GEOLOGICKÝ ZBORNÍK — GEOLOGICA CARPATHICA, 40, 1, BRATISLAVA, FEBRUARY 1989, Pp. 23—36

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THE EVOLUTION OF THE MIOCENE BASIN IN THE POLISH OUTER CARPATHIANS AND THEIR FORELAND

(Figs. 7)

Abstract: During the Lower Miocene two separate basins existed: one tardigeosynclinal within the Outer Carpathians and second in the Carpathian foreland with molasse sedimentation. Analysis of facies distribution of the Miocene deposits of the Carpathian foreland shows that they migrated towards the north and east together with advancing margin of the Carpathians. Two distinct periods of the sea transgression onto the Carpathian foreland and onto the Carpathians took place: first one at the beginning of the Early Badenian and second one at the boundary of the Middle and Late Badenian.

Резюме: В нижнем миоцене существовали два самостоятельных бассейна: один тардигеосинклинальный в рамках Внешних Карпат и второй в форланде Карпат, с молассовой седиментацией. Анализ распределения фаций в осадочных породах миоцена в Карпатском форланде показывает что они перемещались к северу и востоку вместе с поступающим краем Карпат. Определяются два периода трансгресии моря на Карпатский форланд: в начале нижнего бадена и на рубеже среднего и позднего бадена.

Introduction

The Miocene sediments in Southern Poland were deposited in two areas: on the Carpathian Fold and Thrust Belt and its foreland which developed on the North European Platform.

Recent distribution of these deposits within the Alpine orogenic area (the Carpathians and the Carpathian Foredeep) is an effect of the Middle Miocene tectonic movements caused by the collision of the North European Plate and the Slovakian Block (the Pannonian microplate). During these movements the Carpathian sediments had been folded, detached and flysch nappes were overthrust on the molasse deposits of the Carpathian Foredeep. These sediments recorded consecutive stages of the Carpathians overthrusting movements. Simultaneously with the overthrusting, migration of the Miocene depositional centres took place, proceeding towards the north. At the same time a part of the molasse deposits of the southern part of the Carpathian Foredeep was folded, and displaced towards the north, creating a narrow belt along the northern margin of the Carpathians. Both the Carpathians and folded Miocene deposits are overthrust onto the autochthonous Miocene deposits covering the North European Platform. Bulk of sediments representing mainly a lower

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part of the Miocene remained in the south, beneath the Carpathian nappes. According to the deep drillings the amplitude of the overthrust is at least 40 km, but seismic data suggest that in the western part of the Polish Carpathians this amplitude exceeds 60 and in the eastern part 90 km, respectively. It is indicated by the axis of the geomagnetic anomaly which probably coresponds to the southern margin of the North European Platform (J a n k o w s k i et al., 1985).

During the Miocene, andesite volcanism took place. The youngest generation of the andesite dykes were formed at the Badenian—Sarmatian boundary (12.7 ± 0.3 my, B i r k e n m a j e r et al., 1987). All these intrusive bodies are situated in the southernmost part of the Magura Nappe and along the eastern part of the Pieniny Klippen Belt, in the region of steep descending of the North European Platform.

The Early Miocene period

At the turn of the Oligocene and Miocene, prior to the Eggenburgian transgression in the Vienna basin, the Magura basin started to be folded (O s z c z y p k o — Ż y t k o, 1987; Ś l ą c z k a — O s z c z y p k o, 1987) and, probably, the front of the Magura nappe was formed (Fig. 1). Ahead of that front in Silesian, Subsilesian and Skole basins sedimentation of flysch continued (Krosno Fm.). During the Early Miocene, in the lower part of the sequence, turbidites still prevailed (medium- to thin- bedded sandstones and mudstones). Towards the top of the sequence they pass gradually into shaly facies. Within these sediments olistolithes were locally deposited. In the Silesian basin olistolithes and also clastic material were derived from the front of the Magura and Fore-Magura Nappes. In the Skole basin, the olistolithes are composed both of blocks of Subsilesian marls and blocks of diatomic rocks (K o t l a r c z y k, 1985).

NE from the flysch basin, in the Boryslav—Pokuty basin, molasse sediments (Vorotyshche Fm.) were deposited. They are represented by shales, mudstones, salt rocks and gypsum with intercalations of conglomerates. Material was mainly derived from the north. In Poland these deposits build up small, detached thrust sheets near Przemysl and it is supposed that the main part of it exists beneath the Carpathians. The occurrence of the blocks derived from the Carpathians in the Vorotyshche Fm. shows that their frontal part was uplifted, separating the internal — flysch basin from the external — molasse one.

The age of the youngest flysch deposits has not yet been precisely recognised. Foraminifera are very scarse and assemblages from the Krasno Fm. with *Globigerinoides sacculifer, G. quadrilobatus* and *G. trilobus* can be attributed to the Eggenburgian (N o w a k et al., 1985). Preliminary nannoplankton data (J. Ś l é z a k, pers. comm. 1988) show also existence of the Eggenburgian zone (NN 3) and within the highest part of the Upper Krosno Fm. even zone NN 4 (Karpatian) does occur. Nannoplankton data are partly confirmed by radiometric ages (see Van C o u v e r i n g et al., 1981), ranging from 18.4 my (Ottnangian) at locality Bandrow to 15.7 ± 0.3 my at locallity Krywe.

During the Ottnangian, sedimentation of continental and locally brackish molasse embraced also more external part of the contemporaneous foredeep. In its Polish part the molasse deposits are known both from allochthonous (Stebnik Fm.) and autochthonous (Sucha Fm.) position (Fig. 1). The Stebnik

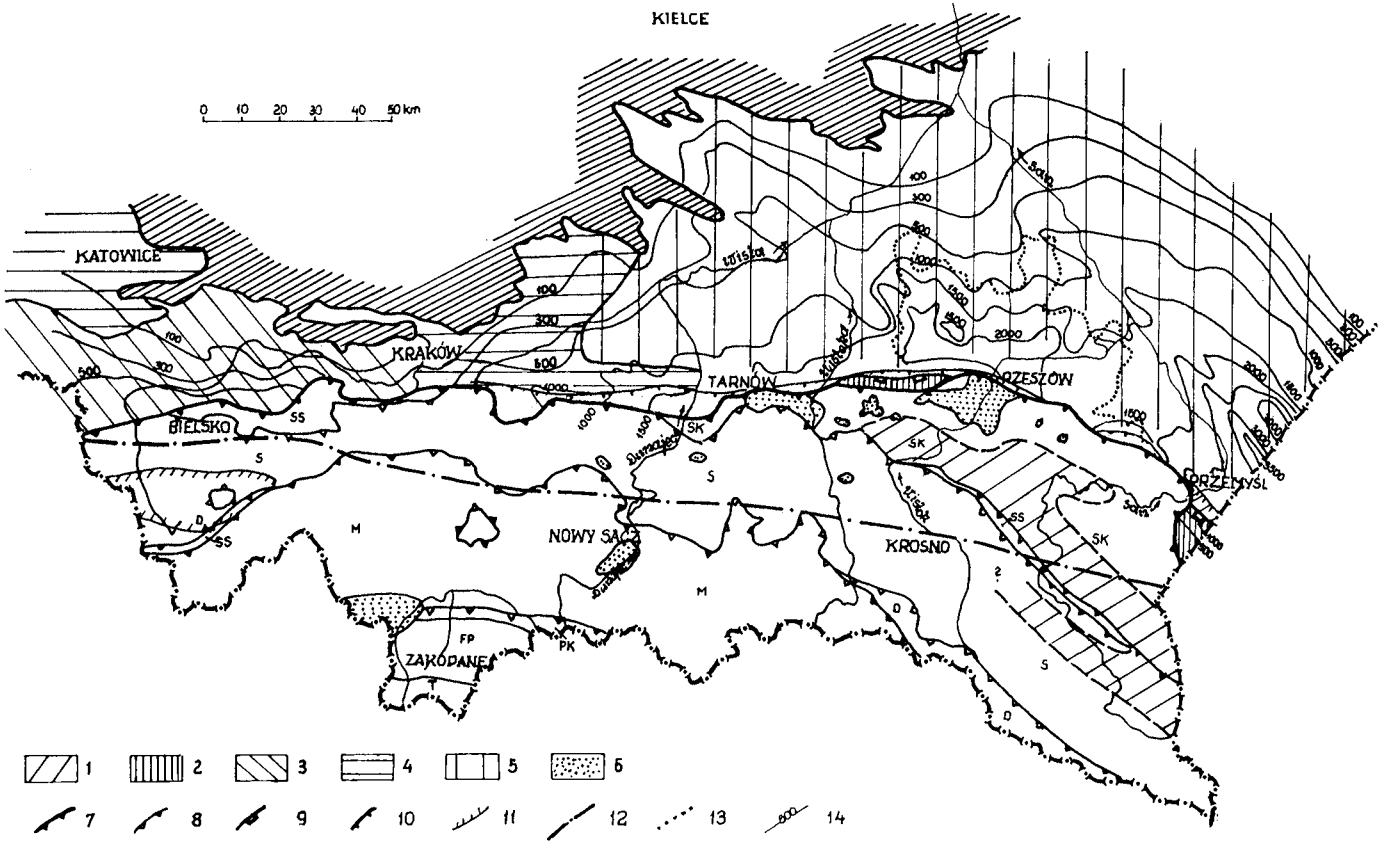

Fig. 1. Map of distribution and thickness of the Miocene deposits of the Carpathian Foredeep and Foreland and Polish West Carpathians.

Legend: 1 - Lower Miocene turbidite deposits of the Outer Carpathians; 2 - Lower Miocene allochthonous deposits in front of the Carpathians; 3—5 - Miocene foredeep and foreland deposits: 3 - Lower Badenian, 4 - Middle and Upper Badenian, 5 - Lower Sarmatian; 6 - piggy-back basin and intramontane basin deposits; 7 - Carpathian overthrust; 8 - other important overthrusts within the Carpathians; 9 - overthrust of the Sambor — Rozniatov (Stebnik) unit; 10 - northern limit of the Badenian folded deposits; 11 - area devoid of the Miocene marine deposits; 12 - northern limit of autochthonous Lower Miocene deposits, beneath the Carpathians; 13 - area devoid of the Lower and Middle Badenian deposits ("Rzeszów Island"); 14 - thickness of the Miocene deposits, in metres.

Additional symbols of tectonic units: Sk — Skole unit; SS — Subsilesian unit; S — Silesian unit; D — Dukla, Grybów and Fore-Magura units; M — Magura unit; PK — Pieniny Klippen Belt; FP — Podhale Flysch; T — Tatra units.

Fm. is preserved in detached thrust sheets in the front of the Carpathians between Bochnia and Przemyśl (Stebnik unit Fig. 1). They constitute western prolongation of the Sambor—Rozniatov unit of the Eastern Carpathians. Lower part of the Stebnik Fm. is represented by sandstones and conglomerates while the upper part is composed of pink and grey marly shales and mudstones. A part of the Stebnik Fm. may have existed much farther towards the south, beneath the Carpathian overthrust, in autochthonous position. Probably, red, coarse grained sediments with flysch olistolithes recorded lately beneath the Skole nappe at a depth of 7000 m in the borehole Kuzmina 1 (Cieszkowski, Slaczka, unpublished data, 1988) represent these deposits. The Sucha Fm. is known only from boreholes and occurs under the Western Carpathians (Ślączka, 1977). The relationship between the Stebnik and Sucha Fms. is not clear. The latter one consists of red clayey shales and sandstones with an intercalation of thick olistosthrome unit, built of flysch blocks up to several metres in diameter. Occurrence of these blocks shows beyond any doubt that prior to the Karpatian the frontal part of the Western Carpathians was folded, uplifted and eroded.

Ottnangian deposits of the Carpathian Foredeep contain scarce reliable paleontological data. Besides redeposited, older flysch foraminifera there are scarse Miocene species.

During the Karpatian, sedimentary basin between Przemysl and Sucha was relatively narrow. It was connected both with the Eastern Carpathians and Moravian—subAlpine basins. The sediments (Balice Fm.) are preserved in a thrust slice in front of the eastern part of the Polish Carpathians (Stebnik unit-prolongation of the Sambor-Rozniatov unit) and in the western part under the Carpathians (Stryszawa Fm.). The Balice Fm. is represented mainly by shales and marly shales with intercalation of friable sandstones (Ney, 1968). Their age was established due to planktonic foraminifera: *Globigerina bolli*, *Globigerinoides bisphericus*, *G. trilobus* (Ney et al., 1974). The Stryszawa Fm. covering the Sucha Fm., is developed in a mudstone-shaly series with conglomerates. Material of conglomerates was being derived both from the Carpathians and from the Foreland bulge. The age is based on occurrence of *Globoquadrina dehiscens* and *Globigerina bolli* (Strzepka, 1981). Towards NW, in the area of Cieszyn—Bielsko, the Karpatian sediments are represented by sandstones, calcareous mudstones and claystones (Zebrzydowice FM. - Buła—Jura, 1983), and locally sandstones and conglomerates bearing shallow water macrofauna (Kuciński—Nowak—Szotowa, 1975).

The Middle Miocene period

After the Karpatian, folding and thrusting of the Flysch Carpathians continued and they moved farther towards the north (25—30 km, Oszczypko—Tomas, 1985; Oszczypko—Ślączka, 1986). As a result of these movements the Carpathians reached in the region of the Moravian Gate their present position (Jurkova, 1979), In the eastern part, the Carpathian margin approached a region situated about 60 km from the present day position (Fig. 2). At the same time, a big part of the foreland, up to the Holy Cross Mts. and the Lublin Upland, was invaded by the sea (Radwanski, 1968; Ale-

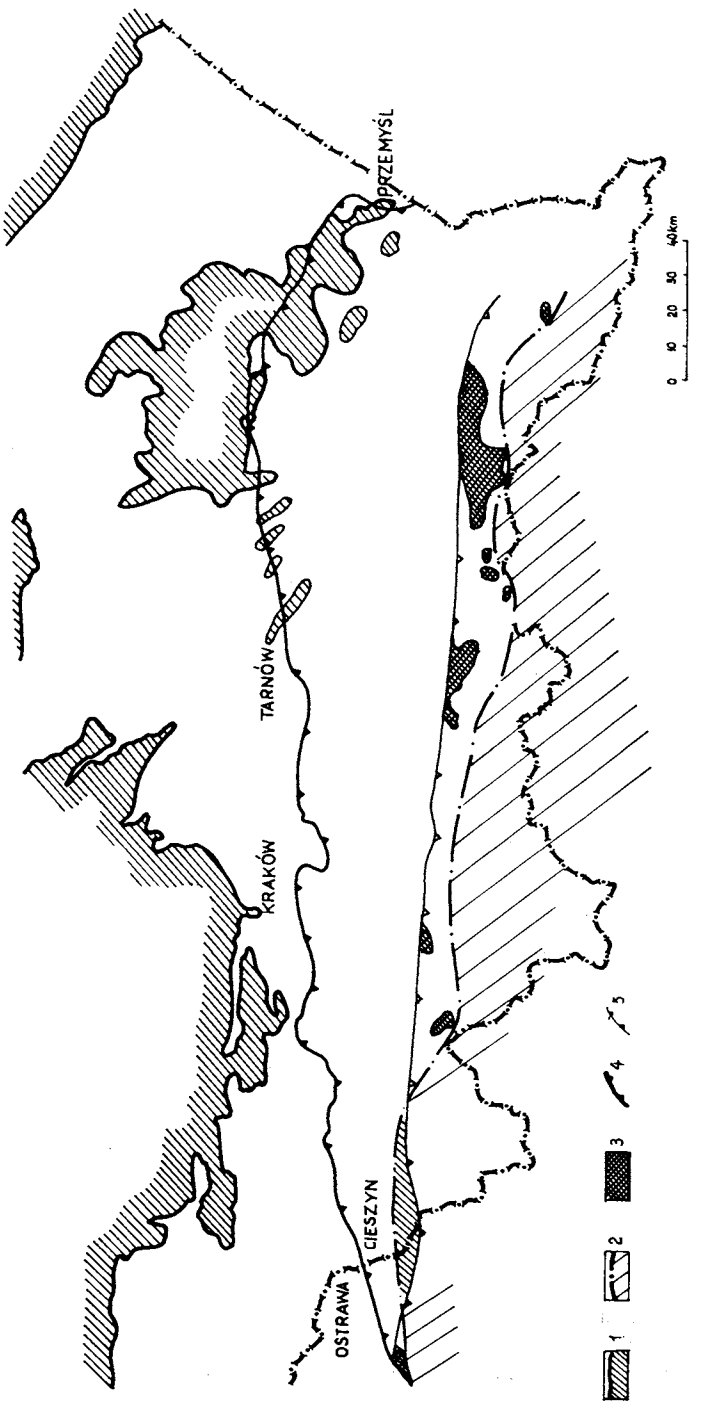

Fig. 2. Paleogeographic and palinspastic map of the Outer Carpathians and their foreland in the Early Badenian (after Oszczypko—Tomas, 1986, simplified).

Legend: 1 - area devoid of the marine Miocene deposits; 2 - southern margin of the Lower Badenian basin; 3 - erosional outliers of the Lower Badenian deposits on the Carpathians; 4 - present-day front of the Carpathian overthrust; 5 - front of the Carpathian overthrust in the Early Badenian.

xandrowicz, 1971). However, the marginal part of the Carpathians was covered by the sea, hence, their overthrusting took place partial under sea level. During the Lower Badenian three types of basins can be distinguished: a piggy-back on the Carpathians, a foredeep basin at the front of the Carpathians and abroad foreland basin. In the hinge zone between the foredeep and foreland, several islands developed. The basins were connected with the Moravian basin in the west and with the eastern Paratethys. The detailed study of the eastern part of the foredeep suggests existence of several facies (Fig. 3). In the deepest part of the basin corresponding to the upper bathial zone, shales with turbiditic intercalations were deposited. The foreland and piggy-back basins were dominated by neritic clayey-sandy deposits. In littoral zones sands and lithotamnium limestones were developed. The fore-deep basin was supplied both from the Carpathians and from the platform (Metacarpathian Swell). Thickness of the Lower Badenian strata is variable changing from several metres in the marginal parts (piggy-back and foreland basins) up to 1000 m in the western part of the foredeep (sedimentation rate up to 133 cm/1000 yr). The age of the Lower Badenian sediments has been established on the basis of micropaleontological investigations (see Alexandrowicz, 1963; Łuczkowska, 1963; Ney et al., 1974), and two foraminifera horizons have been defined: the lower one with *Orbulina suturalis* and the upper one with *Uvigerina costai.*

During or shortly after the Early Badenian, the front of the Carpathians moved to the NE, and west from Kraków reached its present position. Towards the east (Fig. 4) this front was situated more and more south from its present position (near of Przemysl about 40 km). During the overthrusting movements, a part of the Lower Badenian deposits became folded, and displaced towards the north in front of the advancing Carpathians (Fig. 4). In the Western Carpathians the piggy-back basin, which previously had been developed on Subsilesian unit, became strongly shortened and left lateral strike-slip faults were formed (Oszczypko — Tomaś, 1985).

As a result of tectonic movements during that part of the Miocene, the basin situated north from the Carpathians became partly separated from the Eastern Paratethys and salinity crisis began. The rock salt precipitated in the deeper part of the basin, close to the margin of the Carpathians (Garlicki, 1971, 1979). Towards the North (Fig. 5), chloride facies was replaced by the sulphate one (anhydrite and gypsum) and in the marginal part there prevailed carbonatic facies. Sulphate facies deposits were also deposited along the southern margin of the basin, partly on the Carpathians. In the area of Wieliczka, at the end of the sedimentation of chlorides, the southern part of the evaporitic basin was uplifted and eroded. The salt blocks and pebbles together with barren rocks had been redeposited by subaqueous sediment gravity flows towards the north (Kolasa — Ślączka, 1985). At the final stage of the salinity crisis, mainly clayey material was deposited under conditions of the euxinic environment (Chodenice Beds). The lower part of these beds is characterized by occurrence of *Globigerina bulloides* and *Spirialis* (Ney et al., 1974). Thickness of the Middle Badenian depositis attains 110 m, except the area of the Chodenice Beds, where their thickness exceeds 600 m (sedimentation rate about 120 cm/1000 yr.), that of gypsum and anhydrite varying commonly from 10 to 30 m.

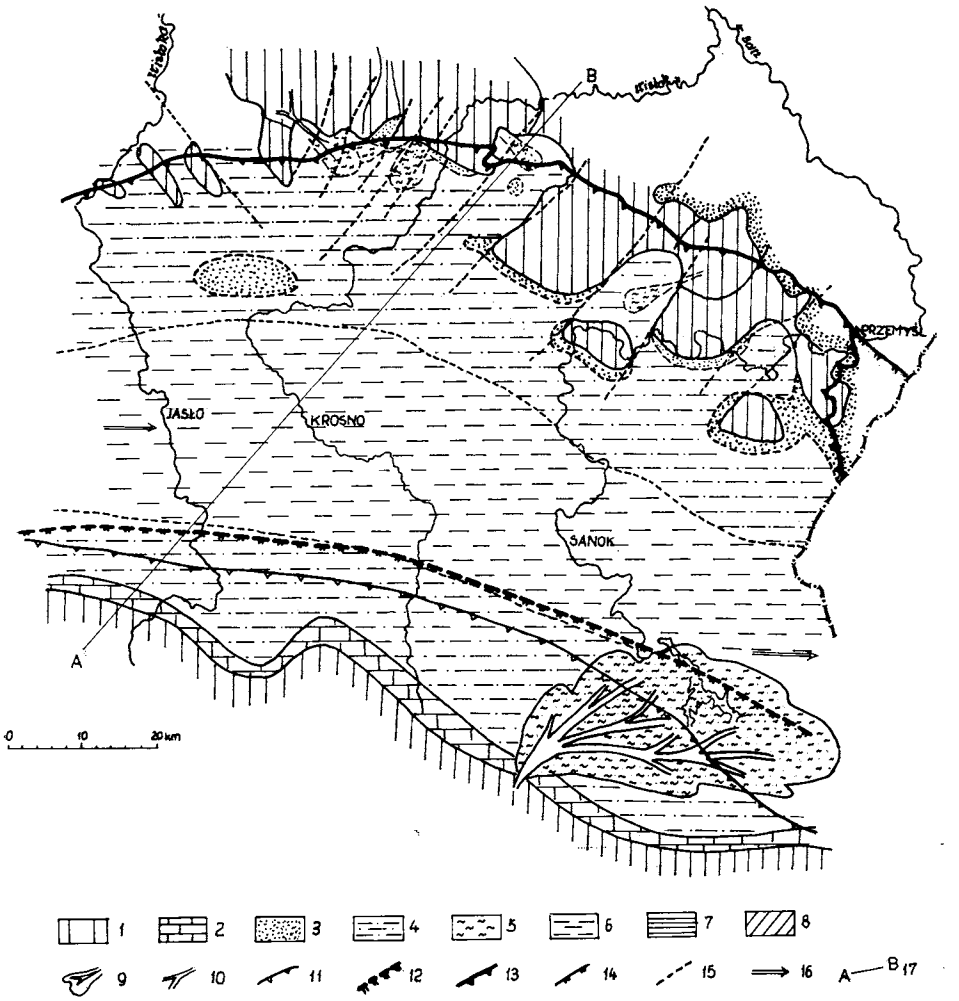

Fig. 3. Paleogeographic and palinspastic map of the Early Badenian between Rzeszów and Przemysl.

Legend: 1 - continental area; 2 - shore carbonate facies with Litothamnian reefs; 3 - shore siliciclastic facies; 4 - sublittoral facies — muds and cross-bedded sandstones; 5 - fan delta facies; 6 - hemipelagic facies (upper bathial) and low density turbidites; 7—8 - evaporites: 7 - gypsum and anhydrite, 8 - halite; 9 - fan delta; 10 - channel; 11 - northern border of the Skole unit; 12 - northern border of the Sambor-Rozniatov (Stebnik) unit; 13 - present day border of the Skole unit; 14 - present day border of the Sambor-Rozniatov (Stebnik) unit; 15 - synsedimentary faults; 16 - direction of distribution of clastic material; 17 - palinspastic cross-section.

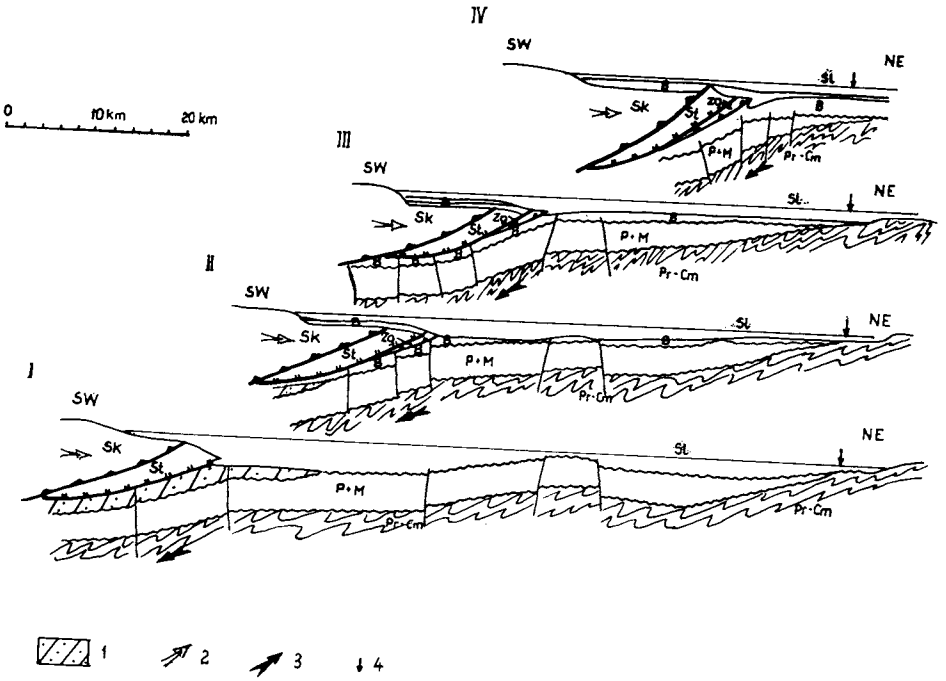

Fig. 4. Palinspastic cross-section.
Legend: 1 - Lower Miocene deposits (Stebnik and Balice Fms.); 2 - direction of the Carpathian overthrusting; 3 - direction of the underthrusting of the North European Platform; 4 - present day northern border of the Carpathians. Other symbols: Sk - Skole unit, St - Sambor-Rozniatov (Stebnik) unit, Zg - folded and overthrusted Badenian deposits, Pr-Cm - Precambrian and Lower Cambrian, P-M - Paleozoic and Mezozoic, B - Badenian sediments; I - Early Badenian (16 ma), II - Middle Badenian (15 ma), III - Late Badenian (14 ma), IV - Early Sarmatian (13 ma).

During the Late Badenian, after the salinity crisis, the Carpathian Foredeep became deeper and was displaced slightly towards the north (Fig. 4). The islands within the basin, separating the foredeep and foreland basins became covered by the sea (Fig. 6). Besides the marginal part, also central part of the Carpathians, near Nowy Sacz was invaded by the sea, and a vast piggy-back basin developed. This basin was supplied from the south by a system of rivers which built several small fan deltas prograding towards the north (D o k t o r, 1983; C i e s z k o w s k i et al., in print). The deeper eastern part of the foredeep basin was dominated by distal turditic facies (Fig. 6). Towards the north, in the foreland basin, turbidites pass into neritic clays and muds with *Pecten*, *Chlamys* and other moluscs. Along the northern margin (Roztocze and Holy Cross Mts. area) litoral facies with reef limestones and detritic sediments rich in fauna were developed. Locally, carbonate facies existed along the southern

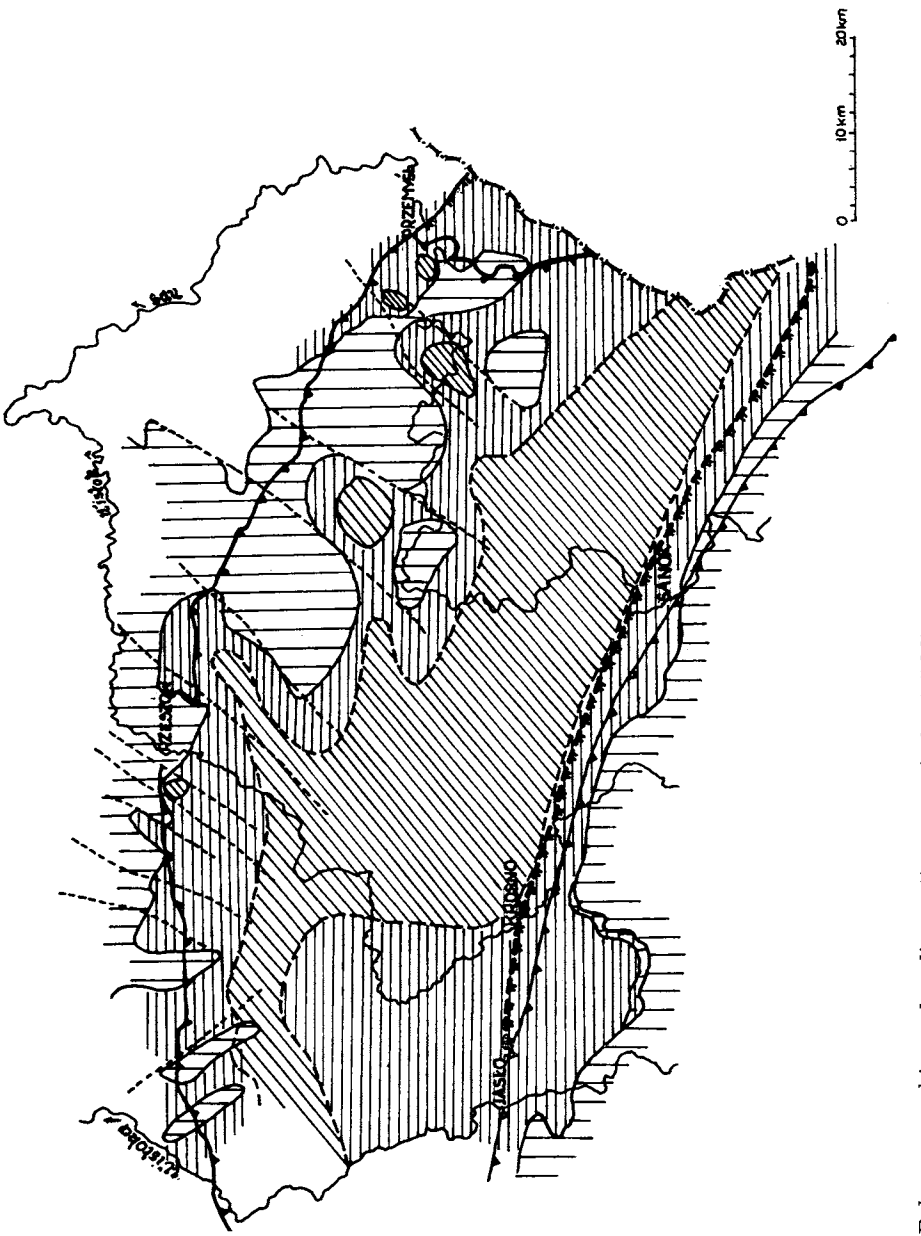

Fig. 5. Paleogeographic and palinspastic map of the Middle Badenian (salinity crisis) between Przemysl and Rzeszów. For explanations see Fig. 3.

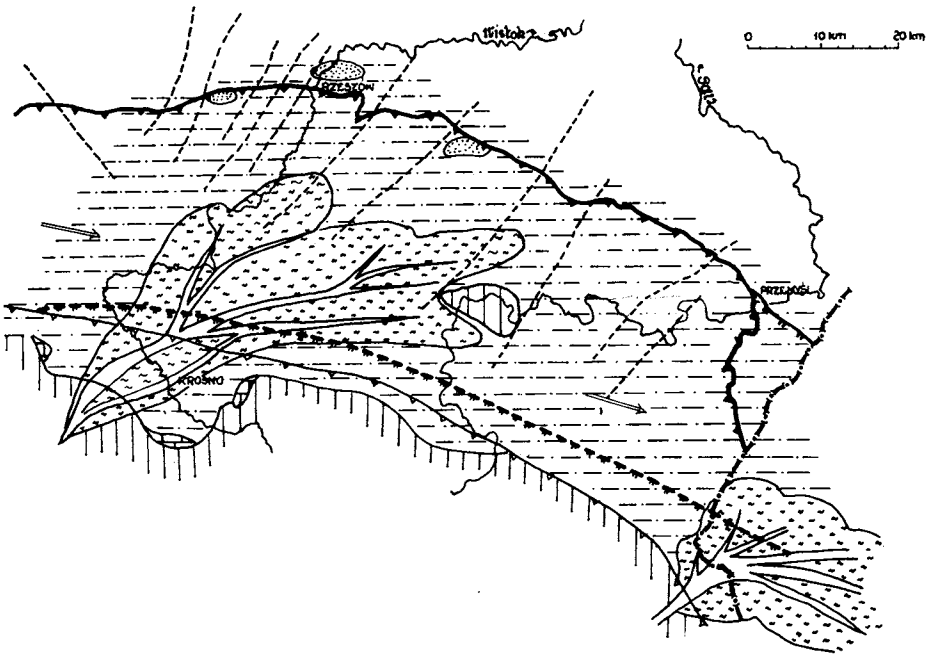

Fig. 6. Paleogeographic and palinspastic map of the Late Badenian between Przemysl and Rzeszów (prepared in collaboration with Dr. S. Leszczynski and Dr. A. Tomas). For explanation see Fig. 3.

margin. In the western part, between Kraków and Bochnia, siliciclastic sediments deposited partly by turbidite currents (Otfinowski, 1981). In the foreland basin thickness of the Upper Badenian neritic sediments did not exceed 80 m, but in foredeep basin (between Tarnów and Rzeszów) they attained 1000 m, with the rate of sedimentation up to 70 cm/1000 yr. and the rate of subsidence exceeding 100 cm/1000 yr. Due to overthrusting movements of the Carpathians a bulk of the Upper Badenian sediments is now covered by the Carpathian nappes.

At the beginning of the Sarmatian, the Carpathians situated east of the Dunajec river, moved about 20 km towards the north (Oszczypko—Tomas, 1985), covering a part of the Late Badenian basin. A part of the Badenian deposits was incorporated in the folded belt in front of the Carpathians (Zgłobice unit, Fig. 4, Kotlarczyk et al., 1985). Sedimentary depocentres migrated further towards the east and relics of the sea withdrew from the Upper Silesian area. Salinity of the basin started to decrease. In the southern part of the basin, in the vicinity of tectonically active Carpathian margin fan delta and turbiditic sedimentation took place (Fig. 7) while in the Rzeszów area, in the embayment situated on the Skole nappe, marly sedimentation did prevail. Towards the NE turbiditic sedimentation was replaced by clayey-sandy (Krakowiec Fm.) and marly facies. Litoral sediments along the northern margin are represented by detritic (sands and

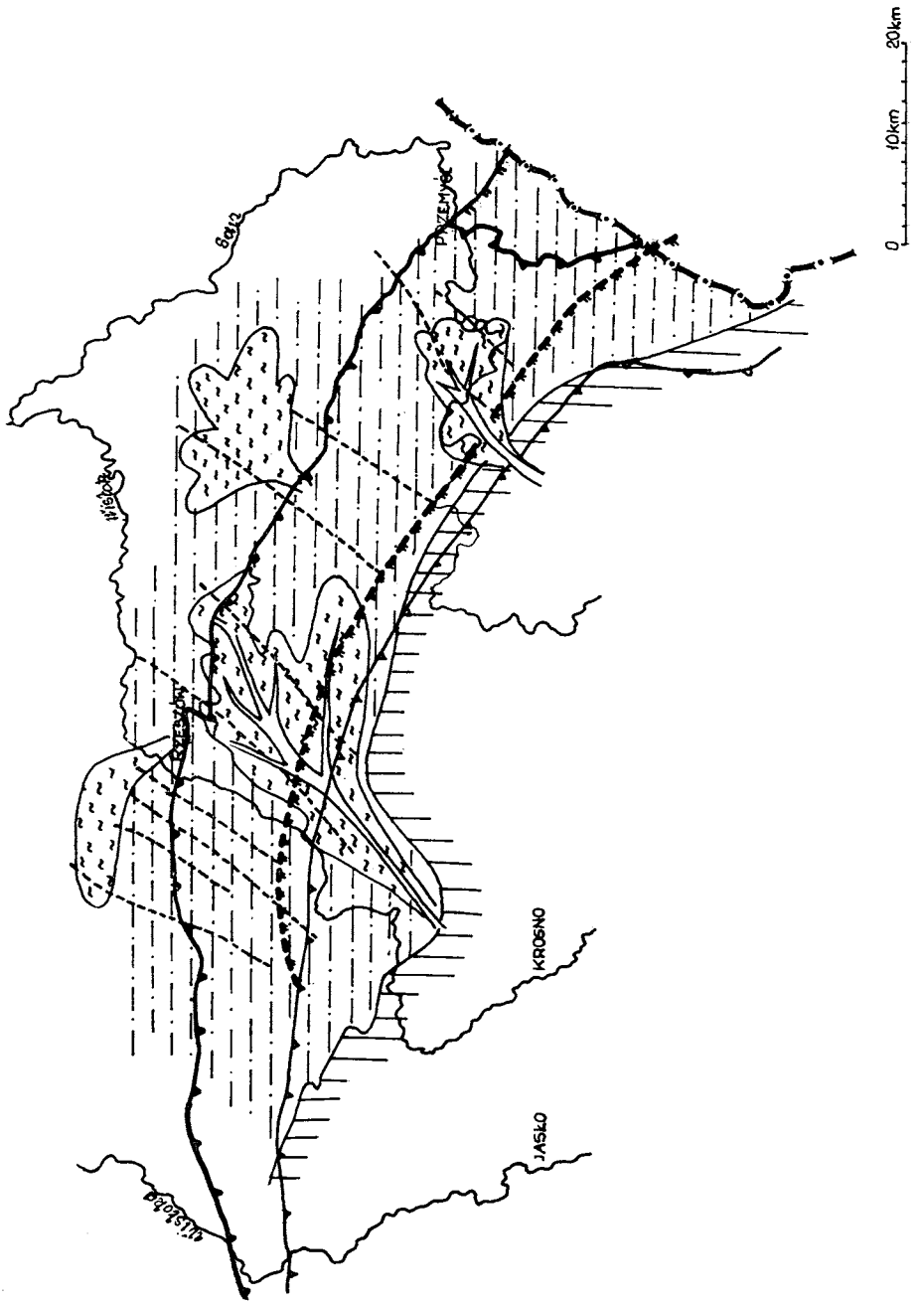

Fig. 7. Paleogeographic and palinspastic map of the Early Sarmatian between Przemysl and Rzeszów (prepared in collaboration with Dr. S. Leszczyński and Dr. A. Tomas). For explanations see Fig. 3.

gravels) and calcareous (Serpula reef) facies. In the innermost part of the Outer Carpathians (Orava basin), an intramontane basin developed with fluvial and paludine facies (sands, marls and lignites) (Birkenmajer, 1978). In the Silesian area the marine deposits are covered by continental ones (gravels, sands and clays with lignite). Thickness of the sediments increases rapidly towards the SE, reaching more than 2400 m in the area of maximal subsidence between Przemysl and Rzeszów (Fig. 7), and the rate of sedimentation was up to 160 cm/1000 yr. (comp. Vass — Čech, 1983). These sediments contain low salinity fauna with *Anomalinoides dividens, Quinqueloculina carreri ovata, G. sarmatica* and *Elphidium hauerianum* (Ney et al., 1974; Łuczkowska, 1964).

At the end of the Early Sarmatian, regional regression took place and the sea retreated towards the SE. After the Early Sarmatian (Moldavian phase) the Carpathians between Tarnów and Przemysl moved towards NE, reaching their present position (Oszczypko — Tomas, 1985). In the inner part of the Outer Carpathians vertical movements began.

Conclusions

1. During the Early Miocene in the southern area of Poland there existed two separate basins: the residual one, which was continuation of the Cretaceous—Paleogene Flysch basin, and the second one, in front of the Carpathian orogen, on the southern margin of the North European Platform with molasse sedimentation. Rate of sedimentation in the molasse basin was greater than that in the flysch basin. These basins were separated by frontal, uplifted part of the Carpathians.

2. Analysis of the distribution and development of the Miocene sediments shows that tectonic evolution of the foredeep and marginal part of the Outer Carpathians was generally continuous. The foredeep basin together with a bulge situated north from it, migrated towards the north and east, together with the moving front of the Carpathian orogen. It is, however, possible to distinguish several periods of increased tectonic activity. During Eggenburgian ("Savian phase"), tectonic movements were evident mainly in the westernmost area of the Outer Carpathians, while in the Polish area, these activities were limited to the frontal, uplifted part of the orogene. During the Late Karpatian, the marginal part of the Outer Carpathians became folded, uplifted and eroded. At the beginning of the Early Badenian there was well-marked displacement of the foredeep basin towards the north and distinct expansion of sea on the Carpathian margin, took place at the bondary between the Middle and Late The next expansion of the sea, proceeded by development of slumps near the Carpathian margin, took place on the border between the Middle and Late Badenian, after salinity crisis. Both events were accompanied by quick subsidence of the foredeep basin and they were probably connected with extensional movements and maximal volcanic activity within the Panonian Basin (comp. Royden et al., 1983; Hámor et al., 1987).

3. The overthrusting of the Carpathians onto the foredeep was caused by movements of the North European Platform to the South, and the Carpathians towards the north. In the Outer Carpathians there is a notable difference in structure between they margin of the eastern and western segments respectively.

The structures of the margin of the East Carpathians invite comparison with modern trenches and subduction zones (Ślączka — Oszczypko, 1987a). This comparison leads to the interpretation of that part of the Carpathians as an accretionary prism, where sedimentation and deformation proceeded simultaneously. In contrary, the West Carpathians flysch nappes are horizontaly overthrust onto the North European Platform. These observations suggest a change of deflection of the subducted plate along the Polish segment of the Carpathians (com. Royden and Karner, 1984).

Acknowledgments: We would like to express our gratitude to dr. hab. Witold Zuchiewicz for his assistance in preparing the manuscript. The part of research was supported by fund from the Institute for Oil and Gas, Kraków.

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The authors are responsible for language correctness and content.

Manuscript received September 9, 1988.