jeol JSM T300. Terminology follows Anonymous (1975) and Ross et al. (1979) with a few additions. For all taxa mentioned, authors' names are given in the list of taxa observed (Appendix). Ecological spectra were composed on the basis of studies of recent diatoms by the method of Abbott & Van Landingham (1972). The basic environmental factors interpreted in the paleoecological analysis were the active water reaction, temperature, nutrient, type of the habitat and halobity. The minimum variance clustering (Ward's method) based on Squared Euclidean distance was used for the paleoecological subdivision and classification of diatom thanatocenoses. Sample clustering included all samples used in the diatom analysis (14). The ratio of diatom frustules to chrysophycean stomatocysts was applied (Smol 1985).

Results and discussion

Species composition, taxonomic structure and analysis of the diatom flora

The diatom flora from the profile V-466, Bitola sub-basin, consists of 127 species, varieties and forms of diatoms, belonging to 30 genera. They are referred to 18 families, 5 orders and two classes. There are 9 species for which no definite identification was possible and one species for which only a tentative, but likely, specific identification can be given. The diatom flora is composed almost entirely (85.9 %) of recent species. The fossil species amount to 14.1 %, but in their relative abundance they show considerable dominance. The species list of the community is given in Appendix.

The species diversity in the studied flora is attributable to the class Pennatophyceae (78.12 %). Most of these species occur sporadically and they are characterized as rare (2nd grade according to Schrader's scale). Among the araphid diatoms, the genus *Fragilaria* is the most abundant (15 species, varieties and forms), whilst among the raphid diatoms (order Raphales) the genus *Navicula* (*sensu lato*) displays the largest species diversity in the material examined (21 species and varieties).

The development of the different genera of the class Centrophyceae, Bacillariophyta, in the continental deposits has been used for the diatom biostratigraphic subdivision. The investigated profile is generally dominated by the genera *Cyclotella*, *Actinocyclus* and *Aulacoseira* of the class Centrophyceae. The genus *Cyclotella* is represented in the sediments of borehole V-466, by 11 species and varieties. Most of these have been examined in both the light- and scanning-electron microscopes. Similar species of this genus have been found in lacus-

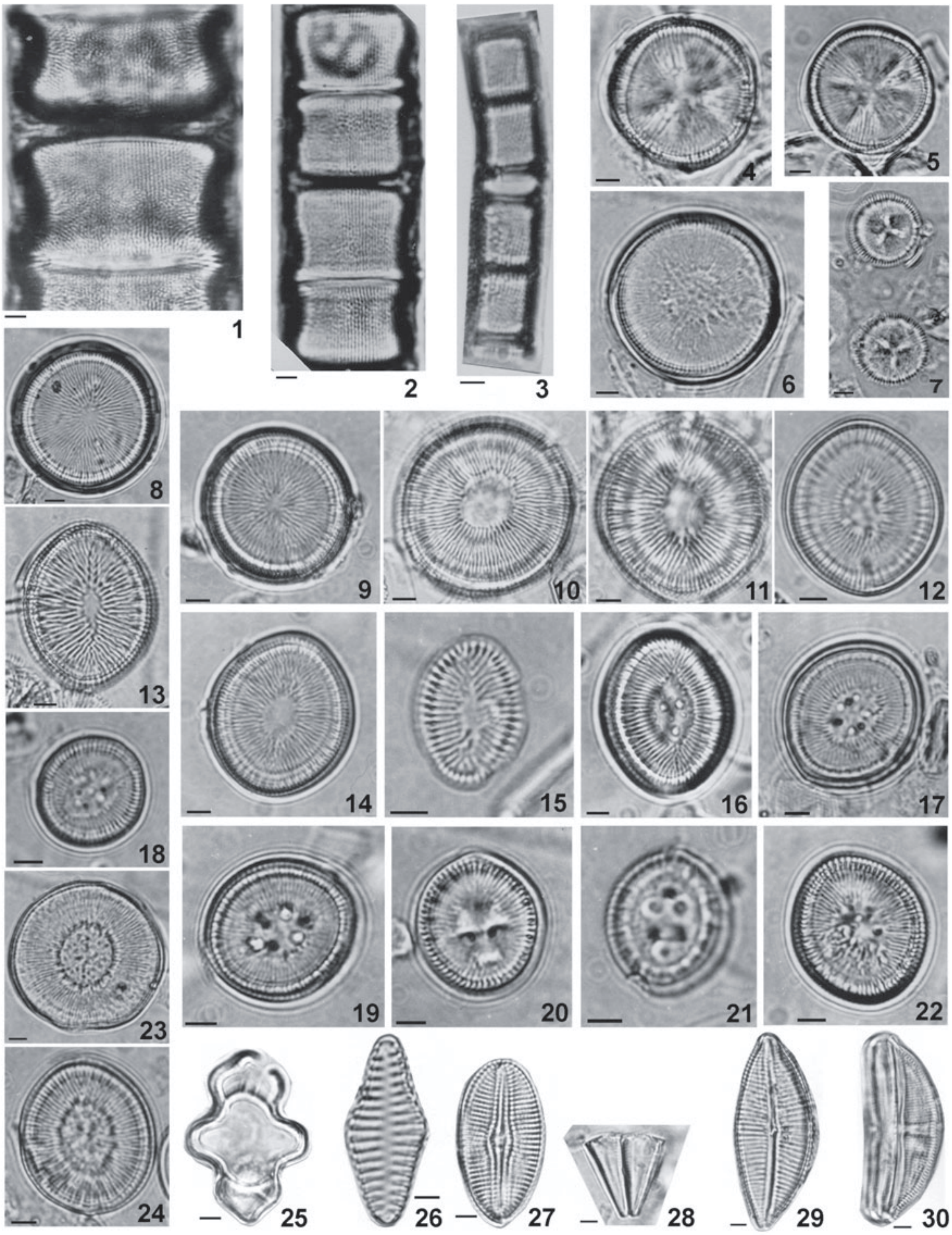

Fig. 2. **1** — *Melosira undulata* (Ehr.) Kütz., V-466, depth 25.00 m. **2** — *M. undulata* (Ehr.) Kütz., V-466, depth 40.00 m. **3** — *Aulacoseira ambigua* (Grun.) Sim., V-466, depth 65.00 m. **4, 5** — *Cyclotella castracanei* Eulenst., V-466, depth 20.00 m. **6, 7** — *C. castracanei* Eulenst., V-466, depth 15.00 m. **8, 9** — *Cyclotella iris* Brun et Hérib., V-466, depth 30.00 m. **10, 11** — *C. iris* Brun et Hérib., V-466, depth 33.94 m. **12** — *C. iris* Brun et Hérib., V-466, depth 70.00 m. **13** — *C. iris* var. *ovalis* Brun et Hérib., V-466, depth 33.94 m. **14** — *C. iris* var. *ovalis* Brun et Hérib., V-466, depth 50.00 m. **15** — *C. iris* var. *cocconeiformis* Brun et Hérib., V-466, depth 33.94 m. **16** — *Cyclotella* sp. 1, V-466, depth 33.94 m. **17** — *Cyclotella* sp. 1, V-466, depth 70.00 m. **18** — *Cyclotella* sp. 1, V-466, depth 65.00 m. **19** — *Cyclotella* sp. 1, V-466, depth 45.00 m. **20** — *Cyclotella* sp. 1, V-466, depth 40.00 m. **21** — *Cyclotella* sp. 1, V-466, depth 70.00 m. **22** — *Cyclotella* sp. 1, V-466, depth 45.00 m. **23, 24** — *Cyclotella elymaea* Econ.-Am., V-466, depth 70.00 m. **25** — *Tetracyclus glans* (Ehr.) Mills, V-466, depth 33.94 m. **26** — *Fragilaria leptostauron* var. *fossilis* (Pant.) Rehák., V-466, depth 75.00 m. **27** — *Diploneis elliptica* (Kütz.) Cl., V-466, depth 70.00 m. **28** — *Gomphonema grovei* var. *herrmanniana* (Patrik) Koc., Stoerm., Yang., V-466, depth 70.00 m. **29** — *Cymbella ehrenbergii* Kütz., V-466, depth 61.00 m. **30** — *Amphora libyca* Ehr., V-466, depth 75.00 m. Scale bar = 5 µm.

trine deposits throughout Southern Europe (Ognjanova-Rumenova 2000). On the basis of their infrageneric classification and the ultrastructural features they may be classified into three informal groups:

1. *Cyclotella castracanei* group — This forms a separate phylogenetic range (Loginova 1989). This group also includes *C. scrobicula* and *C. schambica*. These species have been described from maar sediments of Armenia (Aleshinskaya & Pirumova 1982; Loginova et al. 1990) (Fig. 2.4–7; Fig. 5.5–6; Fig. 6.1–2).

2. *Cyclotella iris* group — The presence of almost all varieties of *Cyclotella iris* in the investigated profile is a very interesting discovery. Similar infraspecific variations of this species had been identified only in the Upper Miocene sediments in the Massif Central (Heribaud 1893; Serieyssol 1981, 1984) and in the Sofia Neogene Basin (Ognjanova-Rumenova 1991, 1996) (Fig. 2.8–15; Fig. 3.1–6).

3. *Cyclotella andancensis* group — The only member of this group isolated was *C. elymaea* Economou-Amilli. It is a rockforming species in the Neogene sediments, belonging to the Servia sub-basin, Pelagonia Basin (Economou-Amilli 1991) (Fig. 2.23–24; Fig. 6.3–4).

Among the *Cyclotella* species, there is one very interesting dominant form in the profile — *Cyclotella* sp. 1. This form is very similar to *Cyclotella ocellata* Pantocsek in the main characteristics (Lowe 1975; Kiss et al. 1996; Hakansson 2002): simple alveoli, a single rimoportula in the submarginal zone of the valve, the marginal fultoportulae appear on every second to sixth valve mantle costa, the ornamentation pattern of the central zone is typical — with large depressions and granuls on the valve face. But there are some differences: the marginal fultoportulae have three (not two) satellite pores (Fig. 4.4); the central fultoportulae are missing; spines are present on some and absent on other valves. On the basis of differences in size range, shape of the valve and some morphological characters, two morphotypes of *Cyclotella* sp. 1 could be distinguished (Fig. 2.16–22):

— Small valves, clearly elliptical in outline with a length/width ratio of 5.9–17.6 µm/4.9–17.6 µm. There are 14–20 striae in 10 µm (Fig. 5.1–4).

— Large valves, circular outline with a diameter of 6.86–22.54 µm and 12–20 striae in 10 µm (Fig. 4.1–5).

The above-described isomorphic populations of *Cyclotella* sp. 1, occurring at various levels up the stratigraphic column V-466, Bitola might be explained by paleoecological parameters in the paleoenvironmental interpretation.

Another characteristic feature of the diatom flora from the Bitola sub-basin is the development of the genus *Actinocyclus*,

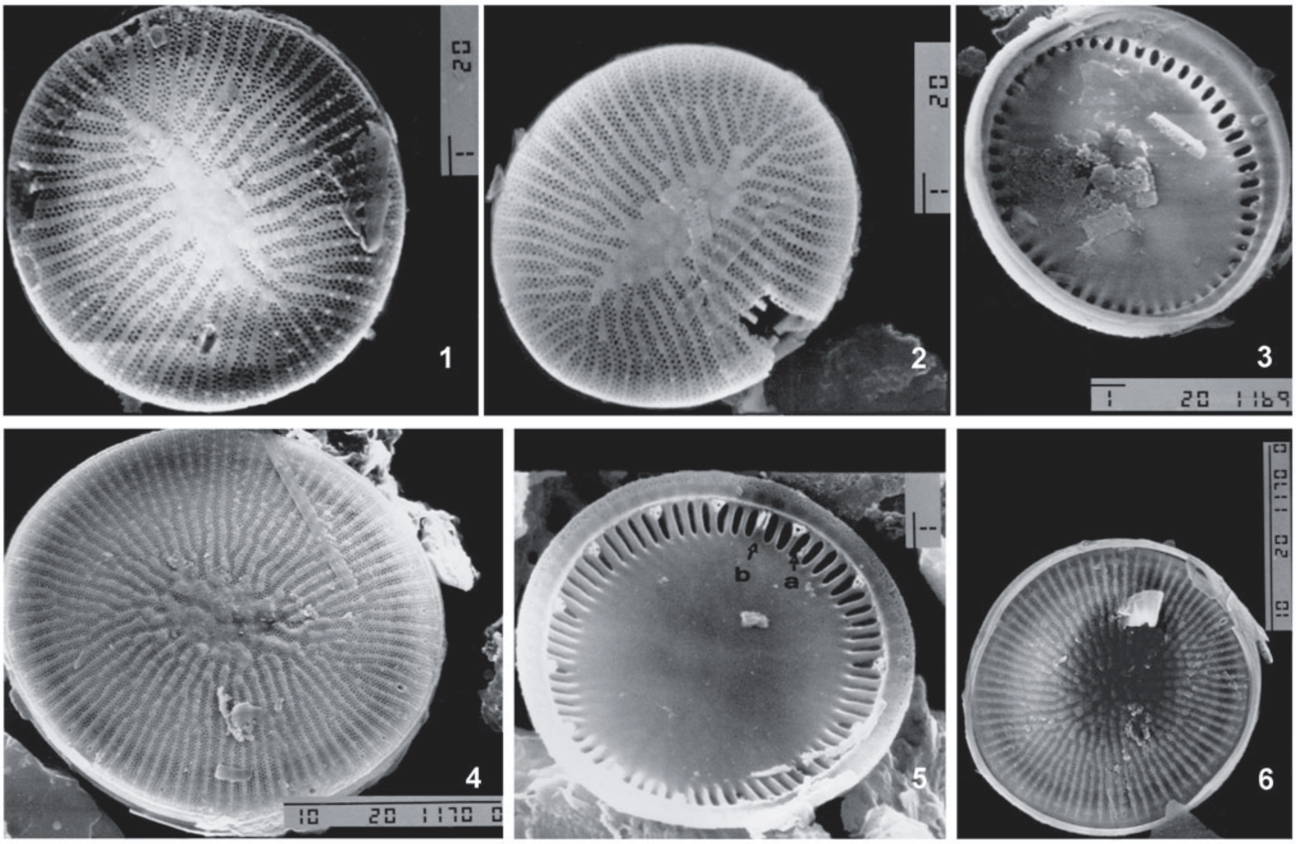

Fig. 3. **1, 2** — *Cyclotella iris* var. *ovalis* Brun et Hérib., valve exterior, V-466, depth 65.00 m. **3** — *C. iris* var. *ovalis* Brun et Hérib., valve interior with spacing of the marginal fultoportulae, V-466, depth 65.00 m. **4** — *Cyclotella iris* Brun et Hérib., valve exterior, V-466, depth 65.00 m. **5** — *C. iris* Brun et Hérib., valve interior with spacing of the marginal fultoportulae (with three satellite pores; a — and the single rimoportula, b — V-466, depth 61.00 m. **6** — *Cyclotella iris* Brun et Hérib., valve exterior, V-466, depth 61.00 m.

represented by various species among which the Late Miocene and Miocene-Pliocene representatives have a high relative abundance (4–5 according to Schrader's scale 1973). There is a concurrence of all representatives belonging to the genus *Actinocyclus* and determined as index species for Upper Miocene sediments of the Sofia and Karlovo Basins, SW Bulgaria: *A. makarovae*, *A. fungiformis*, *Actinocyclus* sp. 1 (Temniskova-Topalova & Ognjanova-Rumenova 1997).

The genus *Aulacoseira* is found across a wide geographical area throughout the Neogene, with massive development in the Miocene and Early Pliocene. All over the world the Neogene flora of *Aulacoseira* species consists of identical or similar species, including *A. granulata, A. ambigua, A. distans, A. islandica,* etc. In general the species composition of *Aulacoseira* does not differ from the above in the material from the Bitola sub-basin investigated here. In addition, *A. distans* var. *scala* an extinct variety with limited stratigraphic distribution, is present and this can used in diatom biostratigraphy as an index indicator.

Diatom biostratigraphy

All taxa (species, varieties and forms) ranking as 4–5 according to Schrader's scale, even if found in only one level in the sequence, are included in the succession diagram. Planktonic diatoms belonging to the class Centrophyceae prevail in depth. Four associations can be distinguished in the development of the diatom flora (Fig. 7) and they are demonstrated by the multivariate cluster analysis (Fig. 8).

At the beginning of the investigated succession (65.00–77.00 m) diatoms are very abundant in the deposits. The widest distribution is observed for species of *Cyclotella* and *Actinocyclus*. The deposit is marked by a significant increase in the number of specimens of *C. elymaea*, *C. iris, Cyclotella* sp. 1 (only circular forms) and *Actinocyclus makarovae*, *Actinocyclus* sp. 1. At 70.00 m *Aulacoseira ambigua* appears and develops in mass. The accompanying species from the class Pennatophyceae are species of the genus *Fragilaria*: *F. construens, F. construens* f. *venter*., *F. construens* f. *binodis*, *F. pinnata*, *F. heidenii.* Among the subdominant pennate species *Tetracyclus glans* is established with single occurrence. The mass development of *Cymbella silesiaca* in the uppermost part of this interval is also remarkable. This diatom association corresponds to cluster group A_4 in the cluster dendrogram.

Above the level of 61.00 m *C. elymaea* decreases considerably and at 45.00 m it disappears completely. Other species of the genus *Cyclotella* develop continually, but their abundance is estimated at 3–4 according to Schrader's scale with the ex-

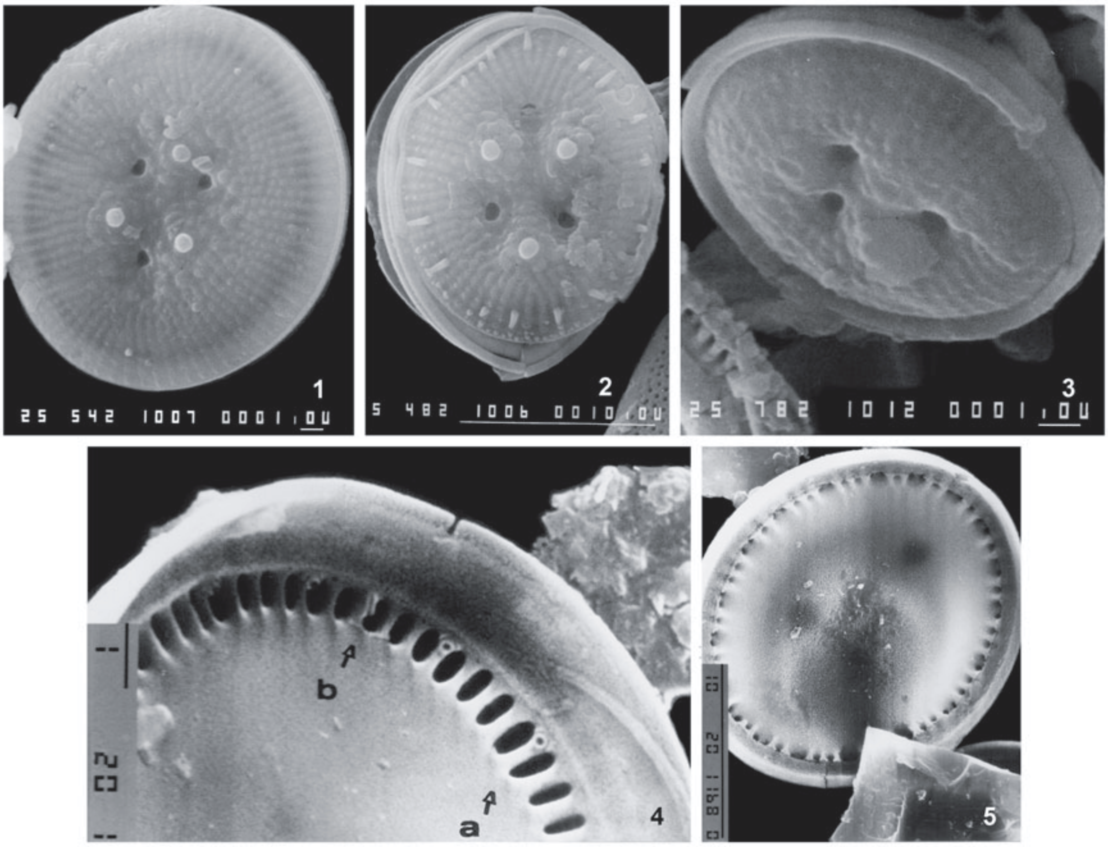

Fig. 4. 1 — *Cyclotella* sp. 1, circular morphotype, valve exterior, V-466, depth 75.00 m. **2** — *Cyclotella* sp. 1, circular morphotype, valve exterior, with spines at the end of the interstrial strips, V-466, depth 75.00 m. **3** — *Cyclotella* sp. 1, circular morphotype, valve exterior, V-466, depth 75.00 m. **4** — *Cyclotella* sp. 1, detail of the valve interior with the marginal fultoportula (with three satellite pores; a — and the single rimoportula, b — V-466, depth 65.00 m. **5** — *Cyclotella* sp. 1, valve interior, V-466, depth 70.00 m.

ception of *C. iris* and *Cyclotella* sp. 1. At 50.00 m the latter species is established in the form of the clearly elliptical morphotype. The abundance of *Aulacoseira ambigua* decreases and the species then disappears. The majority of Pennatophyceae species occur singly or are absent. This second diatom association corresponds to cluster group A_3 in the cluster dendrogram.

Between 25.00–40.00 m *Cyclotella schambica* appears and at some certain levels (25.00 m and 40.00 m) it develops in mass. More abundant are also the varieties of *C. iris*: *C. iris* var. *cocconeiformis* and *C. iris* var. *ovalis*. *C. scrobicula* described by Aleshinskaya & Pirumova (1982) from Pliocene maar sediments in Armenia also appears. The elliptical forms of *Cyclotella* sp. 1 prevail over the circular ones only in the uppermost part of the interval (25.00 m). The frequency of species of *Actinocyclus* decreases considerably. During this interval the abundance of *Aulacoseira ambigua* increases again. This diatom association corresponds to the cluster group A_2 in the cluster dendrogram.

After this interval, the abundance of *Cyclotella* sp. 1 and *C. iris* decreases, but *C. castracanei* becomes dominant (ranking as 5 according to Schrader's scale). The species diversity of the diatom flora decreases and more of the subdominant taxa belonging to the genus *Actinocyclus* disappear. This fourth diatom association corresponds to cluster group A_1 in the cluster dendrogram.

Comparison with diatom biostratigraphic zones in South Bulgaria (Sofia and Karlovo Basins), where the paleolimnological conditions are similar to those in the Bitola sub-basin and the type of the diatom flora is also "*Actinocyclus*" (Temniskova-Topalova & Ognjanova-Rumenova 1997; Ognjanova-Rumenova 2001) shows that the beginning of the Pliocene is characterized by the disappearance of the fossil species of the genus *Actinocyclus.* The extinction of the Miocene *Actinocyclus* species and the appearance of *Cyclotella castracanei,* developing in mass in the upper part of the borehole V-466 indicate that the Miocene-Pliocene boundary probably lies in the uppermost level of the investigated profile (15.00–20.00 m).

Ecological analysis of diatom flora

Of the defined 127 species, varieties and forms of diatoms identified, 93 (72.7 %) have a known ecology. Analysis of the ecological spectra (Fig. 9) shows the following:

Periphytic (epiphytic) diatoms predominate (58.8 %) in almost all diatom thanatocoenoses, followed by periphytic (benthic deep water form) — 29.4 % and planktonic elements (11.8 %). The planktonic representatives have a higher abun-

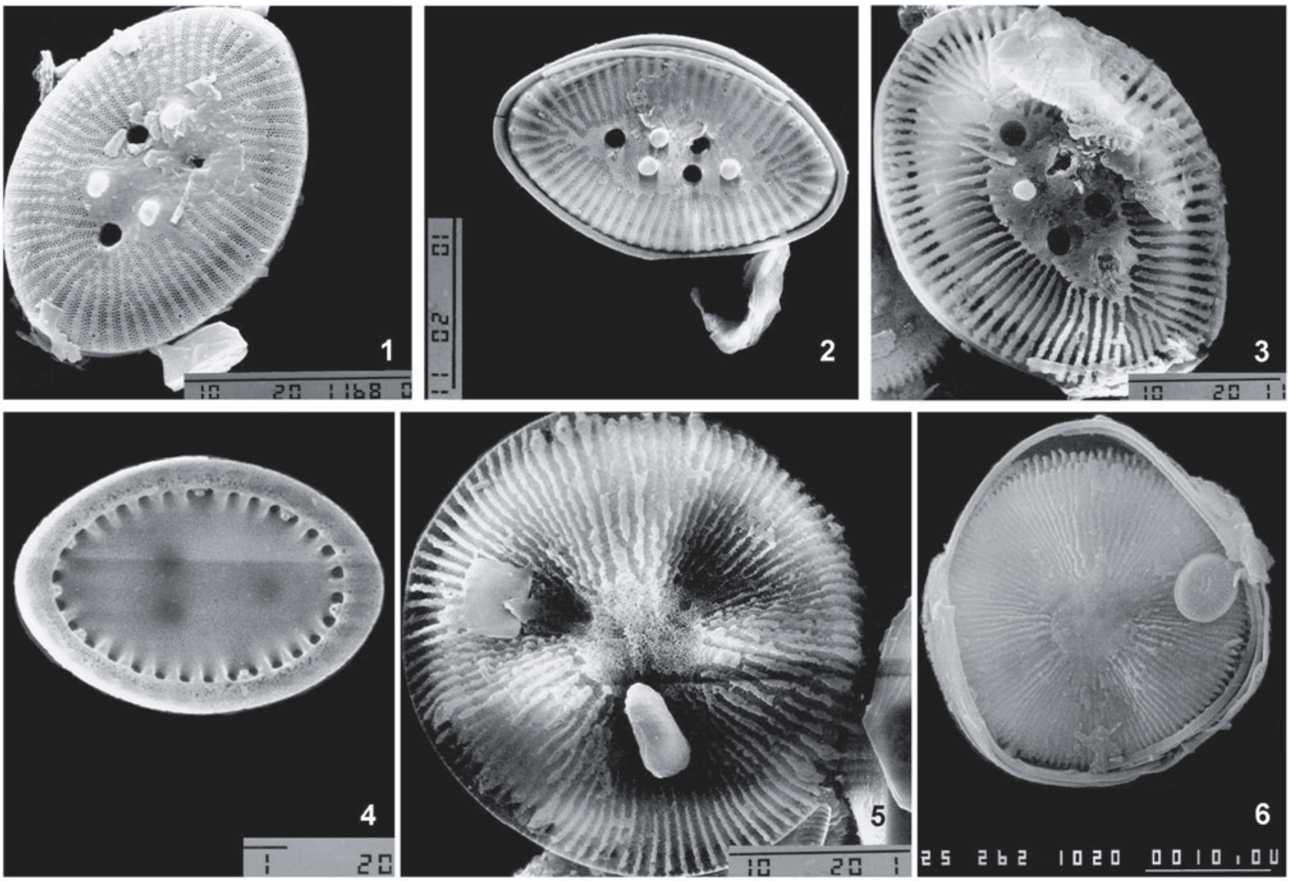

Fig. 5. **1** — *Cyclotella* sp. 1, elliptical morphotype, valve exterior, V-466, depth 70.00 m. **2, 3** — *Cyclotella* sp. 1, elliptical morphotype, valve exterior, V-466, depth 25.00 m. **4** — *Cyclotella* sp. 1, elliptical morphotype, valve interior, V-466, depth 70.00 m. **5** — *Cyclotella castracanei* Eulenst., valve exterior, V-466, depth 20.00 m. **6** — *C. castracanei* Eulenst., valve exterior with a small frustule of *Cyclotella scrobicula* Alesch. et Pirum. on the valve face, V-466, depth 20.00 m.

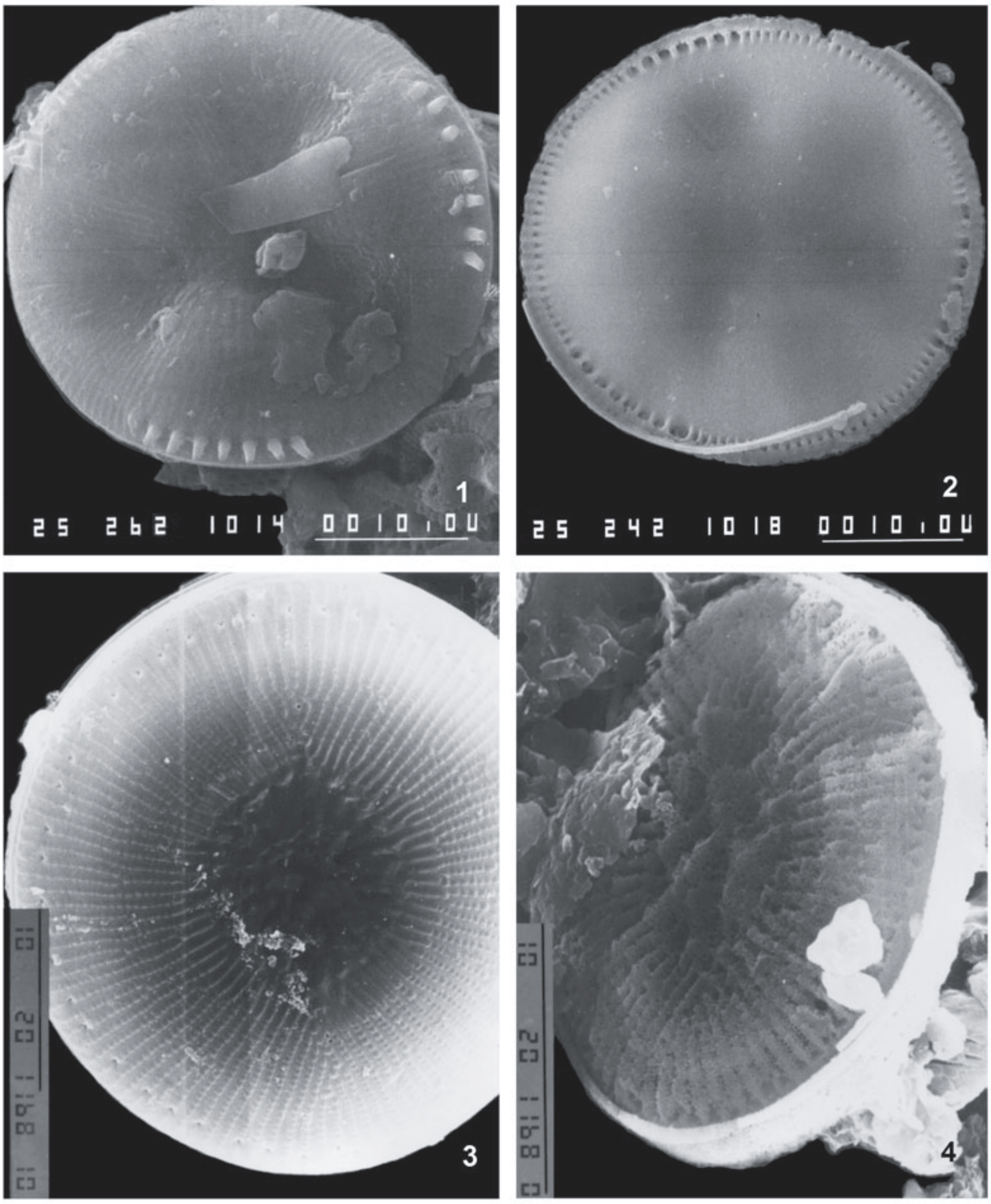

Fig. 6. **1** — *Cyclotella castracanei* Eulenst., valve exterior with spines in the marginal zone, V-466, depth 20.00 m. **2** — *C. castracanei* Eulenst., valve interior with alveolar structure, V-466, depth 20.00 m. **3** — *Cyclotella elymaea* Econ.-Am., V-466, depth 70.00 m. **4** — *C. elymaea* Econ.-Am., V-466, depth 70.00 m.

dance and they compose the rock-forming complex. The ratio of planktonic to periphytic diatom (Fig. 10) shows a decline over the lowermost level (77.00–65.00 m), reflecting mainly a decline in varieties of the infraspecific group of *Cyclotella iris*. Above this level and up to 50.00 m the ratio increases as the plankton component, particularly *Aulacoseira ambigua*, increases. A greater variability in valve form of *Cyclotella* sp. 1 appears at the top of the stratigraphic column (20.00–30.00 m). The distinct dominance of periphyton shows that these diatom sediments most probably represent a shallow-water facies.

The diatoms represent a fresh-water flora. Besides oligohalobous (halophobous and indifferent) diatoms, a small percentage of halophilous (3.4 %), mesohalobous (3.4 %) and marine (2.3 %) forms occur. Their quantitative proportion in the communities varies in a vertical direction (Fig. 10). A relatively weak salinity increase is observed in the interval between 77.00–61.00 m, but above this level the percentage of halophilous and mesohalobous diatoms decreases and finally they disappear. A peak in marine, mesohalobous and halophilous species occurrence appears again at 33.94 m and this coincides with a high abundance of the elliptical form of *Cyclotella* sp. 1. This increased infraspecific variability could be caused by salinity changes, which are directly controlled by the hydrological and hydrochemical regimes of the basin.

Grouping of diatoms according to their pH-preferences shows that alkaliphilous (52.3 %) and pH-indifferent (29.5 %) diatoms clearly predominate. In the levels of lower mineraliza-

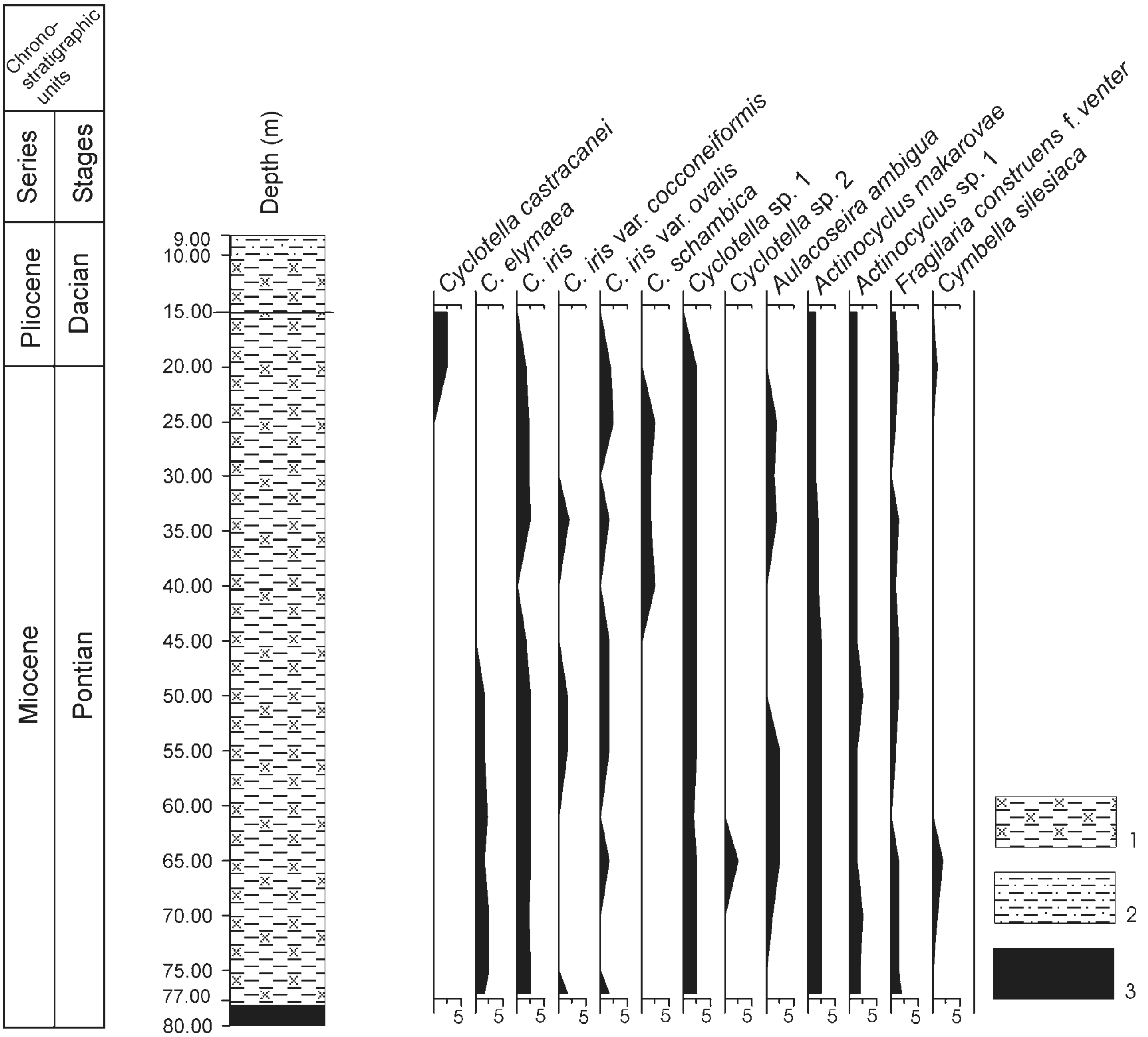

Fig. 7. Diatom diagram from borehole V-466, Bitola. **1** — diatomaceous clays, **2** — sandy clays, **3** — coal deposits.

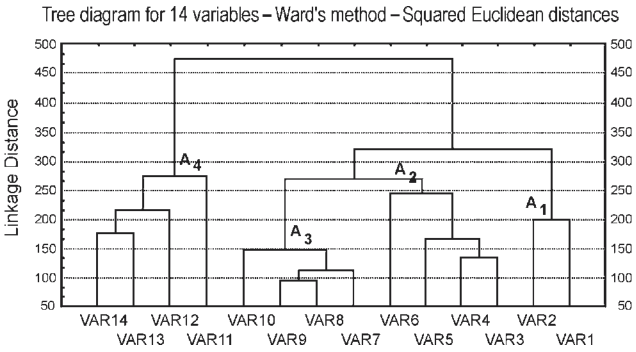

Fig. 8. Samples clustering, including all investigated samples from borehole V-466. Var1 (15.00 m), Var2 (20.00 m), Var3 (25.00 m), Var4 (30.00 m), Var5 (33.94 m), Var6 (40.00 m), Var7 (45.00 m), Var8 (50.00 m), Var9 (55.00 m), Var10 (61.00 m), Var11 (65.00 m), Var12 (70.00 m), Var13 (75.00 m), Var14 (77.00 m).

tion (40.00 m) the number of indifferent diatoms increases (Fig. 10). Some acidophilous diatoms like *Tetracyclus glans*, *Navicula kotschii*, *Eunotia minor*, *E. pectinalis* etc., appear together with pH-indifferent species, but their percentages in depth are always below 10 %.

As regards geographical distribution the cosmopolitan group (69.3 %) is predominant, followed by boreal (18.2 %) and north-alpine species (10.2 %). Tropical species, that is *Cyclotella iris* var. *charetonii* and *Melosira undulata,* constitute 2.3 % of the assemblage.

Results of the relative proportions of diatom frustules/chrysophycean stomatocystae

Where lacustrine conditions are concerned, chrysophytes can provide additional and complementary information to that

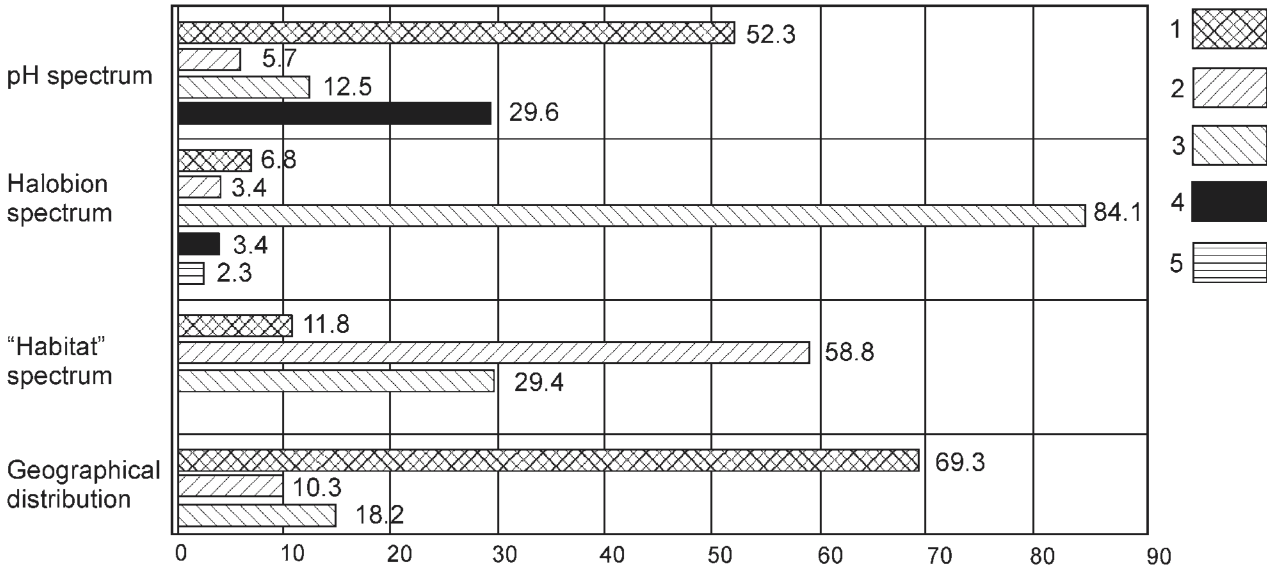

Fig. 9. Histograms — Percentage ratio of the ecological diatom groups. **pH spectrum:** 1 — alkaliphilic, 2 — acidophilic, 3 — alkalibiontic, 4 — indifferent. **Halobion spectrum:** 1 — halophobous, 2 — halophilous, 3 — indifferent, 4 — mesohalobous, 5 — marine. **"Habitat" spectrum:** 1 — planktonic, 2 — periphytic (epiphytic), 3 — periphytic (deep water form). **Geographical distribution:** 1 — cosmopolitans, 2 — north-alpine forms, 3 — boreal forms.

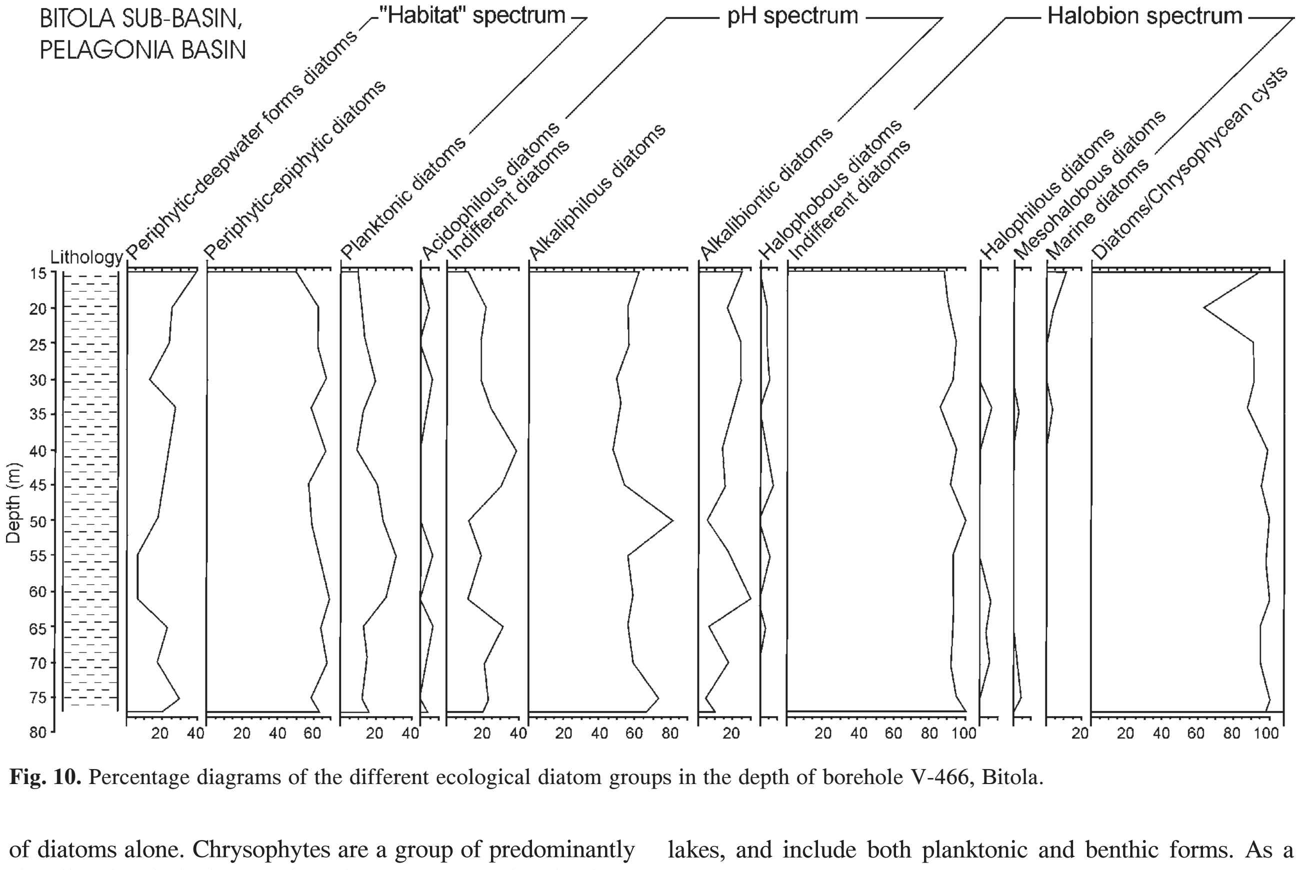

Fig. 10. Percentage diagrams of the different ecological diatom groups in the depth of borehole V-466, Bitola.

of diatoms alone. Chrysophytes are a group of predominantly flagellated and planktonic algae that occur most abundantly in circumneutral pH, low-alkalinity, low-phosphorus, low-productivity lakes. A characteristic feature of this algal group is the production of endogenously formed siliceous resting cysts or statospores, which are well-preserved in many continental sediments. Diatoms, however, also occur in more eutrophic lakes, and include both planktonic and benthic forms. As a group, cysts have been analysed in relation to diatoms (Smol 1985): the ratio of cysts to diatoms has been proposed as a trophic indicator in the succession.

Tracing the ratio of diatom frustules/chrysophycean stomatocysts we observed two peaks in the development of the latter (Fig. 10). The lower part of the profile (77.00–40.00 m) is characterized by a relatively lower abundance of chrysophytes. At the beginning of this stage, the plankton contains a low concentration of eutrophic indicators, but these decrease rapidly with the growth of large populations of *Cyclotella* spp. If the genus is accepted as an indicator of oligotrophic conditions, this would indicate that the trophic level of the pelagic zone had decreased. Chrysophyte abundances generally increase from 33.94 m to 20.00 m and then decrease dramatically to level at 15.00 m. At the top of the core, the eutrophic indicators appear to decrease again in both the periphyton and the plankton components.

Conclusions

— This paper presents the first biostratigraphic study of the Late Miocene–Pliocene lacustrine diatom flora from the Macedonian part of the Pelagonia Basin. The lower part of the Pliocene is marked by the extinction of Miocene *Actinocyclus* species and the first appearance of *Cyclotella castracanei* developing in mass in the uppermost part of the sequence.

— A diverse taxonomical composition is reported for the genus *Cyclotella*. Similar species of the genus have been identified from lacustrine deposits throughout Southern Europe. The *Cyclotella* sp. 1 present in the studied material has a high infraspecific variability as regards the valve outline, which might be explained by the variable ecological conditions in the paleolake during the sediment deposition.

— There is a concurrence of all representatives belonging to the genus *Actinocyclus* and determined as index species for Upper Miocene sediments of the Sofia and Karlovo Basins, SW Bulgaria: *A. makarovae*, *Actinocyclus fungiformis*, *Actinocyclus* sp. 1.

— The results of the diatom analyses presented here allow a reconstruction of the paleoecological conditions of the Bitola sub-basin, Pelagonia Basin, at the end of the Miocene and the beginning of the Pliocene.

Acknowledgments: This study was financially supported by the Bulgarian Ministry of Science and Education under Grant NZ 903/1999 and it is a contribution to the Project IGCP 449: "Global correlation of Late Cenozoic fluvial deposits". I am thankful to Dr. N. Krstić for the borrowed unpublished report including the geological section of borehole V-466 and to Dr. D. Mihajlovic for providing the samples and for helpful discussions.

Appendix

List of the diatom taxa found in the sediment sequence of borehole V-466, Bitola.

Division: Bacillariophyta
Class: Centrophyceae
Order: **Thalassiosirales**
Family: Thalassiosiraceae Lebour emended Hasle
  Thalassiosira sp.
Family: Stephanodiscaceae Makarova
  Cyclotella *castracanei* Eulenstein, 1868
  C. elymaea Economou-Amilli, 1991
  C. iris Brun et Héribaud, 1893
  C. iris var. *charetonii* (Héribaud) Serieyssol, 1982
  C. iris var. *cocconeiformis* Brun et Héribaud, 1893
  C. iris var. *integra* Peragallo et Héribaud, 1893
  C. iris var. *ovalis* Brun et Héribaud, 1893
  C. schambica (Eulenstein) Aleschinskaya et Pirumova, 1981
  C. scrobicula Aleschinskaya et Pirumova, 1990
  Cyclotella sp. 1
  Cyclotella sp. 2
Order: Melosirales
Family: Melosiraceae Kützing
  Melosira *undulata* (Ehrenberg) Kützing, 1844
  M. undulata var. *normannii* Arnott, 1882
  Ellerbeckia *kochii* (Pantoscek) Valeva et Temniskova, 1993
Family: Aulacoseiraceae Moisseeva
  Aulacoseira *ambigua* (Grunow) Simonsen, 1979
  A. distans (Kützing) Simonsen, 1979
  A. distans var. *scala* (Ehrenberg) Ognjanova-Rumenova, 1998
  A. granulata (Ehrenberg) Simonsen, 1979
  A. granulata var. *angustissima* (O. Müller) Simonsen, 1979
  A. islandica (O. Müller) Simonsen, 1979
  A. valida (Grunow) Krammer, 1990
Order: Coscinodiscales
Family: Hemidiscaceae Hendey emended Simonsen
  Actinocyclus *fungiformis* Temniskova, Khursevich, Valeva, 1993
  A. gorbunovii (Sheshukova) Moisseeva et Sheshukova, 1981
  A. aff. *kutzingii* (A. Schmidt) nov. comb.
  A. makarovae (Temniskova et Ognjanova) Temniskova et Ognjanova, 1992
  Actinocyclus sp. 1
  Actinocyclus sp. 2
Class: Pennatophyceae
Order: Araphales
Family: Fragilariaceae (Kützing) De Toni
  Fragilaria *bituminosa* Pantoscek, 1889
  F. brevistriata Grunow, 1885
  F. capucina Desmazieres, 1925
  F. construens (Ehrenberg) Grunow, 1862
  F. construens f. *binodis* (Ehrenberg) Hustedt, 1957
  F. construens f. *venter* (Ehrenberg) Hustedt, 1957
  F. heidenii Østrup, 1910
  F. leptostauron (Ehrenberg) Hustedt, 1931
  F. leptostauron var. *dubia* (Grunow) Hustedt, 1931
  F. leptostauron var. *fossilis* (Pantocsek) Reháková, 1965
  F. martyi (Héribaud) Lange-Bertalot, 1993
  F. pinnata Ehrenberg, 1843
  F. pinnata var. *trigona* (Brun et Héribaud) Hustedt, 1913
  F. transylvanica Pantocsek, 1892
  F. virescens Ralfs, 1843
Family: Diatomaceae Dumortier
  Meridion *circulare* var. *constrictum* (Ralfs) Van Heurck, 1881
Family: Tabellariaceae Schutt
  Tetracyclus *emarginatus* (Ehrenberg) W. Smith, 1856
  T. glans (Ehrenberg) Mills, 1835
Order: Raphales
Family: Naviculaceae Kützing
  Navicula *anglica* var. *minuta* Cleve, 1895
  N. arenariaeformis Pantocsek, 1889
  N. arenariaeformis var. *major* Gasse, 1980
  N. capitata var. *lueneburgensis* (Grunow) Patrick et Reimer, 1966
  N. digitoradiata (Gregory) Ralfs, 1861
  N. gastrum (Ehrenberg) Kützing, 1844
  N. gastrum var. *signata* Hustedt, 1936
  N. hasta Pantocsek, 1892
  N. kotschyi Grunow, 1860
  N. laterostrata Hustedt, 1925
  N. menisculus Schumann, 1867
  N. placentula (Ehrenberg) Kützing, 1844
  N. platystoma Ehrenberg, 1838
  N. platystoma var. *pantocsekii* Wislouch et Kolbe, 1927
  N. porifera var. *opportuna* (Hustedt) Lange-Bertalot, 1985
  N. protracta (Grunow) Cleve, 1894
  N. pseudoanglica Lange-Bertalot, 1985
  N. radiosa Kützing, 1844

  - *N. scutelloides* W. Smith, 1856
  - *N. tuscula* Ehrenberg, 1841
  - *Navicula* sp. 1
  - ***Sellaphora*** *bacillum* (Ehrenberg) Mann, 1989
  - *S. pupula* var. *capitata* (Hustedt) nova comb.
  - ***Stauroneis*** *anceps* Ehrenberg, 1843
  - *S. phoenicenteron* (Nitzsch) Ehrenberg, 1843
  - *S. smithii* Grunow, 1860
  - ***Gyrosigma*** *acuminatum* (Kützing) Rabenhorst, 1853
  - ***Pinnularia*** *borealis* Ehrenberg, 1843
  - *P. esox* Ehrenberg, 1843
  - *P. viridis* (Nitzsch) Ehrenberg, 1843
  - *P. viridis* var. *leptogongyla* (Grunow) Cleve, 1895
  - ***Caloneis*** *schumanniana* (Grunow) Cleve, 1894
  - ***Diploneis*** *carpathorum* (Pantocsek) Pantocsek, 1913
  - *D. elliptica* (Kützing) Cleve, 1891
  - *D. marginestriata* Hustedt, 1922
  - *D. papula* (A. Schmidt) Cleve, 1894
  - ***Neidium*** *iridis* (Ehrenberg) Cleve, 1894
- Family: Achnathaceae Kützing
  - ***Cocconeis*** *neodiminuta* Krammer, 1991
  - *C. minimus* Loseva, 1982
  - *C. placentula* Ehrenberg, 1838
  - *C. placentula* var. *euglypta* (Ehrenberg) Grunow, 1884
  - ***Achnanthes*** *conspicua* Mayer, 1919
  - *A. delicatula* (Kützing) Grunow, 1880
  - *A. delicatula* ssp. *hauckiana* (Grunow) Lange-Bertalot, 1985
  - *A. dispar* Cleve, 1891
  - *A. lanceolata* var. *elliptica* Cleve, 1891
- Family: Eunotiaceae Kützing
  - ***Eunotia*** *minor* (Kützing) Grunow, 1881
  - *E. pectinalis* (Dillw.? Kützing) Rabenhorst, 1864
  - *Eunotia* sp.
- Family: Rhoicospheniaceae Mann
  - ***Rhoicosphenia*** *abbreviata* (Agardh) Lange-Bertalot, 1980
- Family: Cymbellaceae (Kützing) Grunow
  - ***Cymbella*** *affinis* Kützing, 1844
  - *C. cuspidata* Kützing, 1844
  - *C. ehrenbergii* Kützing, 1844
  - *C. helvetica* Kützing, 1844
  - *C. leptoceros* (Ehrenberg) Kützing, 1844
  - *C. naviculiformis* (Auerswald) Cleve, 1894
  - *C. parva* (W.Smith) Wolle, 1890
  - *C. silesiaca* Bleisch, 1864
  - *C. subcuspidata* Krammer, 1982
  - *Cymbella* sp.
  - ***Amphora*** *bornetti* Héribaud, 1903
  - *A. delphinea* var. *jamalinensis* (Cleve et Grunow) Cleve, 1895
  - *A. delphinea* var. *minor* Cleve, 1895
  - *A. libyca* Ehrenberg, 1840
  - *A. pediculus* (Kützing) Grunow, 1880
  - *Amphora* sp.
- Family: Gomphonemataceae (Kützing) Grunow
  - ***Gomphonema*** *angustatum* (Kützing) Rabenhorst, 1864
  - *G. grovei* var. *herrmanniana* (Patrik) Kociolec, Yang et Stoermer, 1988
- Family: Epithemiaceae Grunow
  - *Epithemia sorex* Kützing, 1844
  - *E. turgida* (Ehrenberg) Kützing, 1844
  - *E. turgida* var. *granulata* (Ehrenberg) Brun, 1880
  - *E. zebra* var. *porcellus* (Kützing) Grunow, 1862
  - *E. zebra* var. *saxonica* (Kützing) Grunow, 1862
- Family: Rhopalodiaceae Topatschevski
  - ***Rhopalodia*** *gibba* (Ehrenb.) O. Müller, 1895
- Family: Nitzschiaceae Grunow
  - ***Nitzschia*** *heufleriana* Grunow, 1881
  - *N. sinuata* var. *tabellaria* Grunow, 1881
  - ***Hantzschia*** *amphioxys* (Ehrenb.) Grunow, 1880
- Family: Surirellaceae Kützing
  - ***Surirella*** *bifrons* Ehrenberg, 1843
  - *S. biseriata* f. *punctata* (Meister) Krasske, 1925
  - ***Cymatopleura*** *elliptica* var. *constricta* Grunow, 1862
  - *C. solea* (Brébisson) W. Smith, 1851

References

Abbott W. & Van Landingham S. 1972: Micropaleontology of Miocene nonmarine diatoms from the Harper District, Malheur County, Oregon. *Nova Hedwigia Beih.* 23, 4, 847–907.

Aleshinskaya Z. & Pirumova L. 1982: Morphological studies of diatoms from Pliocene lacustrine deposits of Armenia. In: Menner B. & Druschiza B. (Eds.): The natural of the historical development of fossil organisms**.** *University of Moscow,* 97–109 (in Russian).

Anonymous 1975: Proposal for a standardization of diatom terminology and diagnoses. *Nova Hedwigia*, *Beih.* 53, 323–354.

Bosch H., Van Hoeve M., Steenbrink J. & Van Vugt N. 1996: Reconstruction of the depositional environment in the Late Neogene. *Stuifmail, Palaeobot. Palynol. Soc. Utrecht* 14, 1 (in Dutch).

Dermitzakis M. & Papanikolau D. 1981: Paleogeography and geodynamics in the Aegean region during Neogene. VIIth International Congress on Mediteranean Neogene, Athens 1979. *Ann. Géol. Pays Hellén.* 4, 245–289.

Dumurdzanov N. 1997: Lacustrine Neogene and Pleistocene in Macedonia. In: Mihajlovic D. & Krstić N. (Eds.): Proceed. of the Field Meetings held in Yugoslavia in 1995 and 1996 year, Beograd. *Spec. Publ. Geoinstitute* 21, 31–36.

Dumurdzanov N., Petrov G. & Tuneva V. 1997: Evolution of Lacustrine Neogene-Pleistocene in the Vardar zone in Republic of Macedonia. In: Proceedings: Magmatism, metamorphism and metallogeny of the Vardar zone and Serbo-Macedonian massif. *Stip-Dojran,* 83–88.

Economou-Amilli A. 1991: *Cyclotella elymaea*, a new fossil species from the Neogene basin of Kozani-aeani-Servia, Northern Greece. *Diatom Res.* 6, 2, 223–233.

Gersonde R. & Velitzelos E. 1977: Diatomeenpaleokologie im Neogen-Becken von Vegora N-W Mazedonien. *Ann. Géol. Pays Hellén.* 29, 373–382.

Hakansson H. 2002: A compilation and evaluation of species in the general *Stephanodiscus*, *Cyclostephanos* and *Cyclotella* with a new genus in the family Stephanodiscaceae. *Diatom Res.* 17, 1, 1–139.

Hasle G. & Fryxell G. 1970: Diatoms: Cleaning and mounting for light and electron microscopy. *Trans. Amer. Microsc. Soc.* 89, 4, 469–474.

Héribaud J. 1893: Les Diatomees d'Auvergne. *Clermont-Ferrand,* 1–255.

Kiss K., Rojo C. & Cobelez M.A. 1996: Morphological variability of a *Cyclotella ocellata* (Bacillariophyceae) population in the Lake Las Madres (Spain). *Algological Studies* 82, 37–55.

Kitanov G. 1996: Paleofloristic data about the Pliocene flora of the Republic of Macedonia. II. The fossil flora of the village of Zhivoino–Bitola region. *Fitologija* 48, 60–67.

Knobloch G. & Velitzelos E. 1986: Die Obermiozane flora von Prossilion bei Kozani (Sud-Macedonien, Griechenland). *Documenta Naturae* 29, 29–33.

Koufos G. & Pavlides S. 1986: Correlation between the continental deposits of the Lower Axios Valley and Ptolemais Basin. *Bull. Geol. Soc. Greece* 20, 2, 9–19.

Loginova L. 1989: Morphology and taxonomy of *Cyclotella castracanei* group in sensu of contemporary idea. In: Margaritis L. (Ed.): Proceed. 3th Balkan Congress on Electron Microscopy, Athens, Greece, 1989. *University of Athens,* Athens, 140–141.

Loginova L., Aleshinskaya Z. & Pirumova L. 1990: Ultrastructure and taxonomy of dominant species belonged to genus *Cyclotella* Kutz. in Upper Pliocene sediments from Armenia. In: Velichkevich F. (Ed.): New representatives of fossil fauna and flora for Byeloruss and other regions of the USSR. *Nauka i tehnika,* Minsk, 176–190 (in Russian).

Lowe R. 1975: Comparative ultrastructure of the valve of some *Cyclotella* species (Bacillariophyceae). *J. Phycology* 11, 415–424.

Mihajlovic D. & Lazarevic Z. 2004: Fossil flora from Late Neogene of Bitola area, FYR Macedonia. *Bull. Acad. Serbe Sci. Arts*, *Sci. Natur.* 42, 283–303.

Ognjanova-Rumenova N. 1991: Diatoms in Neogene sediments from the Sofia valley and their stratigraphic significance. *Ph.D. Thesis, Geol. Inst. Bulgarian Acad. Sci.* 1–305 (in Bulgarian).

Ognjanova-Rumenova N. 1996: *Cyclotella iris* Brun. & Herib. group from the Upper Miocene sediments of the Sofia basin, Bulgaria. *Geol. Carpathica* 47, 5, 301–310.

Ognjanova-Rumenova N. 2000: Lacustrine diatom flora from Neogene basins on the Balkan Peninsula: preliminary biostratigraphical data. In: Witkowski A. & Sieminska J. (Eds.): The origin and early evolution of diatoms: fossil, molecular and biostratigraphical approaches. *W. Szafer Institute of Botany PAS,* Krakow, 137–143.

Ognjanova-Rumenova N. 2001: Neogene diatom assemblages from lacustrine sediments of F.Y.R.O.M. (Macedonia) and their distribution in correlative formations of south-western Bulgaria. In: Economou-Amilli A. (Ed.): Proceed. 6th Intern. Diatom Symposium, Athens & Aegean Islands, 2000. *University of Athens,* Athens, 423–432.

Riegel W., Kaouras G. & Velitzelos E. 1993: Ecological aspects of coal formation in Neogene basins in Greece. *Ann. Géol. Pays Hellén.* 36, 649–661.

Ross R., Cox E., Karayeva N., Mann D., Paddock T., Simonsen R. & Sims P. 1979: An amended terminology for the siliceous component of the diatom cell. *Nova Hedwigia*, *Beih.* 64, 513–533.

Schrader H-J. 1973: Proposal for a standardized method of cleaning diatom-bearing deep sea and land-exposed marine sediments. *Nova Hedwigia*, *Beih.* 45, 403–409.

Serieyssol K. 1981: *Cyclotella* species of Late Miocene age from St. Bauzile, France. In: Ross R. (Ed.): *Proceed. 6th Intern. Diatom Symposium, Budapest,* 1980. 27–42.

Serieyssol K. 1984: *Cyclotella iris* Brun & Herib. In: Mann D. (Ed.): Proceed. 7th Intern. Diatom Symposium, Philadelphia, 1982. *O. Koeltz,* Koenigstein, 197–207.

Smol J. 1985: The ratio of diatom frustules to chrysophycean statospores: a useful paleolimnological index. *Hydrobiologia* 123, 2, 199–204.

Temniskova-Topalova D. & Ognjanova-Rumenova N. 1997: Description, comparison and biostratigraphy of the nonmarine Neogene diatom floras from Southern Bulgaria. *Geol. Balcanica* 27, 1–2, 57–81.

Van de Weerd A. 1979: Pliocene rodents and lagomorphs (Mammalia) from the lignites near Ptolemais (Macedonia, Greece). *Proc. K. Nederl. Akad. Wet.* Ser. B, 82, 127–170.

Van de Weerd A. 1983: Palynology of some Upper Miocene and Pliocene Formations in Greece. *Geol. Jb.*, Reihe B, 48, 3–63.

Velitzelos E. & Gregor H.-J. 1986: Geologische data zu den fossilfuhrenden Fundstellen Lava, Prossilion und Licudi (Griechenland) nebst Bemerkung zu den Frucht- und Samenfloren. *Doc. Nature.* 29, 34–40.

Velitzelos E. & Gregor H.-J. 1990: Some aspects of the Neogene floral history in Greece. *Rev. Palaeobot. Palynol.* 62, 291–307.

Velitzelos E. & Kvaček Z. 1999: Review of the Late Miocene flora of Vegora, Western Macedonia, Greece. *Acta Palaeob.*, *Suppl. 2 – Proceed. 5th EPPC,* 419–427.