

# DIATOM ANALYSIS ON NEOGENE SEDIMENTS FROM THE ELHOVO BASIN IN SOUTH BULGARIA



Project No. 329

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(Manuscript received April 4, 1995; accepted in revised form December 14, 1995)

**Abstract:** The diatom flora from Neogene nonmarine sediments from the Elhovo Basin, in South Bulgaria, was studied. There was prepared a paleoecological analysis and a comparison between that diatom flora and other Neogene nonmarine floras.

**Key words:** Neogene, Bulgaria, diatoms, nonmarine.

## Introduction

The continental Neogene basins in the South Bulgaria are depressions (grabens) fulfilled with massive alluvial, proalluvial and rarely marsh-lake sediments. Most of them were formed as a result of different movements.

Diatom floras from the Goce Delchev, Sofia, Palakaria and Karlovo basins were examined (Ognjanova-Rumenova 1991; Temniskova-Topalova & Ognjanova-Rumenova 1979, 1983, 1984, 1990, 1992, 1993; Temniskova-Topalova et al. 1987, 1990a,b, 1993, 1994; Valeva & Temniskova-Topalova 1993, 1994).

The presented paper is the first study of the diatom flora from the Elhovo Basin sediments. We would like to devote it to the sacred memory of the outstanding Bulgarian geologist E. Kojumdjieva, with deep feelings of gratitude for his advice and committed specimens.

## Geological characterization of the Elhovo Basin

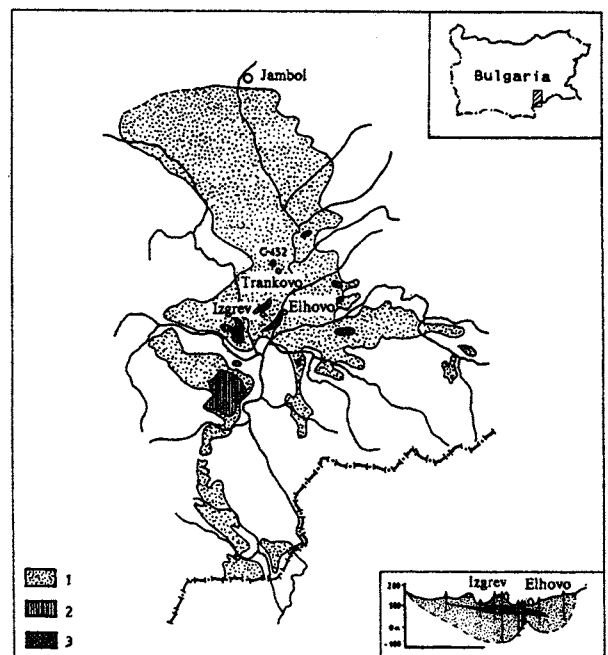
At the end of the Sarmatian, as a result of movements in faults and extensions the Elhovo Basin was formed (Fig. 1). Kojumdjieva et al. (1984) grouped the Neogene sediments in the basin into the following lithostratigraphic units: one single formation — the Elhovo Formation with two members: the Izgrev Member and the Duganovo Member; and an undivided part. The Formation comprised from irregular alternations of gray and green aleurites, sandy clays and sands. In some places there are conglomerates. Within these rocks a large lense of gray and black clays, diatomite clays and lignite coal occur. This is named Izgrev Member. The uppermost parts of the Elhovo Formation are in places segmented by infiltrated limestones and are distinguished as the Duganovo Member.

The thickness of the Elhovo Formation is up to 300 m, but normally it is not more than 150-200 m. It was formed in the interval Meotian-Pliocene (Kojumdjieva et al. 1984), and its uppermost part during the Pontian-Pliocene. The probable

age of the Izgrev Member is Pontian (Early Pontian). The age is determined on the vertebrate faunas (Bakalov & Nikolov 1962). The Elhovo Formation is overlain only by Quaternary materials.

## Materials and methods

The studied sediments are from the drillcore C-432, near the village of Trankovo, district Elhovo. They belong to the



**Fig. 1.** Geological map of the Elhovo Basin (by Kojumdjieva et al. 1984). 1 — Elhovo Formation; 2 — Duganovo Member of the Elhovo Formation; 3 — Izgrev Member of the Elhovo Formation.

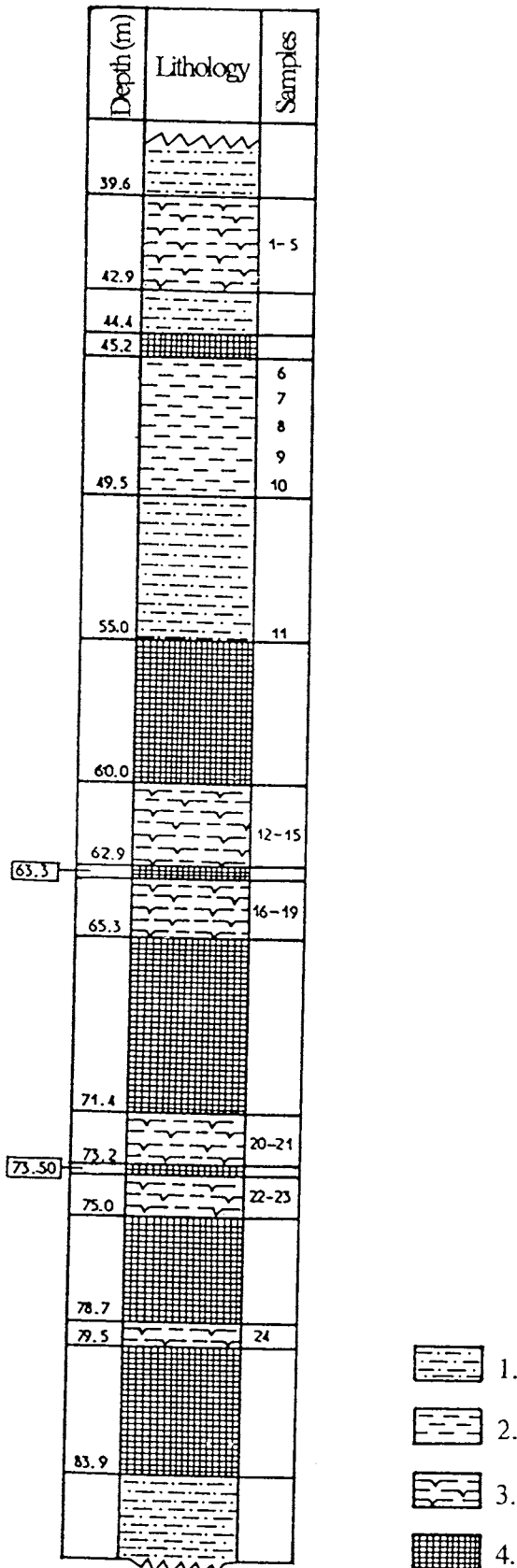


Fig. 2. Lithological column of the drill-core C-432, the village of Trankovo, Elhovo district. 1 — Green sandy clays; 2 — Pure grey clays; 3 — Diatomite clays; 4 — Coals.

Izrev Member, Elhovo Formation. The lithological successions were described by Kojumdjieva (unpubl. data) (Fig. 2).

The laboratory methods of Glezer et al. (1974) were followed.

The samples for SEM were prepared by the method of Hasle & Fryxell (1970). The specimens were examined with a SEM Joel-35.

The quantity of the diatom taxa was based on the relative scale of Schrader (1973). The absolute abundance of the diatom taxa per g/sediment was determined by the method of Jousé et al. (1969).

The Binary proportional coefficient (b. pr. c.) of Dice (1945) modified by Kojumdjieva and the multivariate statistical methods were used for diatom succession determination in the biostratigraphic analysis and for comparison and correlation of the diatom flora. Minimum variance clustering (Ward's method) based on squared Euclidean distance was used (Anderberg 1973). The Euclidian distance was the most adequate one to measure the distance between two observations (i and j)

$$d_{ij}^2 = \sum_{i=1}^p (x_{ik} - x_{jk})^2, \text{ where}$$

$x_{ik}$  — is the value of the variable k for the observation i,

$x_{jk}$  — is the value of the variable k for the observation j,

p — the number of the variables.

For the cluster analysis of samples, observation means sample and variable means species; for the cluster analysis of species, observation means species and variable means sample. Value is the abundance of a given species in a particular sample. All computations were performed using SPSS/PC + (1986).

The results of the cluster analysis of samples and species are presented on a combined diagram. The data matrix (relative quantity of each diatom species for every sample) is displayed between the two dendrograms.

The taxonomic structure of the diatom flora is characterized by the following indices: species number in a family, genera number in a family and species number in a genus.

The taxonomic diversity is shown by the indexes: middle number species in a family (S/F), middle number species in a genera (S/G), and middle number genera in a family (G/F). These indices represent simple relations for the characters of the floristic abundance.

For every diatom species and variety with known ecology, ecological spectra were prepared by VanLandingham (1967) and Abott & VanLandingham (1972). The ecological spectra are: Halobian; pH spectrum; "Current" spectrum; "Habitat" spectrum and nutrient spectrum.

### Species composition, taxonomic structure and analysis of the diatom flora

The diatom flora from the Elhovo Basin consists of 97 species, varieties and forms of diatom, belonging to 20 genera (Tables 1 and 2). They are referred to 11 families, 3 orders and 2 classes. There are 4 species with most likely species belonging (aff.). The middle number species in the family (S/F) is 7.0, the middle number genera in family (G/F) — 1.8, and the middle number species in genus (S/G) — 3.8.

The species diversity in the studied flora is due to the class *Pennatophyceae*, which represents 87.6 % of its composition (85 species, varieties and forms). From the araphid diatoms

**Table 1:** Taxonomic structure of the Pontian diatom flora from Elhovo Basin.

Order	Family	Genus	Sp.	Var.	F.
Aulacosirales	Aulacosiraceae	Aulacoseira	8	3	1
Araphales	Fragilariaceae	Fragilaria	12	3	1
Raphales	Naviculaceae	Navicula	10	2	-
		Anomooneis	2	-	1
		Stauroneis	2	-	-
		Pinnularia	5	2	1
		Caloneis	1	-	-
		Neidium	2	-	-
		Mastogloia	1	-	-
	Achnantheaceae	Cocconeis	1	-	-
		Achnanthes	3	-	-
	Eunotiaceae	Eunotia	4	1	-
	Cymbellaceae	Cymbella	9	-	-
		Amphora	4	1	-
	Gomphonemataceae	Gomphonema	2	4	-
	Epithemiaceae	Epithemia	2	-	-
	Rhopalodiaceae	Rhopalodia	1	-	-
	Nitzschiaceae	Nitzschia	5	-	-
		Hantzschia	2	-	-
	Surirellaceae	Surirella	1	-	-
3	11	20	77	16	4

the most abundant is the genus *Fragilaria*, while from the raphid diatoms (order *Raphales*) 18 species were determined.

The class *Centrophyceae* is represented only by the genus *Aulacoseira* (12.4 %). The dominant and subdominant species that are represented massively on almost all levels (with quantity abundance 4–5) belong to it.

The genus *Fragilaria* has the most large species diversity (16.5 %), followed by *Aulacoseira* and *Navicula* (with 12.4 %), *Cymbella* (9.3 %), *Pinnularia* (8.2 %), *Gomphonema* (6.2 %), *Eunotia*, *Amphora* and *Nitzschia* (with 5.2 %). The genera *Caloneis*, *Mastogloia*, *Cocconeis*, *Rhopalodia* and *Surirella* (1.0 %).

The Elhovo diatom flora is formed almost entirely from recent species (87.1 %). The fossil species were 12.9 %, but in their quantity abundance they have considerable superiority. They are mainly dominants and subdominants. In the fossil flora the species, which appeared during the Miocene (61.3 %) predominate, they are followed by Pliocene (8.6 %) and Pleistocene (9.7 %) species. From the Paleogene there are 8.5 %, from Eocene (1.0 %) — *Aulacoseira italica*, and from Oligocene (7.5 %) — *Fragilaria brevestriata*, *F. construens* with *F. venter*, *F. ulna*, *Achnanthes conspicua*, *Cymbella silesiaca* and *C. affinis*, and they have too wide geographic distribution and today.

All the fossil species have a stratigraphic range: Miocene (*Gomphonema intricatum* var. *fossilis* etc.), Middle Miocene–Pliocene (*Fragilaria bituminosa*, etc.), Late Miocene–Early Pliocene (*Cocconeis dubravicensis*), Late Miocene–Late Pliocene (*Pinnularia major* var. *andesitica* f. *interrupta*) or with wider range — Miocene–Pleistocene (*Pinnularia nobilis* var. *neogena* etc.) (Pantocsek 1886–1905; Řeháková 1980). Other species are known only from recent floras (8.6 %).

The relict species *Pinnularia scythica* is a rare, thermophilic species, known as a recent species for India (Gandhi 1960) and as a fossil — for nonmarine Neogene sediments from Slovakia and South Bohemia (Pantocsek 1886–1905; Řeháková 1965). South Bulgaria is the third fossil deposit for *Pinnularia scythica*.

### Consequence in the diatom evolution and their quantity representation

Directly in overcoaling levels (75.00 m) was established monotonous, poor on *Aulacoseira* species, diatom flora. It consists of heavily silicified frustules from *Aulacoseira granulata* and *A. islandica* (they belong to the "prae" group), which are dominants (with quantity abundance 5). They occur together with the frequently included *Aulacoseira lirata* and single representatives from *A. islandica* f. *curvata*, *A. italica* and *Aulacoseira* sp. Frequently the epiphytic species *Fragilaria construens* with f. *venter*, *F. lapponica* could also be seen and singly: *Fragilaria istvanfii*, *Cymbella cymbiformis*, *C. silesiaca* and *Hantzschia spectabilis*, and the Miocene species *F. nitida*.

After that comes a clearly differentiated, rich and variable association in the interval 60.00–74.00 m. This is the association of *Aulacoseira muzzanensis*, from 74.00 m it is presented frequently to very frequently (quantity abundance 3–4). After 60.00 m it disappears (Fig. 5). The transit dominants *Aulacoseira granulata*, *A. islandica*, *A. italica* and *A. lirata* continue to develop. They were found in almost all parts of the section with quantity from single to massive, and *Hantzschia spectabilis*. The *Fragilaria* species are enriched with the appearance of *F. brevestriata*, *F. heidenii* and the characteristic Miocene species *F. bituminosa*, which can be found on different levels singly, frequently and very frequently (2–3–4). *Eunotia pectinalis* with var. *minor*, *Navicula lundstroemii*, *N. contenta*, *Pinnularia esox*, *P. scythica* (almost evenly distributed through all levels), *Anomooneis sphaerophora* var. *sculpta*, *Cymbella aspera*, *C. cymbiformis*, *C. ehrenbergii*, *C. lanceolata*, *C. leptoceros*, *C. silesiaca*, *Gomphonema intricatum* var. *pumilla*, *G. parvulum* var. *micropus*, *Epithemia sorex*, species *Nitzschia*, *Achnanthes*, *Amphora* developed.

It is necessary to note the appearance and development through this interval of the characteristic Miocene species: *Navicula halionata* with var. *directa*, *N. jimboi* (only at 73.00 m), *Pinnularia major* var. *andesitica* f. *interrupta*, *Gomphonema intricatum* var. *fossilis* and Late Miocene–Early Pliocene species *Cocconeis dubravicensis* (only at 64.50 m).

The subdominants are 1–2 to 5 % of the diatom flora composition.

After that interval are observed the changes in the diatom flora composition (54.00 m). *Aulacoseira muzzanensis* disappeared. *Pinnularia scythica*, *Aulacoseira ambigua* and *A. italica* are frequently to massively developed. *Pinnularia esox* is encountered very frequently. *Aulacoseira granulata* is still a dominant, and the quantity of *A. islandica* decreases. The fossil variety *Pinnularia nobilis* var. *neogena* appeared. *Pinnularia braunii*, *Fragilaria ulna* var. *spathulifera*, *Achnanthes hungarica*, *Stauroneis gracilis*, *Neidium affine* were only represented here. The development continues with *Fragilaria construens*, *F. construens* f. *venter*, *F. nitida*, *F. parasitica*, *Eunotia pectinalis*, *E. pectinalis* var. *minor*, *E. exigua*, *Navicula cuspidata*, *N. lundstroemii*, most species of *Cymbella*, *Gomphonema*, *Hantzschia*, the fossil species *Pinnularia major* var. *andesitica* f. *interrupta*, *Gomphonema intricatum* var. *fossilis* etc.

In the interval 46.00–49.50 m the dominance of *Aulacoseira granulata* and *A. islandica* continue, but together with them as a dominant (with quantity 5) the recent thermophilic, tropical variety *Aulacoseira agassizii* var. *malayensis* also de-

**Table 2:** Taxonomic composition of the diatom flora from the Elhovo Basin.

1. *Aulacoseira agassizii* var. *malayensis* (Hust.) Simonsen 1979.
2. *Aulacoseira ambigua* (Grun.) Simonsen 1979.
3. *Aulacoseira muzzanensis* (Meister) Krammer 1991.
4. *Aulacoseira italica* (Ehr.) Simonsen 1979.
5. *Aulacoseira italica* var. *tennuissima* (Grun.) Simonsen 1979.
6. *Aulacoseira lirata* (Ehr.) Ross 1986
7. *Aulacoseira italica* var. *valida* (Grun.) Simonsen 1979.
8. *Aulacoseira lacustris* (Grun.) Krammer 1990.
9. *Aulacoseira granulata* (Ehr.) Simonsen 1979.
10. *Aulacoseira islandica* (O. Müll.) Simonsen 1979.
11. *Aulacoseira islandica* f. *curvata* (O. Müll.) Valeva & Temniskova 1993
12. *Aulacoseira* sp.
13. *Fragilaria bituminosa* Pantocsek 1889.
14. *Fragilaria brevistriata* Grunow in Van Heurck 1885.
15. *Fragilaria capucina* Desmazieres 1825.
16. *Fragilaria capucina* var. *vaucheriae* (Kütz.) Lange-Bertalot 1980.
17. *Fragilaria construens* (Ehr.) Grunow 1862.
18. *Fragilaria construens* f. *venter* (Ehr.) Hustedt 1953.
19. *Fragilaria heidenii* Oestrup 1910.
20. *Fragilaria istvanffyi* Pantocsek 1902.
21. *Fragilaria lapponica* Grunow in Van Heurck 1881.
22. *Fragilaria leptostauron* (Ehr.) Hustedt 1931.
23. *Fragilaria nitida* Héribaud 1903.
24. *Fragilaria parasitica* (W. Sm.) Grunow 1881.
25. *Fragilaria ulna* (Nitzsch.) Lange-Bertalot 1980.
26. *Fragilaria ulna* var. *amphirhynchus* (Ehr.) comb. nova
27. *Fragilaria ulna* f. *biceps* (Kütz.) Lange-Bertalot 1991
28. *Fragilaria ulna* var. *spathulifera* (Grun.) comb. nova
29. *Navicula abiskoensis* Hustedt 1942.
30. *Navicula amphibola* Cleve 1891.
31. *Navicula contenta* Grunow in Van Heurck 1885.
32. *Navicula cuspidata* (Kütz.) Kützing 1844.
33. *Navicula gastrum* (Ehr.) Kützing, 1844.
34. *Navicula gastrum* var. *signata* Hustedt in Schmidt et al. 1936.
35. *Navicula gothlandica* Grunow in Van Heurck 1880.
36. *Navicula cari* Ehrenberg 1836.
37. *Navicula halionata* Pantocsek, 1886.
38. *Navicula halionata* var. *directa* Pantocsek, 1889.
39. *Navicula jimboi* Pantocsek, 1892.
40. *Navicula lundstroemii* Cleve in Cleve et Grunow, 1880.
41. *Anomoeoneis sphaerophora* (Kütz.) Pfitzer 1871.
42. *Anomoeoneis sphaerophora* f. *sculpta* (Ehr.) Krammer 1985.
43. *Anomoeoneis vitrea* (Grun.) Ross 1966.
44. *Stauroneis gracilis* Ehrenberg 1841.
45. *Stauroneis phoenicenteron* (Nitzsch) Ehrenberg 1841.
46. *Pinnularia braunii* (Grun.) Cleve 1895.
47. *Pinnularia esox* Ehrenberg 1841.
48. *Pinnularia legumen* (Ehr.) Ehrenberg 1843.
49. *Pinnularia major* var. *andesitica* (Pant.) Pant. f. *interrupta* Řeháková 1980.
50. *Pinnularia nobilis* var. *neogena* (Grun.) Cleve 1895
51. *Pinnularia pulchra* Ostrup var. *angusta* (Cl.) Krammer 1984.
52. *Pinnularia scythica* (Pant.) Gandhi 1960.
53. *Pinnularia viridis* (Nitzsch) Ehrenberg 1843.
54. *Caloneis botnica* Cleve 1894.
55. *Neidium affine* (Ehr.) Pfitzer 1871.
56. *Neidium iridis* (Ehr.) Cleve 1894.
57. *Mastogloia elliptica* (Ag.) Cleve 1893.
58. *Cocconeis dubravicensis* Pantocsek 1892.
59. *Achnanthes conspicua* Mayer 1919.
60. *Achnanthes hungarica* Grunow in Cleve & Grunow 1880.
61. *Achnanthes laterostrata* Hustedt 1933.
62. *Eunotia exigua* (Bréb. ex Kütz.) Rabenhorst 1864.
63. *Eunotia nodulosa* Meister 1932.
64. *Eunotia pectinalis* (Dillw., Kütz.) Rabenhorst 1864.
65. *Eunotia pectinalis* var. *minor* (Kütz.) Rabenhorst 1864.
66. *Eunotia* sp.
67. *Cymbella affinis* Kützing 1844.
68. *Cymbella aspera* (Ehr.) Cleve 1894.
69. *Cymbella cistula* (Ehr.) Kirchner 1878.
70. *Cymbella cymbiformis* Agardh 1830.
71. *Cymbella ehrenbergii* Kützing 1844.
72. *Cymbella helvetica* Kützing 1844.
73. *Cymbella lanceolata* (Ehr.) Kirchner 1878.
74. *Cymbella leptoceros* (Ehr.) Kützing 1844.
75. *Cymbella silesiaca* Blisch in Rabenhorst 1864.
76. *Amphora coffeaeformis* (Ag.) Kützing 1844.
77. *Amphora coffeaeformis* var. *protracta* (Pant.) Cleve 1895.
78. *Amphora holsatica* Hustedt 1930.
79. *Amphora proteus* Gregory 1857.
80. *Amphora* sp.
81. *Gomphonema gracile* Ehrenberg 1838.
82. *Gomphonema intricatum* Kützing 1844.
83. *Gomphonema intricatum* var. *dichotomum* (Kütz.) Grunow 1880.
84. *Gomphonema intricatum* var. *fossilis* Pantocsek 1889.
85. *Gomphonema intricatum* var. *pumilum* Grunow in Van Heurck 1880.
86. *Gomphonema parvulum* (Kütz.) Grun. var. *micropus* (Kütz.) Cleve 1894.
87. *Epithemia argus* (Ehr.) Kützing 1844.
88. *Epithemia sorex* Kützing 1844.
89. *Rhopalodia gibba* (Ehr.) O. Müller 1895.
90. *Nitzschia dubia* W. Smith 1853.
91. *Nitzschia palea* (Kütz.) W. Smith 1853.
92. *Nitzschia recta* Hantzsch in Cleve & Grunow 1880.
93. *Nitzschia scalaris* (Ehr.) W. Smith 1853.
94. *Nitzschia* sp.
95. *Hantzschia amphioxys* (Ehr.) Grunow 1880.
96. *Hantzschia spectabilis* (Ehr.) Hustedt 1959.
97. *Surirella ovata* Kützing 1844.

veloped. The quantity of *Aulacoseira islandica* f. *curvata* also increases. The benthic species *Surirella ovata* appears here. Most of the *Aulacoseira* species remained, and only some of the species *Fragilaria*, *Navicula*, *Gomphonema*, *Pinnularia* (*P. esox*, *P. scythica*, *P. major* var. *andesitica* f. *interrupta*), *Cymbella*, *Anomoeoneis* (*A. sphaerophora* var. *sculpta*) etc. The common species diversity of diatom flora decreases and 58.8 % of its species disappeared.

After 46.00 m the diatom flora becomes extinct. Between 42.00 and 44.20 m is a lignite coal layer. The sediments over it (39.00–42.90 m) are described as diatomite clays (by unpublished data of Kojumdjieva). The microscopic analysis revealed that there are no diatoms in them (they are sterile clays).

Because of the geologist's suggestions, that some diatom clays alternated with lignite coals, are low quality diatoms, it was necessary to determine the whole frustule amount in the

sediments from the studied levels. Their quantity is 14–25 mln/g sediment. A larger quantity of frustule (40–44 mln/g) is found in the sediments from 60.00, 63.50 and 64.00 m. This confirmed the correct determination of the studied sediments as diatom clays and in further exploitation of the lignite coals from the Elhovo Basin, these sediments are useful only after additional enrichment.

Two associations emerged in the flora development: of *Aulacoseira muzzanensis* and of *Aulacoseira agassizii* var. *malayensis*, demonstrated with the multivariate cluster analysis (Fig. 5, cluster A<sub>1</sub>, A<sub>2</sub>).

1 — Association of *Aulacoseira muzzanensis* (60.00–74.00 m). It is characterized by the dominance of *Aulacoseira granulata* and *A. islandica*, that represent from 70 to 80 % from the quantity composition of the diatom flora. *Aulacoseira muzzanensis* is a subdominant, it appeared on 74.00 m and extincted on 60.00 m. Attended species are: *Fragilaria construens* with f. *venter*, *F. lapponica*, *F. bituminosa*, *F. nitida*, *Navicula halionata* with var. *directa*, *N. lundstroemii*, *Anomoeoneis sphaerophora* var. *sculpta*, *Pinnularia scythica*, *P. viridis*, *Gomphonema gracilis*, *G. intricatum* var. *dichotomum* and var. *fossilis*.

*Aulacoseira italica* var. *tenuissima*, *Fragilaria capucina* var. *vaucheriae*, *F. leptostauron*, *F. ulna* with var. *amphirhynchus*, *Eunotia* sp., *Navicula amphibola*, *N. contenta*, *N. gothlandica*, *N. graciloides*, *N. jimboi*, *Pinnularia legumen*, *Stauroneis phoenicenteron*, *Anomoeoneis sphaerophora*, *Caloneis bothnica*, *Neidium iridis*, *Cocconeis dubravicensis*, *Achnanthes conspicua*, *Cymbella aspera*, *C. cistula*, *C. helvetica*, *Amphora coffeaeformis* with var. *protracta*, *A. holsatica*, *Amphora* sp., *Epithemia argus*, *E. sorex*, *Hantzschia amphioxys*, *Nitzschia dubia*, *N. palea*, *N. recta*, *N. scalaris* were found only in this association.

2 — Association of *Aulacoseira agassizii* var. *malayensis* (46.00–49.50 m). Its characteristic feature is that *Aulacoseira agassizii* var. *malayensis* appears as a dominant together with *Aulacoseira granulata* and *A. islandica*. The subdominants are *Aulacoseira italica* var. *valida*, *A. lacustris*, *Navicula gastrum* with var. *signata*, *Pinnularia nobilis* var. *neogena*, *Anomoeoneis vitrea*, *Mastogloia elliptica*, *Cymbella affinis*, *C. ehrenbergii*, *Rhopalodia gibba*, *Surirella ovata*, etc.

Changes in the paleoecological conditions in the basin probably determined the association's replacement.

The reviewed consequence in the diatom flora development, appeared that it consists of a total of 24 species, varieties and forms of diatoms. They form the characteristic diatom complex for the studied sediments from the Elhovo Basin. The vertical distribution and the quantity abundance of the species is represented on a diagram (Fig. 6). The fossil flora also includes some typical Miocene species, only on definite levels and with quantity mainly single (2) or rarely-frequent (3): *Navicula jimboi*, *N. halionata* var. *directa*, *Cocconeis dubravicensis*, *Pinnularia major* var. *andesitica* f. *interrupta*, *P. nobilis* var. *neogena* and *Gomphonema intricatum* var. *fossilis*. The other species occur singly to rarely, this can also be seen in clusterization of the species (Fig. 5, cluster B<sub>3</sub> at the formation of many little clusters).

### Paleoecological reconstruction

From the defined 97 species, varieties and forms of diatom, 68 have a known ecology. The analysis of their ecological

spectra revealed the following correlation between the different ecological groups of diatoms (Fig. 3).

The diatom flora consists almost entirely of oligohalobous (94.5 %), and the indifferent species predominate (83.7 %). Rarely there are indifferent-halophobous (2.5 %) and halophobous (7.3 %). From them *Aulacoseira lirata* and *A. italica* on some definite levels overlined those that are with great quantity (with abundance assessment 5). From halophobous *Eunotia pectinalis* with var. *minor* and *Pinnularia legumen* are widely distributed species too. The halophilous are 3.6 %. There were established mesohalobous *Amphora coffeaeformis* with var. *protracta* and halophilous species *Amphora proteus*. The changes in the percentage correlation of the halobious groups with depth are presented on Fig. 4.

Depending on the active reaction of the water the alkaliphilous species are predominant (56.1 %), followed by the indifferent (31.8 %), alkalibiontic (9.1 %) with the acidophilous (3.0 %) coming last.

The habitat spectrum is indicated by the predominance of the benthic diatoms (87.5 %), with a large percentage of epiphytes (76.8 %) and with relatively lower percentage of bottom species (23.2 %). The plankton species are only 12.5 %, but in quantity they prevail over the benthic species and reach up to 95–99 %. In origin they are euplanktonic. The current spectra proved the big dominance of the limnophilous species, which are mixed with singly presented rheophilous species.

The eutrophics are abundant in the nutrient spectrum with the presence of two oligotrophic-eutrophic species.

In geographical distribution the cosmopolitan group (66.7 %) is predominant, followed by the boreal ones (25.5 %) and with the lower percentage are the northalpine species (9.8 %).

On the basis of the diatom ecological spectra, the ecological characteristics and the replacement of associations the following reconstruction of the probable ecological conditions in the basin, during the formation of the sediments, was prepared.

The Elhovo Basin was an eutrophic lake. This was proved by the limnophilic eutrophic abundance. Most attended species are also eutrophic, developed mainly at the interval of

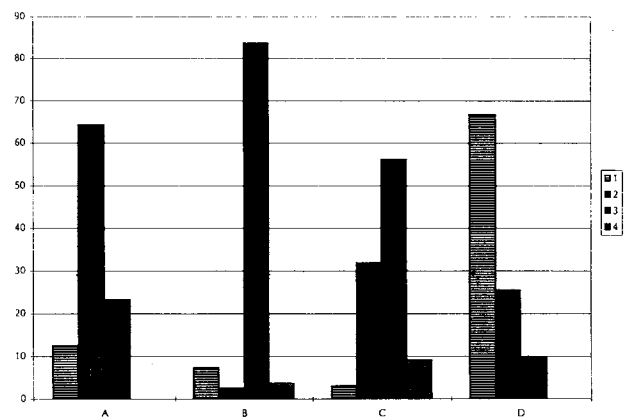


Fig. 3. Histograms (A–D). Percentage proportion of the ecological groups diatoms from Pontian sediments, the village of Trankovo, Elhovo district. A — Habitat: 1 — Planktonic; 2 — Benthos-epiphytic; 3 — Benthos-bottomed. B — Halobious groups: 1 — Halophobous; 2 — Indifferent-halophobous; 3 — Indifferent; 4 — Halophilous and mesohalobous. C — pH spectrum: 1 — Acidophilous; 2 — Indifferent; 3 — Alkaliphilous; 4 — Alkalibiontic. D — Geographical distribution: 1 — Cosmopolitans; 2 — Boreal forms; 3 — Northalpine forms.

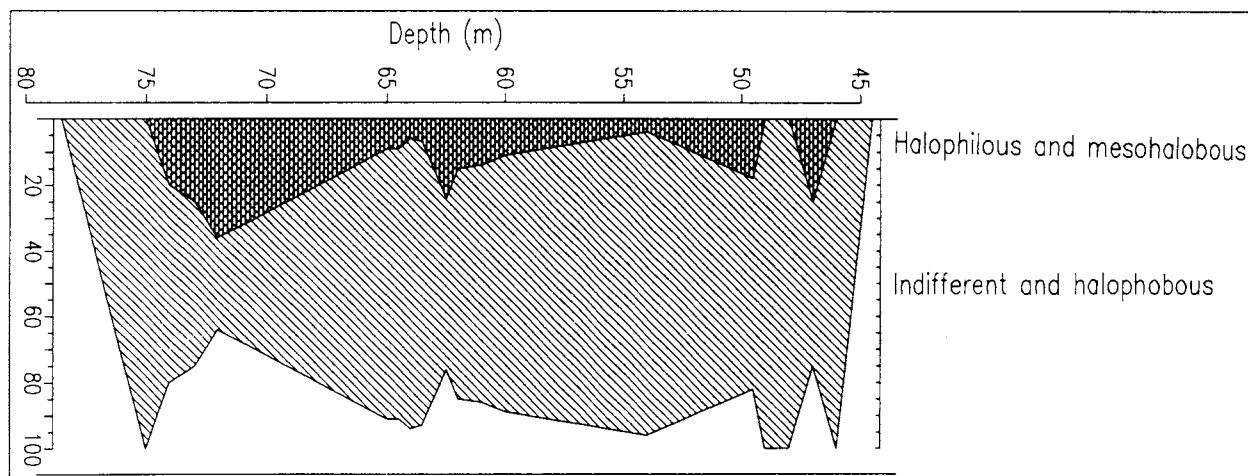


Fig. 4. Correlation in percentages and distribution of halophobous and indifferents, and halophilous and mesohalobous in the Pontian sediments from the drill-core C-432, village of Trankovo, Elhovo district.

54.00–77.00 m and on defined levels a quantity abundance of 4–5 is reached (*Fragilaria construens* etc.). The availability of single rheophilic species is due to their transfer from rivers and streams. The lake had a large open surface, and well developed littoral zone, overgrown with water plants. The studied region of the basin was from the pelagic zone of the lake, as is confirmed by the quantity development of the euplanktonic species *Aulacoseira*. The large quantity of the planktonic species, proves the large size of the lake, because their distribution is frequently connected with a large water surface availability (Abott & VanLandingham 1972). The probable depth of the lake in the studied part of the basin was around 10–15 m. According to Prescott (quoted by Abott & VanLandingham 1972) the benthic diatoms in nonmarine basins developed up a depth of 15 m. The low quantity presentation of the bottom benthic species depended to some extent on light insufficiency, because of the water strimation. For the small depth of the basin, a proovement is the large number of genera and species, inhabitants of the shallow littoral and overgrows.

Probably the lake regime of that ancient basin was not permanent and it changed into a marsh one. That is proved by the sediment rocks, containing diatoms and coal levels replacement (Moisseeva 1980).

The lake waters were fresh with a salinity of (0.2) 0.3–0.5 ‰. The lowest salinity measurements were reached at the time of sediment formation in the interval between 64.00–65.00 m, where the following halophobous were frequent to very abundant: *Aulacoseira lirata*, *Eunotia pectinalis* with var. *minor*, *Pinnularia legumen* (singly), and the indifferent-halophobous *Aulacoseira lirata*. A relatively weak salinity increase was observed through definite periods, when there appeared single specimens or where halophilous species frequently developed (*Navicula graciloides*, *Anomoeoneis sphaerophora*) and mesohalobous (*Amphora holsatica*, *A. coffeaeformis* with var. *protracta*) (61.00, 62.50, 63.50 m).

The active water reaction was neutral to slightly alkaline (pH = 7–8), which corroborated the great representation of aliphilous and indifferents.

The lake waters were rich in biogene elements and silica acid, which supposed diatom development.

The water temperature was higher than that in the modern lakes from temperate latitudes, which confirmed the subtropical species development (*Pinnularia scythica*, *Aulacoseira agassizii* var. *malayensis*). An indicator of higher temperature is the predominance of *Aulacoseira granulata*, with frustules, which possess very little diameter, but with a considerable height, and commonly curved by the transapical axis.

#### Correlation with other examined Neogene nonmarine diatom floras

Among the Miocene European nonmarine diatom floras the Elhovo flora has the greatest similarity with the Mydlovary Formation in the South Bohemian Basin (Řeháková 1965) — 30.9 % b. pr. c. In both floras common are the dominant species (*Aulacoseira granulata*, *A. islandica*, *Navicula halionata* and var. *directa*, *Pinnularia scythica* and consequence of transit species from the genera *Fragilaria*, *Pinnularia*, *Cymbella*, *Eunotia*, *Hantzschia*, *Nitzschia*. From the taxonomic composition of the Elhovo Basin 38.3 % were also represented in the Miocene sediments of the two South-Bohemian basins.

The diatom flora from the Elhovo Basin has similarities with Late Miocene diatom floras from Beuern (29.4 % b. pr. c.), Homberg (24.9 % b. pr. c.) and Altenschlirf (24.4 % b. pr. c.), Germany (Krasske 1934). This is because of the great extend of equal transition species from the genera *Fragilaria* (*F. construens* f. *venter*, etc.), *Achnanthes* (*A. conspicua*), *Navicula*, *Cymbella* (*C. cistula*, etc.), *Gomphonema* (*G. intricatum*, etc.), which are frequent inhabitants of the Miocene continental basins and have wide stratigraphic and geographical distributions.

With the Miocene diatom flora from Byelorussian Ponemania (Khursevich 1977) the coefficient of similarity is 25.1 %. The dominant species *Aulacoseira islandica* and *A. granulata*, the Miocene species *Navicula jimboi*, *Gomphonema intricatum* var. *fossilis* and species *Fragilaria*, *Eunotia*, *Navicula*, *Anomoeoneis*, *Cymbella*, *Gomphonema* are common to both.

By the roughly frustuled *Aulacoseira* species the studied flora presented similarity with the Miocene diatom floras from Primorian and Habarovian regions, Pribaikal district, the river

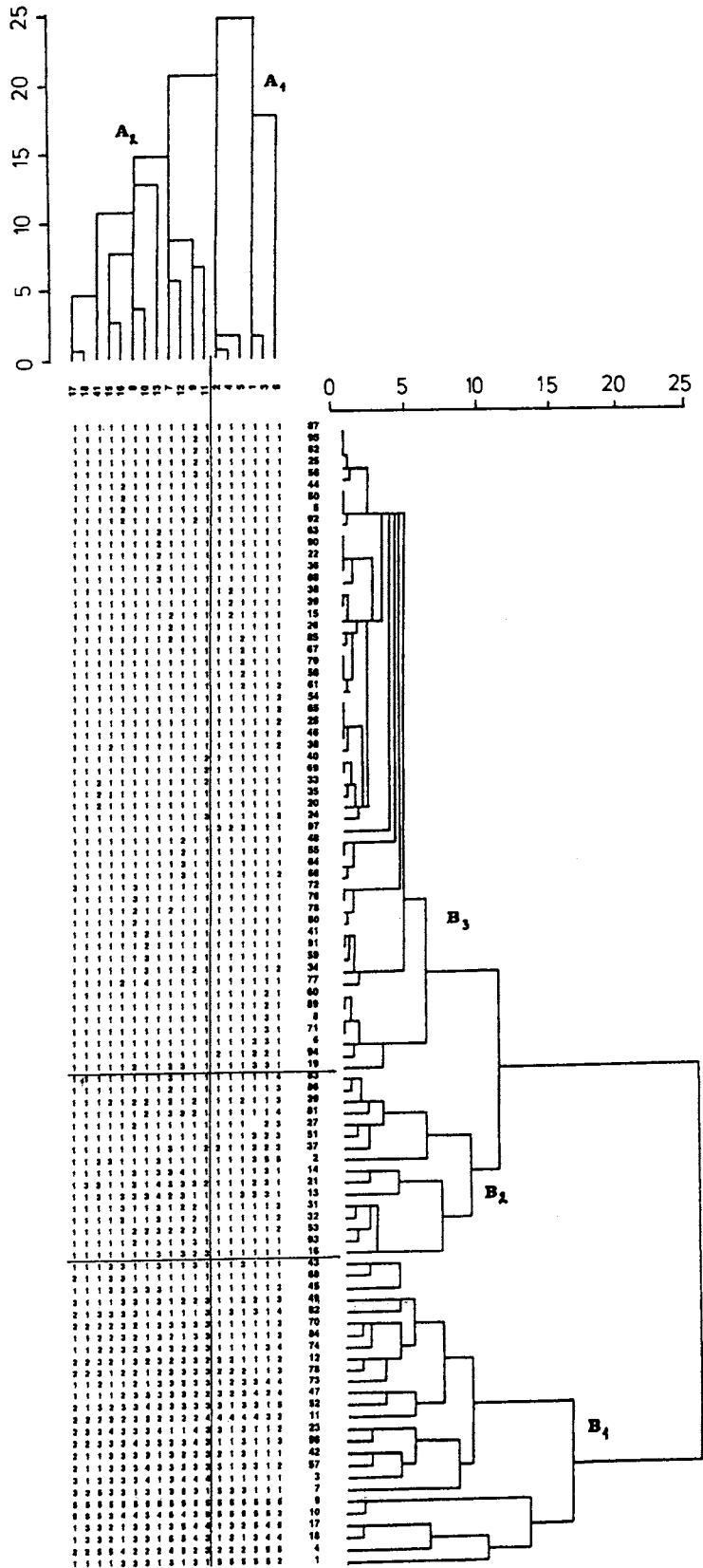


Fig. 5. Combined diagram, integrating the results from analysis of the specimens and diatom species from sediments at the village of Trankovo (C-432) Elhovo district. Samples: 1. 46.00 m 2. 47.00 m 3. 48.00 m 4. 49.00 m 5. 49.50 m 6. 54.00 m 7. 60.00 m 8. 61.00 m 9. 62.00 m 10. 62.50 m 11. 63.50 m 12. 64.00 m 13. 64.50 m 14. 65.00 m 15. 72.00 m 16. 73.00 m 17. 74.00 m 18. 85.00 m. (For numbers of diatom species see Table 2).

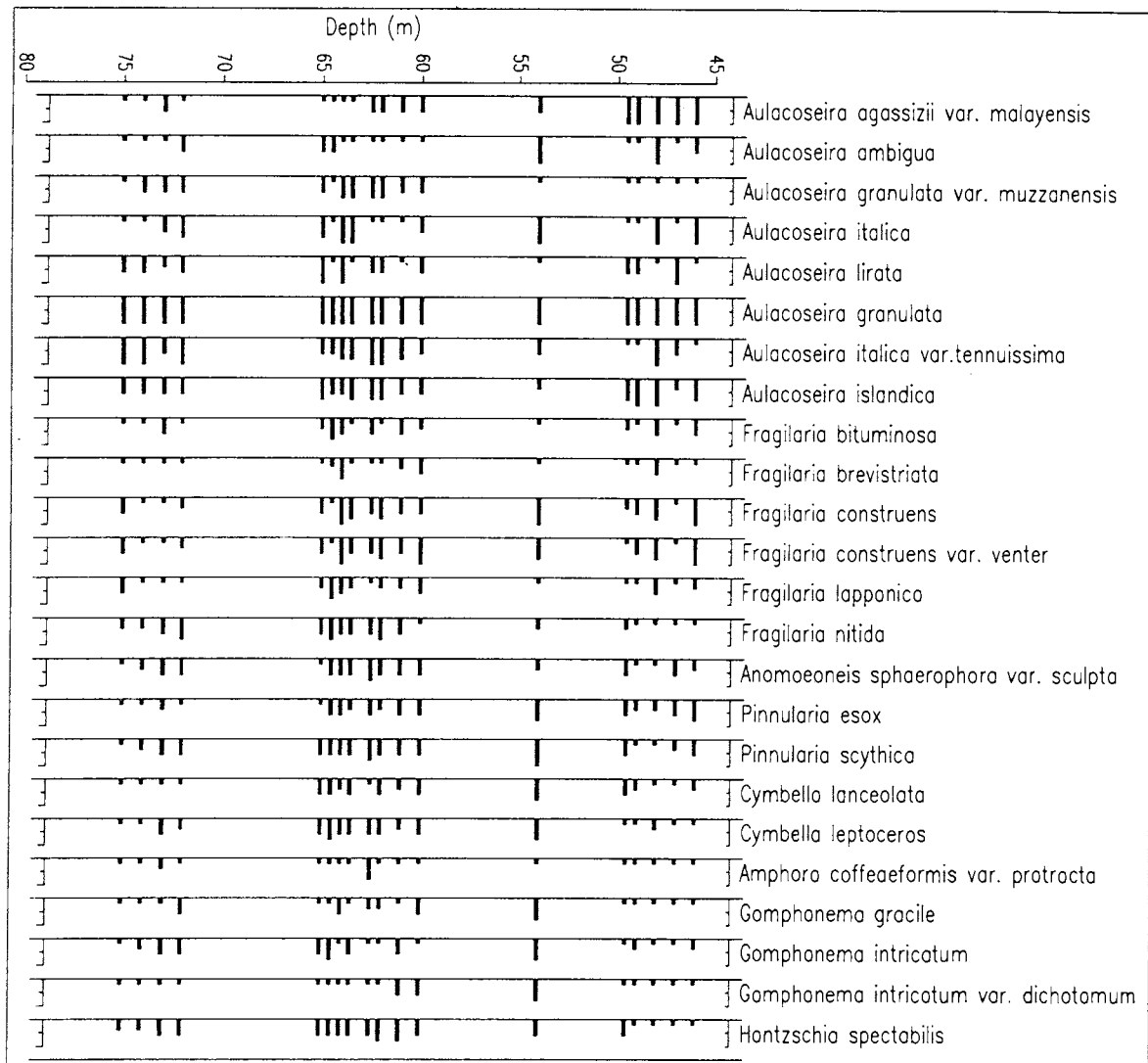


Fig. 6. Distribution and quantity abundance of the dominants and characteristic diatoms from the Pontian sediments from the drill-core C-432, village of Trankovo, Elhovo district.

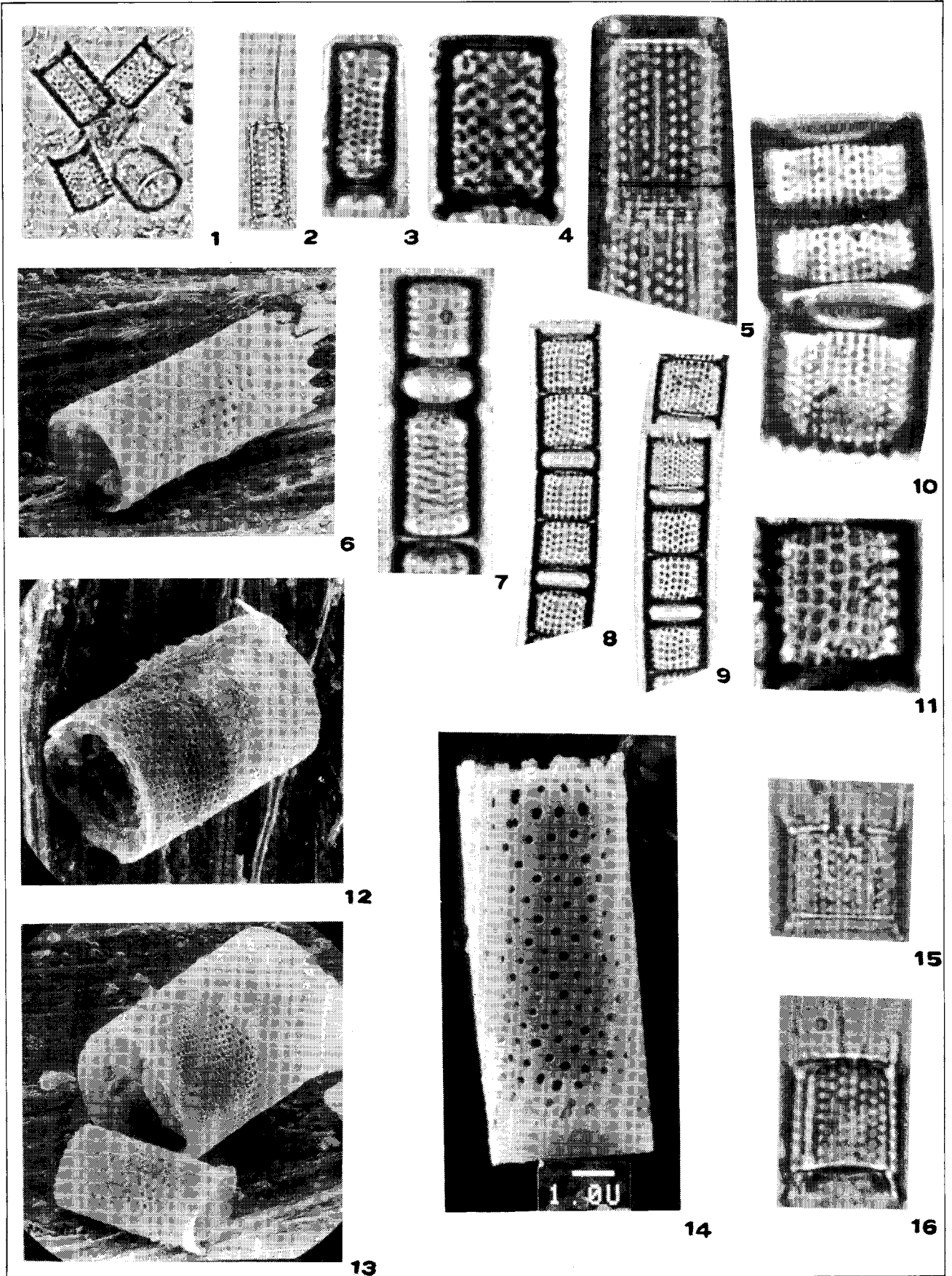
Tym, West Siberia (Moisseeva 1960, 1967a,b, 1971, 1975; Chere-misinova 1973a,b, 1975; Rubina 1969; Sheshukova-Poretzkaya et al. 1981). Among these the flora from the river Tym and Pribaikal district has a relatively great similarity with the Elhovo Basin's flora (18.8 % b. pr. c. and 19.4 % b. pr. c. respectively).

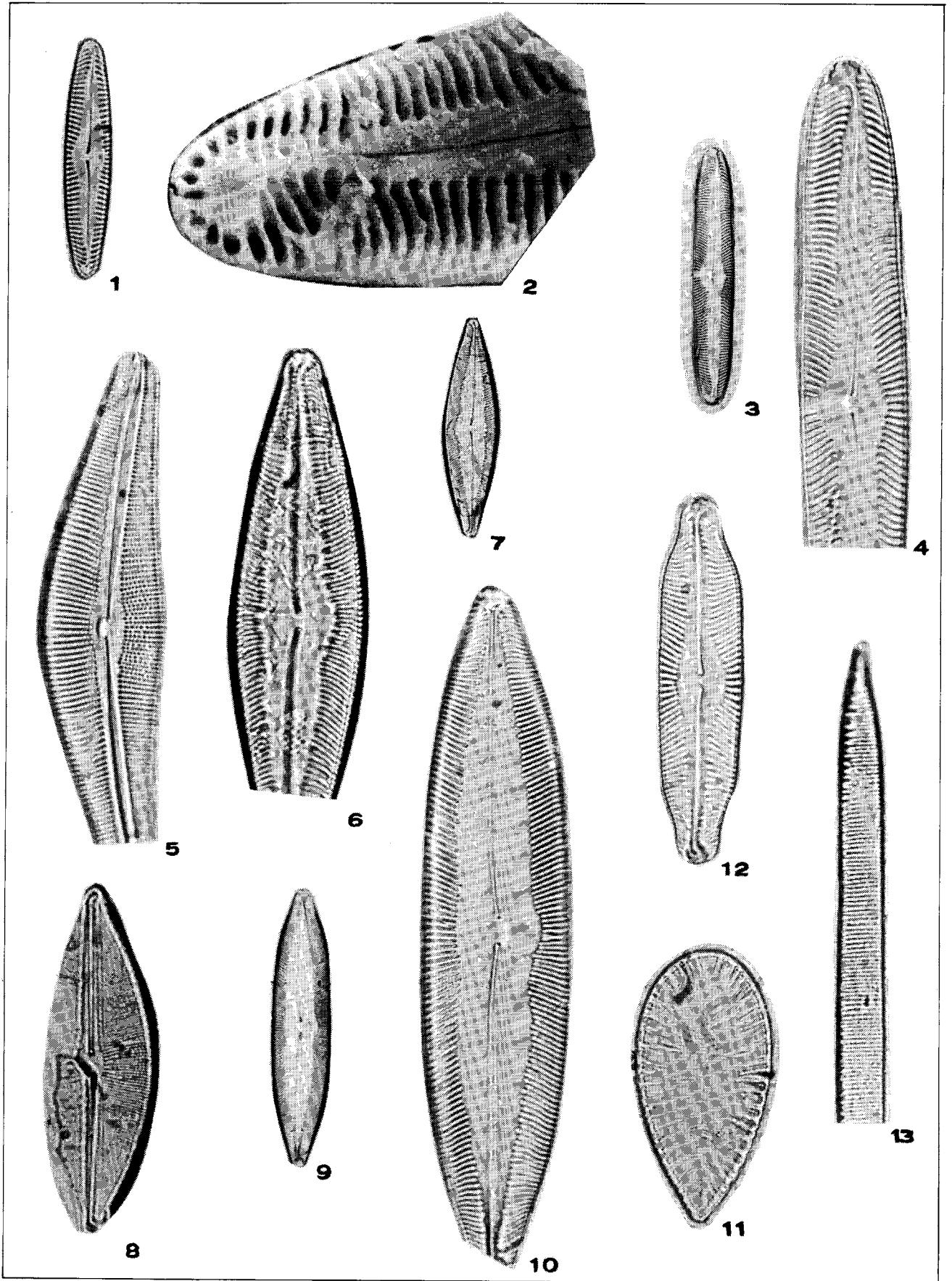
The comparison with the Miocene nonmarine floras from the states of Nebraska, Montana, Oregon and Washington showed many common species with the Elhovo Basin flora, also known from other European Miocene continental basins: *Aulacoseira ambigua*, *A. italica*, *Fragilaria brevistriata*, *F. heidenii*, *Navicula cuspidata*, *N. graciloides*, *Achnanthes conspicua*, *Eunotia pectinalis*, *Cymbella lanceolata*, *Gomphonema parvulum* var. *micropus*, *G. intricatum* var. *dichotomum* etc. (VanLandingham 1964, 1967, 1970; Abott & VanLandingham 1972; Andrews 1970, 1971). From these floras, the flora from Nebraska — 22.7 % b. pr. c. has the highest coefficient of equality with the Elhovo Basin.

The dominant species in the floras from Washington and Montana are species from the genus *Aulacoseira* (*A. granulata*, *A. distans*, *A. italica*, *A. canadensis*), that represent up to 60 % of the composition of the Washington flora. Applied illustrations proved that most of the *Aulacoseira* species are roughly frustuled (*A. granulata*, *A. distans*, pl. 31, Fig. 16, 20; pl. 33, Fig. 131 — VanLandingham 1964; pl. 5, Fig. 1-33;

**Plate I: Figs. 1-6.** *Aulacoseira granulata* (Ehr.) Simonsen. 1 —  $\times 800$ ; 2, 3 —  $\times 1000$ ; 4, 5 —  $\times 1600$ ; 6 —  $\times 3600$ ; SEM. **Fig. 7.** *Aulacoseira ambigua* (Grun.) Simonsen. —  $\times 1800$ . **Figs. 8-12.** *Aulacoseira islandica* (O. Mull.) Simonsen. 8, 9 —  $\times 800$ ; 10 —  $\times 1000$ ; 11 —  $\times 1600$ ; 12 —  $\times 3000$ ; SEM. **Fig. 13.** *Aulacoseira granulata* (Ehr.) Simonsen and *Aulacoseira islandica* (O. Mull.) Simonsen —  $\times 3000$ ; SEM. **Fig. 14.** *Aulacoseira italica* (Ehr.) Simonsen. **Figs. 15, 16.** *Aulacoseira agassizii* var. *malayensis* (Hust.) Simonsen —  $\times 1000$ .







pl. 6, Fig. 7-37 — VanLandingham 1970). Because of this they are very close to the Elhovo Basin's flora.

The comparison of the Elhovo Basin's flora with known Pliocene floras from Europe, Asia and America gave the highest coefficient of similarity with Late Pliocene flora for Trais Horloff — 25.55 % b. pr. c. (Krasske 1934), the Pliocene flora from South Bohemia — 22.3 % b. pr. c. (Řeháková 1965), Nurnus and Arzni, Armenia — 20.7 % b. pr. c. (Poretzky 1953a), Kisatibi, Georgia — 18.1 % b. pr. c. (Poretzky 1953b), Willershausen, Germany — 19.8 % b. pr. c. (Krasske 1934). The transition species are common to these floras and the Elhovo Basin flora. The Pliocene floras have a high species diversity and quantity abundance of the species from class *Pennatophyceae*, with the development of the species *Cymatopleura*, *Surirella*, *Campylodiscus*. The species *Cyclotella*, *Stephanodiscus*, *Coscinodiscus* etc. (Krasske 1934) were also represented, but they are absent from the Elhovo Basin.

The Elhovo flora is similar to the Early-Pliocene flora from Burnos (Khursevich 1977, 1978) with roughly frustuled *Aulacoseira* species, but the Burnos flora is more diversified with species from *Tetracyclus*, *Tabellaria*, *Opephora*, *Diatoma*.

From Asian Pliocene floras (Moisseeva 1967a,b, 1971; Lupikina 1968; Cheremisinova 1973a,b, 1975; Sheshukova-Poretzkaya et al. 1981) the Elhovo flora is similar to that from the Tunkinskian Valley — 19.9 % b. pr. c. (Cheremisinova 1973b). The equality is on the basis of the roughly frustuled species *Aulacoseira* and some transit species (*Fragilaria construens*, *Navicula amphibola*, *Cymbella silesiaca* etc.).

The Elhovo Miocene flora shows similarity with the quoted Miocene or Early Pliocene floras on common rock forming species or on common attended species, mostly transit (because of their relatively higher number, b. pr. c. reaches 24-29 %). On the basis of rock forming species and a considerable part of the other common species the Elhovo flora is closest to the Late Miocene (Pontian) flora from Gotse Delchev Basin in South Bulgaria. Both floras are referred to the so-called "Aulacoseira"-type diatom floras (Temniskova-Topalova 1994). They are characterized by the dominance of the species *Aulacoseira*, relatively poor taxonomic composition and low quantity of attended species. Characteristic for them is lack of characteristic Miocene species of class *Centrophyceae* (species *Actinocyclus*, *Cyclotella* etc.). That gave the possibility of dating the diatom flora to the Late Miocene (Pontian), with which we confirm the age of the sediments from the Izgrev Member, determined by Kojumdjieva et al. (1984).

### Conclusion

The Late Miocene (Pontian) diatom flora from Elhovo Basin possesses the following characterizations: **1** — Up to 90 % consists of species of the genus *Aulacoseira* (roughly frustu-

led *A. granulata* and *A. islandica* 70-80 %) and *Aulacoseira agassizii* var. *malayensis*, *A. ambigua*, *A. italica*, *A. lirata* (15-25 %); **2** — The attended species have low percentage proportions in the fossil flora (1-2 to 5 %); **3** — The examined flora consists mainly of 24 species, varieties and forms of diatoms, which form two assemblages (of *Aulacoseira muzzanensis* and of *Aulacoseira agassizii* var. *malayensis*); **4** — Low percentage of fossil species; **5** — Lack of typical Miocene species from the class *Centrophyceae*.

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**Plate II: Figs. 1, 2.** *Pinnularia scythica* (Pant.) Gandhi. 1 —  $\times 320$ ; 2 —  $\times 6000$ ; SEM. **Figs. 3, 4.** *Pinnularia major* var. *andesitica* (Pant.) Pant. f. *interrupta* Řeháková. 3 —  $\times 320$ ; 4 —  $\times 1000$ . **Fig. 5.** *Cymbella aspera* (Ehr.) Cleve —  $\times 800$ . **Figs. 6, 7.** *Navicula halionata* Pantocsek. 6 —  $\times 320$ ; 7 —  $\times 1000$ . **Fig. 8.** *Navicula jimboi* Pantocsek —  $\times 800$ . **Figs. 9, 10.** *Navicula halionata* var. *directa* Pantocsek. 9 —  $\times 320$ ; 10 —  $\times 800$ . **Fig. 11.** *Surirella ovata* Kützing —  $\times 320$ . **Fig. 12.** *Pinnularia legumen* (Ehr.) Ehrenberg —  $\times 800$ . **Fig. 13.** *Nitzschia* sp. —  $\times 1000$ .

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