Paleoecology and organic matter in the Late Badenian and Early Sarmatian marine basin of the Polish part of the Carpathian Foredeep

Iwona Czepiec*, Maciej J. Kotarba**

The studies aim to determine both the ecological and geochemical conditions of the Late Badenian and Early Sarmatian sedimentary basin located in the outer part of the Carpathian Foredeep. Particularly interesting are: depositional environment of organic matter, depth of the basin and water temperatures. The Late Badenian sea was presumably only slightly deeper than the outer shelf, i.e. about 200 meters. The warm climate resembling that of the warm temperate zone resulted in surface water temperatures 17–20°C. In the Sarmatian the sea depth was initially about 30–50 meters thus, the existence of submarine meadows was inferred. Then, progressing shallowing to about 10 meters took place. The Sarmatian sea was a warm basin with temperatures roughly corresponding to those of the Late Badenian ones. Organic matter deposited during both the Badenian and the Sarmatian reveals terrestrial origin. Organic matter in the Late Badenian and Early Sarmatian strata is immature or, at most, early matured but at depth below 3000 meters. Very low correlation of both the concentrations and the maturation degree of the organic matter with its depth of occurrence suggest the similarity of sedimentary environments in the whole Miocene succession and the lack of thermal transformation after deposition. Almost exclusive occurrence of the humic organic matter points to the fast and rhythmic supply of terrestrial clay matter to the deltaic environments in the shallow Miocene basin. A rapid sedimentation of terrestrial, deltaic sediments took place in the Miocene basin, therefore the humic organic matter (type III kerogen) prevailed there and the marine type II kerogen was hardly detectable.

Key words: *areal geology, Badenian, Sarmatian, basin analysis, foraminifers, paleoecology, organic materials, Carpathian Foredeep, Poland*

Introduction

The joint studies on microfossils and organic geochemistry of the Late Badenian and Early Sarmatian sediments aim to determine both the ecological and organic matter deposition conditions in the sedimentary basin located in the outer part of the Carpathian Foredeep. Special attention was paid to depositional environment of the organic matter (OM), depth of the basin and water temperatures. These data are crucial for the reconstruction of generation and accumulation systems of natural gases (Szafran, 1990; Kotarba et al., 1998a). Such preliminary reconstruction has been based upon the results of routine geochemical analyses of hydrocarbons (Rock Eval and extraction) as well as upon the studies on microfossil assemblages with the reference to other fossil remains (particularly to their taxons composition and degree of preservation in the sediment).

The study has been undertaken as a part of research projects of the Carpathian Foredeep financed by the State Committee for Scientific Research in Warsaw (grant No. 9 9214 92 03) and National Fund for Environmental Protection and Water Management (grant No. 2.14.0100.00.0).

Material and methods

The source materials were 85 core claystone/mudstone samples of autochthonous Late Badenian and Early Sarmatian sediments of the Carpathian Foredeep collected from the following 11 wells (Fig. 1): Brzóza Stadnicka 1 (BS 1), Czarny Las 3 (CL-3), Dobra 4 (Do-4), Jaksmanice 257 (J-257), Jodłówka 4 (Jo-4), Komorów 2 (Km-2), Łazy 9

*University of Mining and Metallurgy, Department of Stratigraphy & Regional Geology, al. Mickiewicza 30, 30-059 Kraków, Poland, email: iwczep@geolog.geol.agh.edu.pl
**University of Mining and Metallurgy, Department of Fossil Fuels, al. Mickiewicza 30, 30-059 Kraków, Poland, email: kotarba@uci.agh.edu.pl

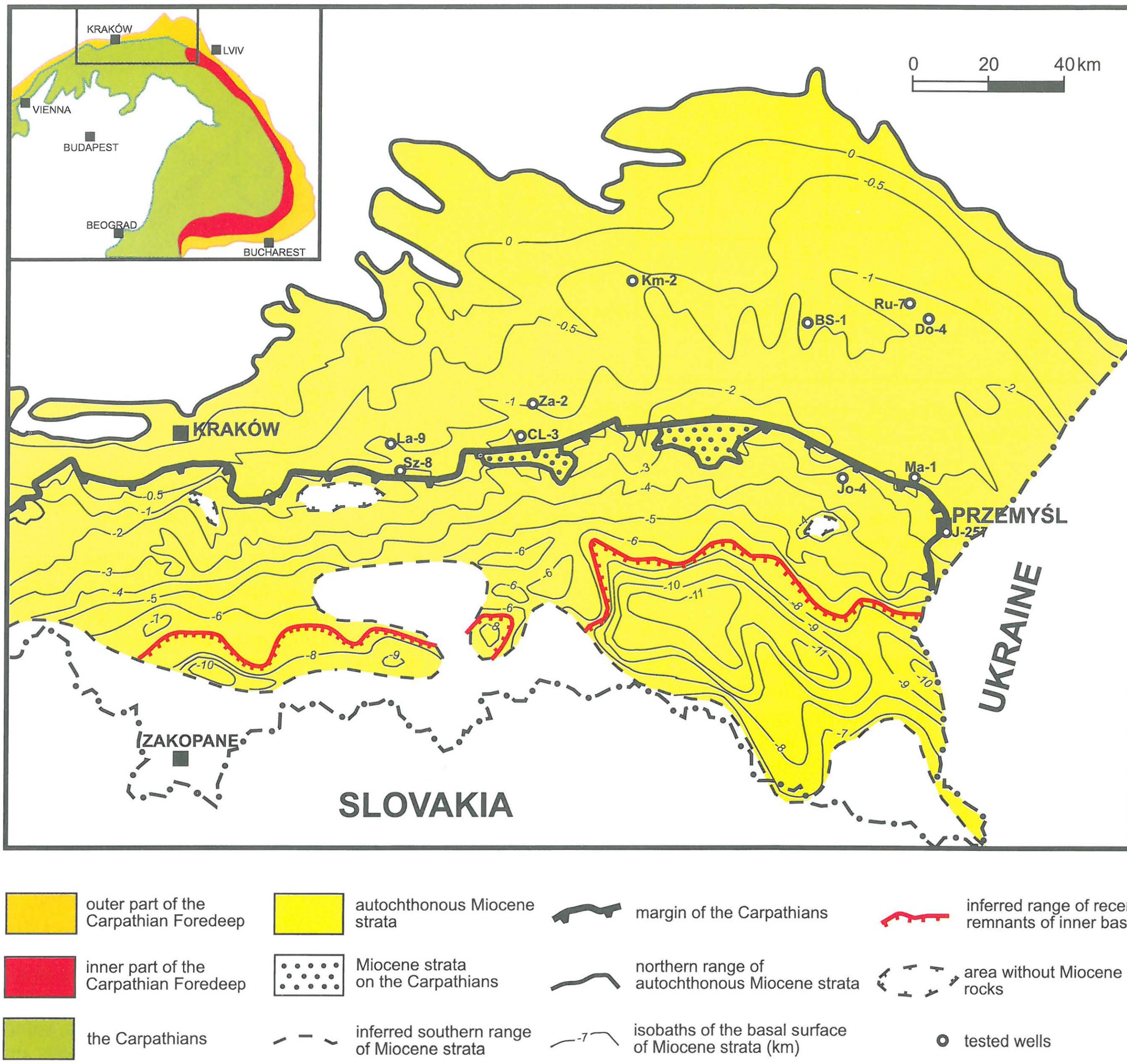

Fig. 1. Sketch map of the central and eastern parts of the Polish Carpathian Foredeep and location of studied wells

(La-9), Maćkowice 1 (Ma-1), Rudka 7 (Ru 7), Szczepanów 8 (Sz-8) and Zasów 2 (Za-2). All samples were pulverized, then extracted with the chloroform in the Soxhlet apparatus. Pyrolysis assay of the samples was run with the Delsi Model II Rock-Eval instrument equipped with an organic carbon module.

Microfossils were sought in 50 samples collected from all the 11 wells. Samples were disaggregated and wet-washed on sieves. Microfauna were separated from the obtained material and taxonomic determination was made. Redeposited specimens were excluded. Total number of 68 foraminifers species were identified. Quantitative studies included determination of the number of tests and number of taxons in each sample.

The reconstruction of paleoenvironmental conditions of the Late Badenian and Early Sarmatian sea was based upon the uniformitarianism principle. Although the Miocene microfauna included, in most part, the species different from the recent ones (despite some long-living forms — e.g., *Elphidium crispum, Elphidium macellum, Cibicides lobatulus, Ammonia beccari, Globigerina bulloides*) the species belong to the same genera and form the same assemblages.

The studied sediments represent the Late Badenian and Early Sarmatian sequence of the Central Paratethys (Fig. 2). Basing on the nannoplankton studies from the Pecten Beds (Upper Badenian) and the Krakowiec Clays (Lower Sarmatian), the sediments were included into the NN 8–9 zone (Gaździcka, 1994). The studies on foraminifers allowed to define the five biostratigraphic foraminiferal zones. The upper zone of the Late Badenian — *Cibicides crassiseptatus* was found in the western part of the area, in the wells: Łazy 9, Czarny Las 3, Zasów 2 and Szczepanów 8. To the east, in the wells Rudka 7, Maćkowice 1, Komorów 2, Dobra 4, Jaksmanice 257, Brzóza Stadnicka 1, the Lower Sarmatian zones appear: *Anomalinoides dividens, Cycloforina karreri ovata, Varidentella sarmatica* and *Elphidium hauerinum* which is the uppermost zone of the Early Sarmatian. Only the borehole — Jodłówka-4 — represents both the Late Badenian and the Early Sarmatian sediments.

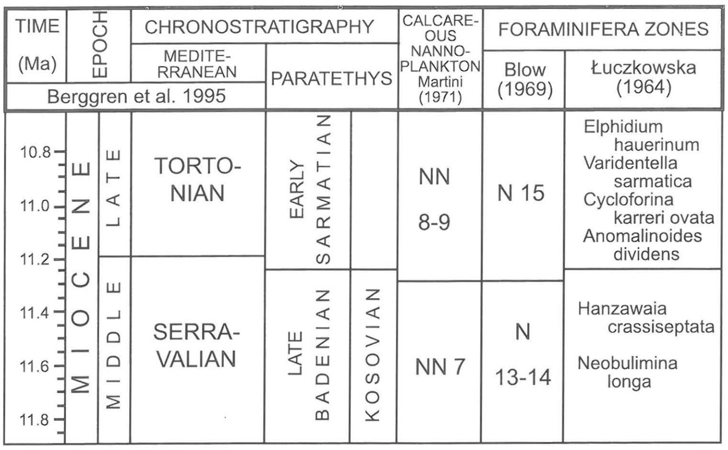

Fig. 2. Generalized stratigraphic section and regional Middle Miocene correlation (after Berggren et al., 1995; Martini, 1971; Blow, 1969; Łuczkowska, 1964)

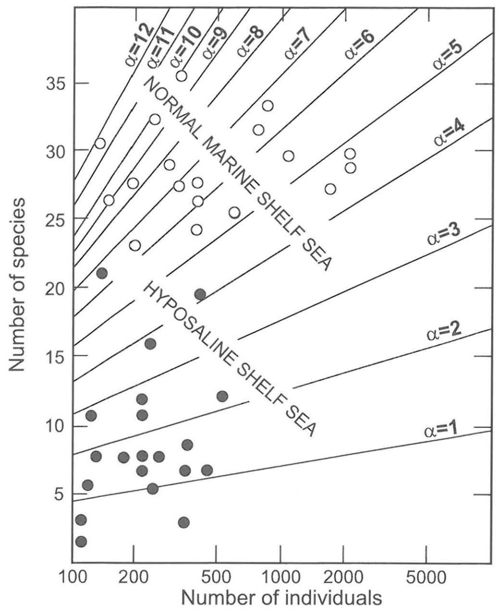

Fig. 3. Fischer diversity values for Micene foraminifera assemblage of the Carpathian Foredeep. Open dots — Upper Badenian, black dots — Lower Sarmatian

Paleoecology

The foraminiferal assemblages found in Late Badenian strata indicate the bathymetric conditions deeper than the outer shelf. Assemblages from the samples 400, 598, 700 and 706 m (La-9 well), 3,004 m (Jo-4 well) and 1,213 m (Za-2 well) comprise almost exclusively the agglutinating and planktonic forms. In the remaining samples from these wells over 90% of foraminifers belong to the planktonic population. Only the assemblages from the CL-3 well and 499 m from La-9 well show differences in composition but even there the taxons: *Bulimina, Uvigerina, Pullenia, Melonis*, with strong contribution of *Globigerina* predominate i.e., the forms common in the environments from outer shelf to upper bathyal zone.

Generally, the presence of abundant plankton corresponds to greater depth. At least, the percentage of planktonic forms increases with the depth of the basin and the distance from the shoreline. In the outer shelf plankton may constitute up to 18% and in upper bathyal zone — up to 40% of organisms (Boltovskoy & Wright, 1976). This author described relationships between test morphology of benthonic forms and the depth. Recent representatives of *Bulimina*, of the size about 0.5 mm, with few spines appear on the shelf and extend down to the bathyal zone. Similar bathymetric conditions are preferred by small, non-ornamented *Bulimina,* the size of which increases with the depth. Numerous ribbed *Uvigerina* are typical of the upper bathyal zone (160–600 m). In the studied samples *Bulimina* tests are smooth or ribbed whereas the spinose forms are rare. The tests of *Uvigerina* are costate. *Pullenia* reveals the similar range of occurrence (Bandy, 1964). Paleoecological interpretation of the agglutinating foraminifers is controversial. Some authors regard this group as typical of deep and cold waters whereas others advocate their high tolerance for both the salinity and the depth of the basin (Murray, 1973). More precise determination of the bathymetry of Badenian sea is difficult. Presumably, the basin was somewhat deeper than the outer shelf, i.e. from below 160 meters to, may be, 250–300 meters (Łuczkowska, 1967, 1974; Oszczypko, 1997).

Another important environmental factor strongly affecting the marine live is the temperature. The Badenian climate was highly diversified. The coiling direction of *Globigerinidae* tests have been used as an indicators of paleoclimatic conditions. Paleotemperature interpretation based upon the distribution of the dextral and sinistral form point to the two periods of warmer climate. The first, probably sub-tropical period has occurred in the Moravian (surface water temperature 20–25°C) whereas the second, maybe warm temperate one, has dominated the Kosovian (surface water temperature 17–20°C). In the Wielician the significant cooling took place (Czepiec, 1991). The warming of climate during the Kosovian is documented by the appearance of stenothermal species, e.g. *Globigerinoides trilobus* and *Orbulina universa* (Łazy 9 and Szczepanów 8).

Salinity of the Kosovian sea was close to normal, as demonstrated by the diversity of taxa (Łuczkowska, 1967; Szczechura, 1982; Gonera, 1994).

The Sarmatian sea was inhabitated by miliolids-elphidiids, miliolids or elphidiids-nonionids assemblages. Recently, these assemblages occur in tropical and warm waters but are limited to bays, deltas of larger rivers, estuaries and coastal marshes. *Elphidium* always occurs in the shelf zone but *Miliolidae* may settle in the deeper waters. The assemblage encountered in the *Anomalinoides dividens* Zone is typical of shallow, near-shore parts of the basin and is definitely most abundant in both the species and the number of tests in the whole Sarmatian succession (Łuczkowska, 1964, 1967, 1972; Rutkowski, 1976; Szczechura, 1982). The Sarmatian assemblages still contain some Badenian forms which might have met favourable living conditions in the Early Sarmatian. The perfect preservation of microfossils (including the delicate, fragile tests, e.g. of some *Miliolidae*) points to the quiet sedimentation.

The assemblages lack both the deep-water and the agglutinating forms. Moreover, the numerous tests of *Anomalinoides dividens* accompanied by those of *Miliolidae, Elphidium, Cibicides* and *Ammonia* document the depths from 30–50 meters (Łuczkowska, 1967) down to 100 m (Gonera, 1994). Both the common *Miliolidae* and the absence of agglutinating species suggest the abundance of calcium carbonate in the sea water. In the upper parts of the *Anomalinoides dividens* Zone deterioration of bottom conditions is observed, presumably related to the decreasing oxygen content. It is documented by the large number of pyritic moulds of microfossils and coalified plant remains (Łuczkowska, 1967).

In the *Cycloforina karreri ovata* Zone numerous *Ammonia beccari* tests were observed apart from the index taxon. Increasing percentage of both *Elphidium* and *Nonion*, i.e. the forms mostly tolerant of lower salinity evidences the change of environment conditions and gradually decreasing salinity of sea water. The basin was also subjected to slow shallowing as indicated by growing number of *Protelphidium martkobi*. In the recent seas the protelphids prefer water depth less than 10 meters (Murray, 1973).

The *Varidentella sarmatica* Zone. The samples contained large number of fine miliolids which represent only the three species: *Varidentella sarmatica, V. reussi,* and *Articularia articulinoides*. These are accompanied by *Elphidium* and *Protelphidium*. Microfossils show decrease in size in tendency to dwarfism. These trends are observed in the whole Carpathian Foredeep basin (Łuczkowska, 1964; 1967, 1974; Czepiec, 1996). Apart from sea shallowing, and decrease in both the salinity and calcium carbonate content, the lack of nutrients might have played the role. At the end of this zone miliolids completely disappeared. In this time the Maćkowice, Rudka and Komorów sites were located in the near-shore part of the basin, as suggested by abundant plant detritus, mica flakes, glauconite, large quartz grains and crushed bivalve and gastropod shells.

The *Elphidium hauerinum* Zone. In the studied area this zone was encountered only 1,586, 1,769 m and 1,773 meters in samples from the Jo-4 well. The assemblages consist solely of *Elphidium, Protelphidium,* and *Nonion* specimens with the increasing number of *Ammonia beccari* tests, i.e. taxons which accept minimum salinity. The tests are two-, even three times smaller that typical specimens. Such an assemblage is typical of the estuaries, coastal bays, lagoons or deltas of larger rivers environment where the salinity varies from 0 to 9‰ (Boltovskoy & Wright, 1976).

The Sarmatian sea was a warm basin. No evidence was found for temperature change between Kosovian and Early Sarmatian. Temperatures of the Sarmatian sea are roughly similar to those of the Late Badenian basin.

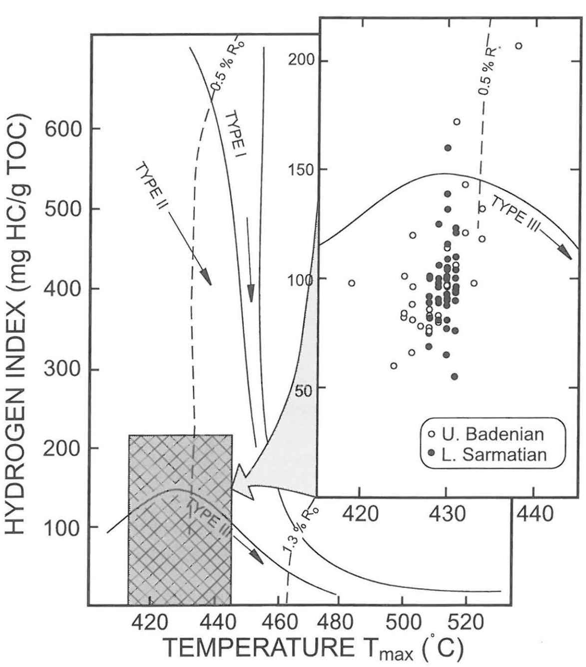

Fig. 4. Temperature T_{max} versus hydrogen index

In last years the concepts have been developed on the deltaic character of the Middle Carpathians foreland in Late Badenian and Early Sarmatian (Karnkowski, 1989). Microfossil studies may seem to support these opinions. The observed Sarmatian assemblages are characteristic of the environments of near-shore barriers or large river deltas. Moreover, the typical features are: large amounts of plant detritus and mica flakes supplied from the land, i.e. the components usually abundant in deltaic sediments. Some studied samples contained plant detritus as the only organic matter.

The application of Fishers method of salinity interpretation based upon the ratio of individuals to species numbers (Murray, 1973) allowed to confirm the opinion on abnormal salinity of the Sarmatian basin. The alpha index rises to maximum value $\alpha = 4$. Such values are indicative of hyposaline lagoons, estuaries and deltas of large rivers. All the Sarmatian samples locate outside the area of normal salinity (Fig. 3).

Decreasing salinity took place in the whole Paratethys area. According to Papp (1963), salinity was reduced from 30‰ at the beginning of Sarmatian to 16‰ at its end. Brackish character of the basin is confirmed by the boron contents (Czapowski, 1994). In the vicinity of Przemyśl which occupies the marginal parts of the basin water salinity at the end of Sarmatian was probably even lower — about or, may be, less than 9‰, as supported by the monotonous assemblage of dwarfed elphidiids and nonionids.

Organic matter

Samples studied for microfossils were also analyzed with organic geochemical methods. Full geochemical characterization of the OM in the Late Badenian and Early Sarmatian strata of the Polish part of the Carpathian

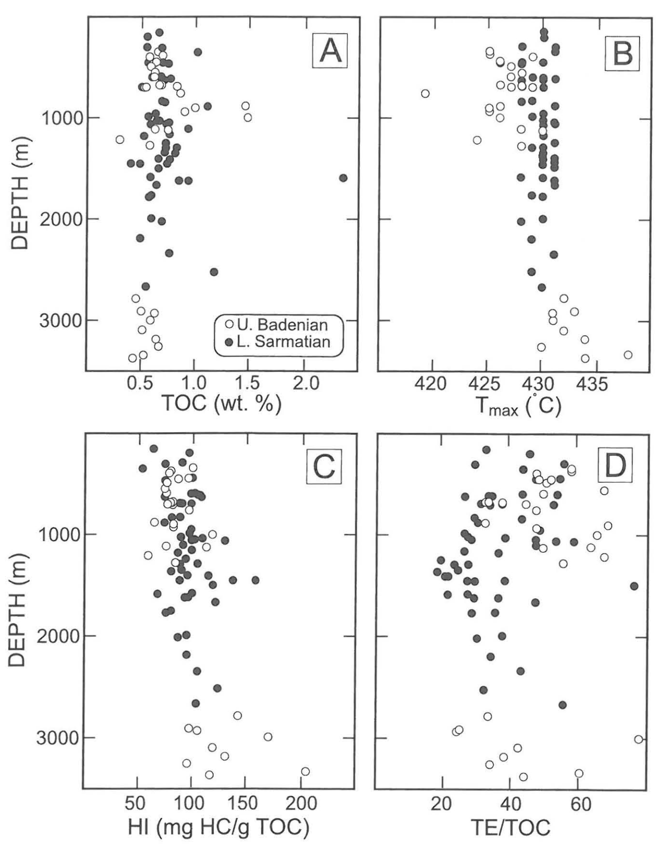

Fig. 5. TOC (**A**), temperature T_{max} (**B**), hydrogen index (**C**) and bitumen ratio (**D**) versus depth

Foredeep is contained in the separate paper (Kotarba et al., 1998b).

Results of Rock Eval pyrolysis and extraction analyses provide geochemical signature of OM. Total organic carbon (TOC) contents vary from 0.30 to 2.36 wt. % (average: 0.70 wt. % in 78 samples). In the Upper Bedenian samples the TOC vary between 0.30 and 1.48 wt.% (average: 0.66 wt. % in 31 samples) whereas in the Lower Sarmatian specimens the TOC changes from 0.50 to 2.36 wt. % (average: 0.73 wt. % in 54 samples). The results of Rock Eval pyrolysis indicate the prevailing terrestrial character of the OM in the Miocene sequence (Figs 3 and 4), which supports the previous observations (Kotarba et al., 1987; 1995). The Rock Eval T_{max} temperatures change from 419 to 438°C which proves the immature or, at most, early mature character of the OM in deposits at depth below 3,000 meters (Figs 4 and 5). The TOC, T_{max} temperatures, hydrogen index and bitumen ratio values (Fig. 5) for both the Upper Badenian and the Lower Sarmatian OM show very low variability with depth of recent occurrence which suggests similar deposition conditions of the OM in the whole studied sequence and the lack of thermal transformation after sedimentation.

Almost exclusive humic character of the studied OM indicates the fast and rhythmic supply of terrestrial clay matter which produced deltaic sediments in the shallow basin. Interesting is the complete absence of marine type II kerogen in the studied samples although microfaunal observations proved the abundant foraminiferal assemblages as well as fish and bivalve remains. A rapid sedimentation of terrestrial, deltaic sediments took place in the Miocene basin, therefore the humic organic matter (type III kerogen) prevailed there and the marine type II kerogen was hardly detectable.

Conclusions

Depth of the Late Badenian basin probably exceeded that of the outer shelf and was about 200 meters. Interpretation of palaeotemperatures based upon the coiling directions of *Globigerina bulloides* specimens points to the surface sea water temperature of about 17–20°C.

The presence of abundant specimens of *Anomalinoides dividens*, accompanied by *Miliolidae, Elphidium, Cibicides* and *Ammonia* in the Sarmatian strata indicates depths 30–50 meters and probable environment of submarine meadows where foraminifers might have lived attached to seagrass. Then, the Sarmatian basin slowly shallowed as documented by the growing number of *Protelphidium martkobi*. In the recent seas *Protelphidium* prefer water depths above 10 meters. Water temperature of the Early Sarmatian sea was similar to that of the Late Badenian.

The TOC contents in the Miocene sequence change between 0.30 and 2.36 wt.% (average from 78 samples — 0.70 wt. %). The OM reveals terrestrial origin and immature or, at most, early mature character but at depths below 3000 meters. Very low diversity of both the OM concentrations and maturation degree with the depth of recent occurrence point to the similar depositional conditions of the OM in the whole studied Miocene sequence and to the lack of thermal transformation processes after sedimentation. Almost exclusive humic character of the OM indicates fast and rhythmic supply of terrestrial clay matter to the shallow basin. A rapid sedimentation of terrestrial, deltaic sediments took place in the Miocene basin, therefore the humic organic matter (type III kerogen) prevailed there and the marine type II kerogen was hardly detectable.

References

BANDY O. L. 1964 — Foraminiferal biofacies in sediments of Gulf of Batabano, Cuba, and their geologic significance. Amer. Ass. Petrol. Geol. Bull., 48: 1666–1679.

BERGGREN W.A., KENT D.V., SWISHER III C.C. & AUBRY M.P. 1995 — A revised Cenozoic geochronology and chronostratygraphy. [In:] Berggren W.A., Kent D.V., Aubry M.P., Hardenbol J. (eds) — Geochronology Time Scale and Global Stratigraphic Correlation, SEPM Special Publication, 54: 129–212.

BLOW W.H. 1969 — Late Middle Eocene to recent planctonic foraminiferal biostratygraphy. [In:] Proceedings of the First International Conference on Planktonic Microfossils, Geneva 1967, Leiden: Brill.

BOLTOVSKOY E. & WRIGHT R. 1976. — Recent Foraminifera. W. Junk b.v. Publishers — the Hague.

CZAPOWSKI G. 1994 — Sedimentation of Middle Miocene marine complex from the area near Tarnobrzeg (north-central part of the Carpatian Foredeep). Kwart. Geol., 38: 577–592.

CZEPIEC I. 1991 — Rekonstrukcja paleotemperatur w badenianie (mionen M4) na podstawie prawo- i lewoskrętności otwornic planktonicznych. Geol.
AGH, 17: 29–42.

CZEPIEC I. 1996 — Biostratygrafia i warunki depozycji osadów północnej strefy brzeżnej sarmatu Polski. Geologia, Kwart. AGH, 22: 309–338.

GAŹDZICKA E. 1994 — Nannoplankton stratigraphy of the Miocene deposits in Tarnobrzeg area (north-eastern part of the Carpathian Foredeep). Kwart. Geol., 38: 553–570.

GONERA M. 1994 — Palaeoecology of marine Middle Miocene (Badenian) in the Polish Carpathians (Central Paratethys). Bull. Pol. Acad. Sc. Eartch. Sc., 42: 107–125.

KARNKOWSKI P. 1989 — Utwory deltowe przedgórza Karpat. Prz. Geol., 37: 28–32.

KOTARBA M.J., BURZEWSKI W., WILCZEK T., SŁUPCZYŃSKI K., KOSAKOWSKI P. & BOTOR D. 1998a — Model of gaseous hydrocarbon generation in the Miocene strata of the Polish part of the Carpathian Foredeep. Prz. Geol., 46: 737–742.

KOTARBA M.J., KOSAKOWSKI P. & BOTOR D. 1995 — Habitat of hydrocarbons in the Miocene strata of the Polish part of the Carpathian Foredeep. Conference and exhibition Modern Exploration and Improved Oil and Gas Recovery Methods, 1995, Kraków. Extended Abstract Book: 161–164.

KOTARBA M.J., SZAFRAN S. & ESPITALIÉ J. 1987 — A study of organic matter and natural gases of the Miocene sediments in the Polish part of the Carpathian Foredeep. Chem. Geol., 64: 197–207.

KOTARBA M.J., WILCZEK T., KOSAKOWSKI P., KOWALSKI A. & WIĘCŁAW D. 1998b — A study of organic matter and habitat of gaseous hydrocarbons in the Miocene strata of the Polish part of the Carpathian Foredeep. Prz. Geol., 46: 742–750.

ŁUCZKOWSKA E. 1964 — Stratygrafia mikropaleontologiczna miocenu w rejonie Tarnibrzeg–Chmielnik. Pr. Geol. Kom. Nauk Geol. PAN Oddz. w Krakowie, 20: 1–71.

ŁUCZKOWSKA E. 1967 — Paleoekologia i stratygrafia mikropaleontologiczna miocenu okolic Grzybowa koło Staszowa. Acta Geol. Pol., 17: 219–249.

ŁUCZKOWSKA E. 1972 — Facjostratotyp sarmatu facji przybrzeżnej na Roztoczu Lubelskim. Spraw. z Pos. Komis. Nauk. PAN Oddz. w Krakowie, 16: 224–226.

ŁUCZKOWSKA E. 1974 — Miliolidae (Foraminiferida) from the Miocene of Poland. Part II. Biostratygraphy, Paleoecology and Systematics. Acta Palaeont. Pol., 19: 1–176.

MARTINI E. 1971 — Standard Tertiary and Quaternary calcareous nannoplankton zonation. [In:] Proceedings of the II Planktonic Conference, Roma 1969. Rome, Edizioni Tecnoscienza: 739–785.

MURRAY J.W. 1973 — Distribution and ecology of living bentonic foraminiferids. Heinemann, London, 1–288.

OSZCZYPKO N. 1997 — The Early–Middle Miocene Carpathian peripheral foreland basin (Western Carpathians, Poland). Prz. Geol., 45: 1054–1063.

PAPP A. 1963 — Die biostatigraphische Gleiderung des Neogens im Winner Backen. Mitteilungen der Geologischen Gesellschaft, Wien, 56: 225–317.

RUTKOWSKI J. 1976 — Detrytyczne osady sarmatu na południowym obrzeżeniu Gór Świętokrzyskich. Pr. Geol. Kom. Nauk Geol. PAN Oddz. w Krakowie, 100: 1–72.

SZAFRAN S. 1990 — Warunki paleotemperaturowe utworów miocenu autochtonicznego zapadliska przedkarpackiego w Polsce. Spraw. z Pos. Komis. Nauk. PAN Krak., 32: 162–164.

SZCZECHURA J. 1982 — Middle Miocene Foraminiferal Biochronology and Ecology of SE Poland. Acta Palaeont. Pol., 27: 3–44.