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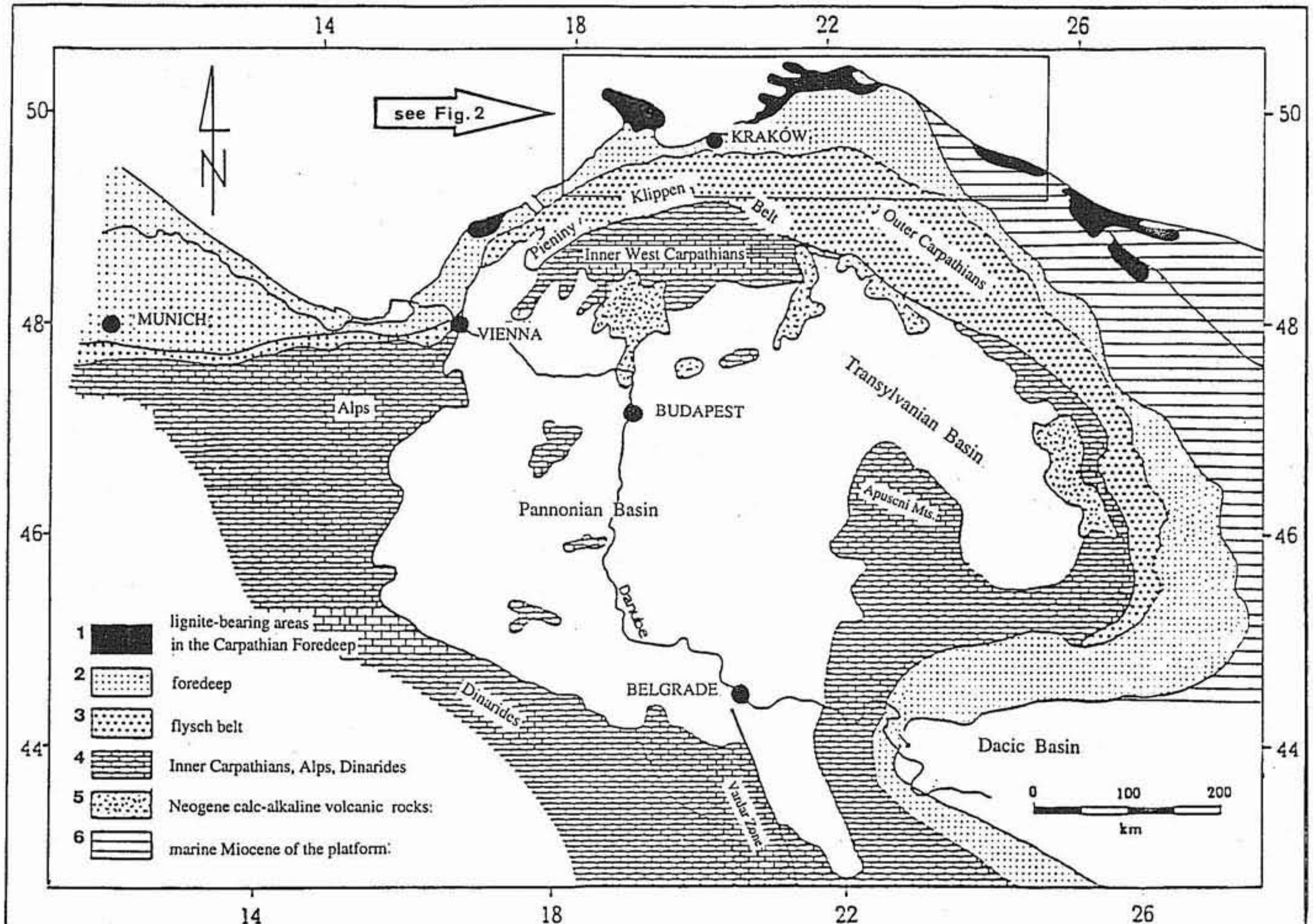
Neogene coal-forming sedimentation in the Carpathian Foredeep, southern Poland

Phytogenic sediments of the Carpathian Foredeep originated in close relationship to transgressive and regressive stages of the Badenian/Sarmatian marine cycle. Allocyclic mechanisms (sea level changes) mostly influenced phytogenic accumulation there. Phytogenic sedimentation was controlled by basement morphology. Brackish conditions, favourable for peat-forming vegetation, covered the valleys developed at the southern slope of the Holy Cross Mts. Therefore, caustobiolithes occur mostly along the northern margin of the foredeep.

INTRODUCTION

Phytogenic sediments are common in numerous profiles of the Carpathian Foredeep Neogene, though they comprise only a small part of the great rock mass of the basin's sedimentary fill. Studies of the basin architecture and history, and also exploration for fossil fuel resources, were two major reasons that the phytogenic deposits were a topic of many works as early as the end of the 19-th century, i.e. by J. B. Pusch, H. Łabędzki, A. M. Łomnicki, F. Roemer, R. Michael and W. Friedberg (see A. S. Makowski, 1947; W. Krach, 1954, 1958, 1962; S. W. Alexandrowicz, 1963; B. Areń, 1971), and during the first half of the twentieth century (K. Kowalewski, 1923, 1930; J. Samsonowicz, 1932; J. Czarnocki, 1933).

Phytogenic deposits form thin benches, lenses and intercalations alternating with clastics and clays. They are most frequent in the northern, distal margin of the foredeep, and on its northern foreground on the Palaeozoic platform area, outside tectonic frames of the depression. They form an irregular, intermittent belt from Upper Silesia through the southern foreland of the Holy Cross Mts. to the south-west edge of the Lublin Upland (Figs. 1, 2). Neogene phytogenic deposits also occur outside Poland: to the west they are known in Czechia (Lažánki deposit; V. Havlena, 1964); to the east they are known in Ukraine.



see Fig. 2
MUNICH
VIENNA
KRAKÓW
BUDAPEST
BELGRADE
Pieniny Klippen Belt
Inner West Carpathians
Outer Carpathians
Alps
Transsylvanian Basin
Apuseni Mts.
Pannonian Basin
Danube
Dinarides
Vardar Zone
Dacic Basin
0 100 200
km
14 18 22 26
44 46 48 50
1 lignite-bearing areas in the Carpathian Foredeep
2 foredeep
3 flysch belt
4 Inner Carpathians, Alps, Dinarides
5 Neogene calc-alkaline volcanic rocks:
6 marine Miocene of the platform:

Relatively rich lignite deposits occur there near Dżurów, Myszyna and Ispas in the Sub-Carpathian Lignite District and between Rawa Ruska, Złoczów and Krzemieniec in the Dniester Lignite District (N. Zieleznova *et al.*, 1983).

SEQUENCES WITH PHYTOGENIC DEPOSITS — OCCURRENCE AND LITHOLOGY

Phytogenic deposits commonly occur in the lower part of the Miocene profile of the Carpathian Foredeep. These deposits are locally lignite-bearing and, occasionally, they compose lignite resources. The deposits consist of:

— hypolignite (according to the Alpern Coal Classification, B. Alpern *et al.*, 1989) with ash dry content A^d up to 30%;

— coaly middlings with A^d 30–50%;

— clayey middlings with A^d 50–80%;

— humic clay with A^d more than 80%;

— palaeosols with coalified root fragments (rhisoids).

Coaly/clayey middlings and humic clay include fine-dispersed lignite matter, so-called coal dust.

Phytogenic deposits occur inside few major types of rock series, which are:

— sands and sandy silts with clay intercalations, developed along southern margin of the Holy Cross Mts., in the Opatówka river valley and in the vicinity of Sandomierz and Tarnobrzeg (S. Pawłowski *et al.*, 1985);

— clays at the southern border of the Lublin Upland, near Zaklików, Węglin and Trzydnik (M. Bielecka, 1957, 1967);

— clays with sandy intercalations in the Korytnica Embayment, in the vicinity of Chomentów and Działoszyce Trough near Proszowice (J. Czarnocki, 1932*a*, *b*, 1933);

— silts and silty clays with sandy intercalations (marly in place) in the Upper Silesian part of the Carpathian Foredeep (S. W. Alexandrowicz, 1970*a*, *b*; S. W. Alexandrowicz, A. S. Kleczkowski, 1974).

In Upper Silesia, phytogenic deposits also occur among clays in the upper part of the Miocene profile (Fig. 3).

Phytogenic deposits of the Carpathian Foredeep originated in a continental/brackish environment, sometimes with occasional marine influence (intercalations of marine sediments). They contain fresh-water and brackish fauna (gastropods, bivalves and foraminifers).

Fig. 1. Position of the northern part of the Carpathian Foredeep on a background of the Paratethys Miocene basin (after A. Becker, 1993, modified)

Położenie północnej części zapadliska przedkarpackiego na tle mioceńskiego basenu Paratetydy (według A. Beckera, 1993, uzupełnione)

1 — obszary węglonośne w zapadlisku przedkarpackim; 2 — zapadlisko; 3 — strefa fliszowa; 4 — Karpaty wewnętrzne, Alpy, Góry Dynarskie; 5 — wapienno-alkaliczne skały wulkaniczne neogenu; 6 — miocen morski na platformie

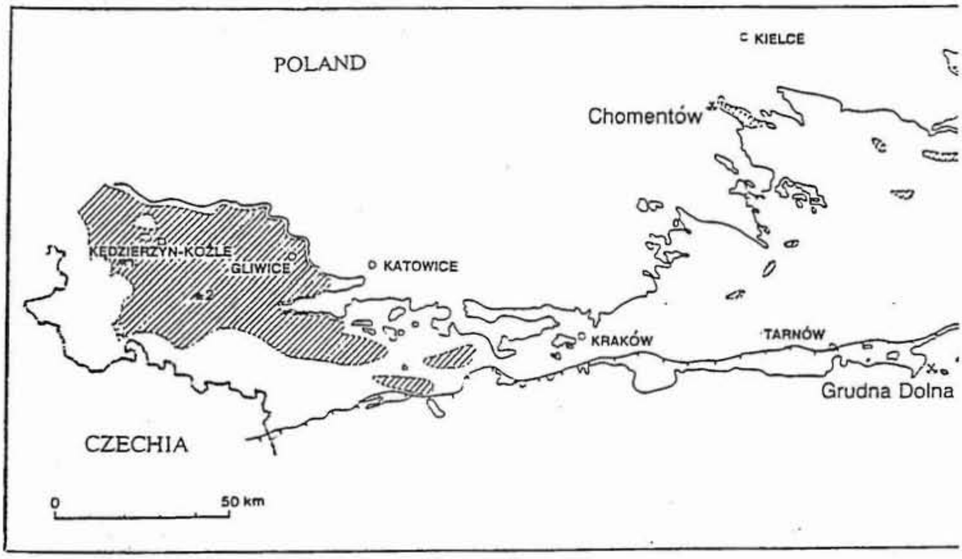


Fig. 2. Areas of Neogene phytogenic sedimentation within the northern part of the Carpathian Foredeep and its foreland (after E. Ciuk, M. Piwocki, 1988, modified)

UPPER SILESIA

Three major sedimentary series have been recognized in the Neogene profile in the Upper Silesian part of the Carpathian Foredeep (S. W. Alexandrowicz, A. S. Kleczkowski, 1974). The lowermost series consists of lignite-bearing sediments which originated in fresh-water and/or brackish environments, the middle one is composed of marine sediments occurring in so-called *tegel* and *schlier* facies, and the upper Miocene series comprises the fresh-water/brackish sediments with lignite intercalations.

The lower lignite-bearing series, known as the Kłodnica Formation, is Late Karpatian/Early Moravian in age. The middle marine unit, subdivided into Skawina, Wieliczka and Machów Formations, represents the Late Badenian to Early Sarmatian. The uppermost lignite-bearing unit is Late Sarmatian/Early Pannonian in age and it is known as the Kędzierzyn Formation (S. W. Alexandrowicz *et al.*, 1982; W. Nowak, 1984) — Table 1.

KŁODNICA FORMATION

The Kłodnica Formation has been recognized in Upper Silesia between Wawrzyńcowice, Pszczyna and Oświęcim (S. W. Alexandrowicz, 1963, 1970*b*; S. W. Alexandrowicz, A. S. Kleczkowski, 1974; A. Sadowska, 1985). Its lowermost part is represented by green-gray sandy clays with fresh-water (*Planorbis, Congeria*) and brackish faunas: *Hydrobia, Ammonia beccarii* (Linne). A complex consisting of fine-grained sands, silts, and calcareous clays with a fresh-water mollusc fauna (*Limnaea, Planorbis*) overlies that series. Gray-brown coaly clays and silts make up the uppermost part of this unit where coalified plant remains and lignite lenses up to 1 m thick (occasionally up to 3 m) are frequent.

Obszary neogeńskiej sedymentacji fitogenicznej w północnej części zapadliska przedkarpackiego i na jego przedpolu (według E. Ciuka, M. Piwockiego, 1988, uzupełnione)
1 — węgiel brunatny; 2 — nieczynna kopalnia węgla brunatnego; 3 — zasięg miocenu; 4 — czoło nasunięcia karpackiego; 5 — granica państwowa; 6 — otwory wiertnicze (patrz fig. 3)

The Kłodnica Formation is up to 100–150 m thick in the central part of the Upper Silesian Basin, in the Kędzierzyn – Koźle Trough area, but this decreases down to 50 m towards the margin.

MARINE COMPLEX

Marine sediments covering the Kłodnica Formation have been subdivided into three lithostratigraphic units (S. W. Alexandrowicz *et al.*, 1982; W. Nowak, 1984):

— the Skawina Formation (Moravian);

— the Wieliczka Formation (Wielician), corresponding to the Krzyżanowice Formation to the east;

— the Machów Formation (Kosovian and Lower Sarmatian).

KĘDZIERZYN FORMATION

Sediments of the Kędzierzyn Formation (Late Sarmatian to, probably, Pannonian) were deposited in the northern part of the Upper Silesian part of the Carpathian Foredeep. In the central part of the Upper Silesian Basin, this formation is represented by gray-green clays with sandy intercalations, frequent clayey siderite, and variegated clays in the uppermost part of the profile. Thin clayey lignite lenses, up to 1 m thick, coaly middlings and plant remains occur in this unit.

To the west, sediments of the Kędzierzyn Formation interfinger with clayey deposits of the Poznań Formation (i.e. the Poznań Series *sensu* S. Dyjor and A. Sadowska, 1986).

Table 1

Neogene time scale and lithostratigraphic correlation

CHRONOSTRATIGRAPHY						LITHOSTRATIGRAPHY		
	Ma BP	Tethys	Paratethys – Central	Paratethys – Eastern	North Sea	Upper Silesia	Carpathian Foredeep (northern part)	Polish Lowland
PLIOCENE	1.64	PIACENZIAN	ROMANIAN	APSHERONIAN AKCHAGYLIAN	TEGELIAN REUVERIAN	Gozdnica Formation		Gozdnica Formation
PLIOCENE	3.40	ZANCLIAN	DACIAN	KUYALNITSKIAN CIMMERIDIAN	BRUNSSUMIAN			
MIOCENE – CASTELLANIAN	5.2	MESSINIAN	PONTIAN	MEOTIC/SARMATIAN	SUSTERIAN			Karczew Mb. (bunter clays)
MIOCENE – CASTELLANIAN	6.7	TORTONIAN	PONTIAN PANNONIAN	KONKIAN KARAGANIAN	GRAMMIAN	Poznań Formation		Poznań Formation: Rycice Mb. (green clays)
MIOCENE – CESSOLIAN	10.4	SERRAVALIAN	PANNONIAN SARMATIAN BADENIAN: KOSOVIAN	CHOKRAKIAN TARKHANIAN	LANGENFELDIAN	Kędzierzyn Formation Machów Formation	Janów Formation Chmielnik Formation	Poznań Formation: Jędrzejnik Mb. (gray clays)
MIOCENE – CESSOLIAN	14.2	LANGHIAN	BADENIAN: WIELICIAN BADENIAN: MORAVIAN	TARKHANIAN SAKARAULIAN	REINBEKIAN	Wieliczka Formation Skawina Formation Kłodnica Formation	Krzyżanowice Formation Baranów Formation Trzydnik Formation	Adamów Formation Pawłowice Formation
MIOCENE – GIRONDIAN	16.3	BURDIGALIAN	KARPATIAN OTTNANGIAN EGGENBURGIAN	SAKARAULIAN	REINBEKIAN HEMMOORIAN			Ścinawa Formation/ /Krajenka Formation
MIOCENE – GIRONDIAN	21.5	AQUITANIAN	EGERIAN	SAKARAULIAN POLTAVA	VIERLANDIAN			Rawicz Fm./Gorzów Fm.
OLIGOCENE	22.2	CHATTIAN	EGERIAN	POLTAVA	CHATTIAN			Leszno Formation

Thickness of the Kędzierzyn Formation is 150 m in the central part of the basin but it decreases to 10–20 m in the marginal parts, where sandy intercalations occur more frequently.

CENTRAL CARPATHIAN FOREDEEP

Lignite-bearing sediments have been recognized in the large area between Wiślica, Połaniec and Kraśnik in Poland. More rich lignite concentrations have been noted (M. Bielecka, 1957, 1967; K. Kowalewski, 1958*b*; S. Pawłowski *et al.*, 1985): (1) in the vicinity of Chmielnik, Chomentów and Korytnica, (2) near Staszów and Suliszów, (3) in the Opatówka river valley, and (4) in the area between the Vistula and San rivers, from Baranów Sandomierski to Nisko and Zaklików to the east and the vicinity of Kraśnik to the north. A few major lithological complexes have also been recognized in this area. They are as follows:

— continental/brackish complex,
— lower marine complex,
— evaporitic series,
— upper marine complex
— marine/brackish complex.

CONTINENTAL/BRACKISH COMPLEX

Sediments of the continental/brackish complex were deposited the time of the Karpatian/Badenian boundary and during the Early Moravian. They built up a lithological unit in the lowermost part of the Baranów Formation (B. Kubica, 1992). In the northern part of the basin they have been distinguished as the individual Trzydnik Formation (S. W. Alexandrowicz *et al.*, 1982; W. Nowak, 1984). There are sandy-silty and clayey sediments with sandy/clayey lignite lenses and intercalations. Frequent coalified plant remains, root horizons, rhisoids and rhisoliths and also well-developed palaeosol horizons with pedoglobules and pedotubules occur there. Palaeosols and root horizons locally directly cover the top surface of the older, pre-Miocene deposits. Lignite occurs in the form of thin seams and lenses, usually interbedded with barren rocks; lignite intercalations are about 1 m thick. However, coal seams may be as thick as 7.8 m.

Mollusc debris occurs frequently in clayey/silty and sandy intercalations, and even in lignite horizons. Locally, these remains built thin beds of lumachelle. Shell fragments have been mostly identified as brackish- and fresh-water species. There are the brackish forms e.g. *Hydrobia, Congeria, Potamides, Mohrensternia, Modiola* and both terrestrial and fresh-water ones, e.g. *Helix, Pupa, Succinea, Limnaea, Planorbis*. The brackish-nearshore ichnocoenoses of *Ophiomorpha nodosa* Lundgren with fragments of *Calianassa* crabs have been observed immediately below lignite benches in Męczennice near Sandomierz (A. Radwański, 1969, 1973).

The lignite-bearing or continental/brackish complex is from a few up to 50–70 m thick and it passes laterally into marine sediments.

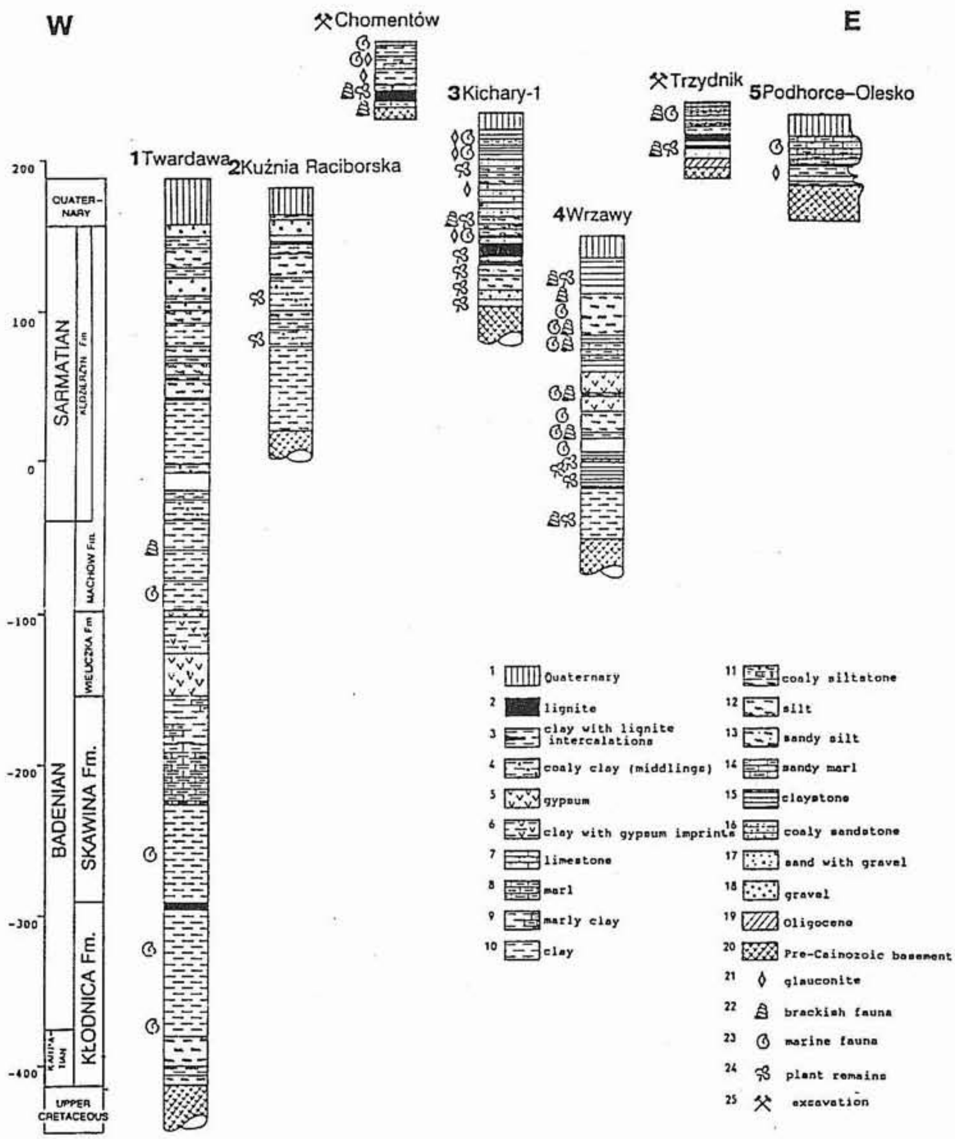


Fig. 3. Position of the lignite-bearing association in Neogene profiles of the Carpathian Foredeep (for location see Fig. 2)

Pozycja osadów asocjacji brunatnowęglowej w profilach neogenu zapadliska przedkarpackiego (lokalizacja na fig. 2)

1 — czwartorzęd; 2 — węgiel brunatny; 3 — ił z wkładkami węgla brunatnego; 4 — ił węglisty; 5 — gips; 6 — ił ze skupieniami gipsu; 7 — wapień; 8 — margiel; 9 — ił marglisty; 10 — ił; 11 — mułowiec węglisty; 12 — mułek; 13 — mułek piaszczysty; 14 — margiel piaszczysty; 15 — iłowiec; 16 — piaskowiec węglisty; 17 — piasek ze żwirem; 18 — żwir; 19 —oligocen; 20 — podłoże podkenozoiczne; 21 — glaukonit; 22 — fauna brakiczna; 23 — fauna morska; 24 — szczątki roślin; 25 — wykop

LOWER MARINE COMPLEX

The lower marine complex makes up the upper part of the Baranów Formation of Late Moravian age. This consists of *Lithothamnium* limestones, clayey siltstones with marly and sandy admixture, sands and sandstones and tuffites, enriched in bivalve and gastropod fauna. The characteristic *Ervilia* Bed with mollusc fauna of *Ervilia pussilla* Phillippi and *Modiola hoernesi* Reuss occurs at the top of this sequence.

The lower marine complex is from a few up to 80 m thick.

EVAPORITIC SERIES

The evaporitic series consists of gypsum, post-gypsum limestones and native sulphur (e.g. S. Pawłowski *et al.*, 1985; B. Kubica, 1992). A scanty foraminiferal fauna with *Elphidium delicatulum* Bermudez occurs there. This series is known as the Wieliczka and Krzyżanowice Formations, and it is Wielician in age. This association originated in hypersaline conditions. This sequence various in thickness but can as much as 60 m.

UPPER MARINE COMPLEX

The upper marine complex of Late Badenian (Moravian) age, belongs to the Chmielnik Formation. It consists of clayey marls and marls with frequent tuffite intercalations. Rich mollusc fauna of few species of the genus *Chlamys* occurs there. This sequence is up to 50 m thick.

MARINE/BRACKISH COMPLEX

The uppermost marine/brackish complex (Early Sarmatian) is known as the Krakowiec Clays and belongs to the Machów Formation. Two major lithologic units belong to this complex: the lower, silty-marly unit and the upper, sandy silty one.

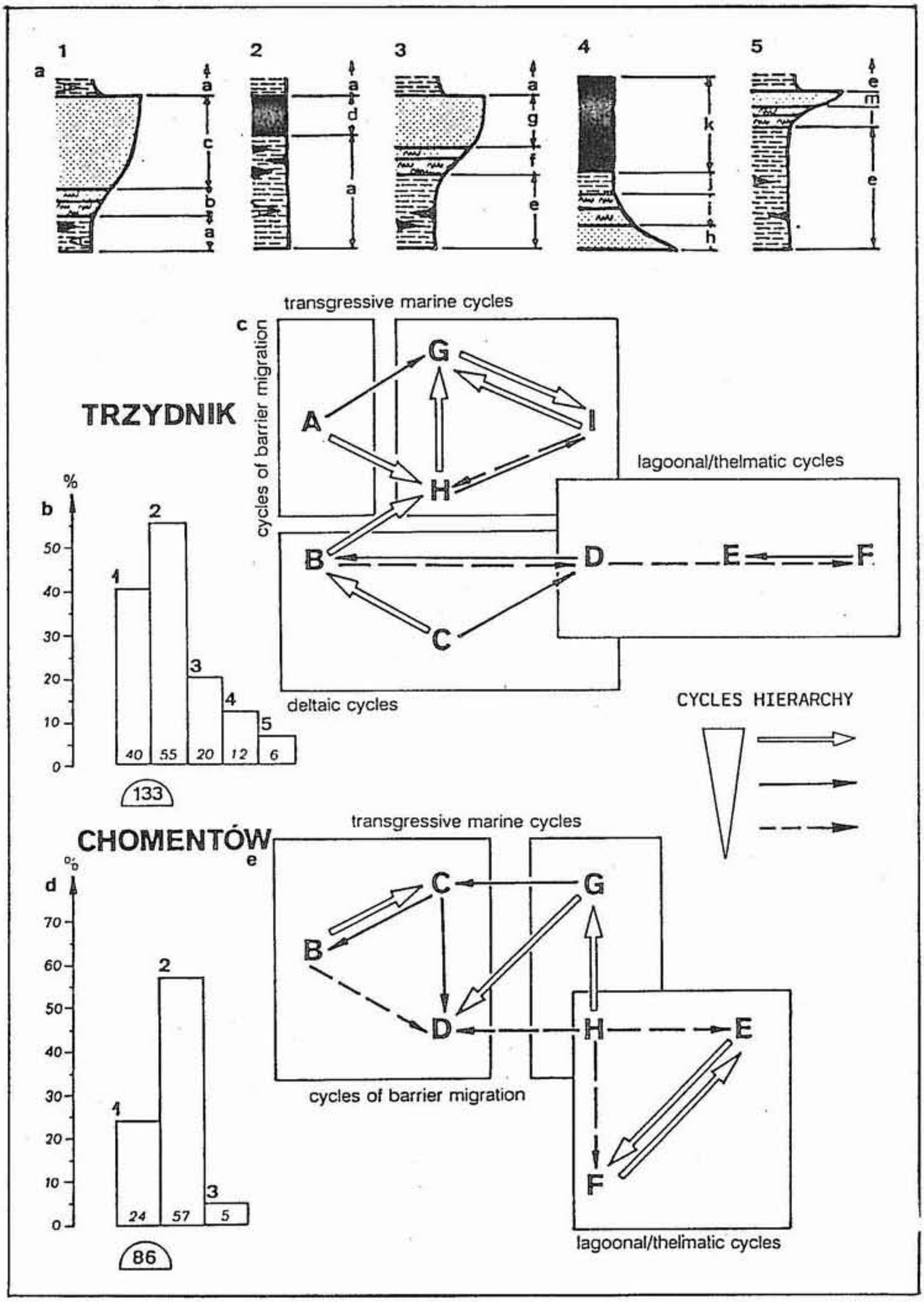
The lower unit consists of calcareous siltstones and clayey marls with frequent tuffite and bentonite intercalations. Arich molluscan fauna of the genus *Syndesmya* occurs there. The presence of specimens of the genera *Hydrobia* and *Mohrensternia* suggests brackish conditions, which periodically dominated the basin during that period. This sequence is 10–40 m thick.

The upper unit, known as "the unfossiliferous beds", consists of calcareous sandy siltstones. Plant remains, of different degrees of coalification, are common. This complex partially corresponds to the Kędzierzyn Formation in the Upper Silesian Basin. However, phytogenic deposits equivalent to the lignite of the Kędzierzyn Formation are lacking in the central and eastern part of the Carpathian Foredeep. This terrigenous sequence reaches up to 500 m in thickness.

ORIGIN OF PHYTOGENIC DEPOSITS

GENERAL REMARKS

Origin of phytogenic deposits in the Neogene basin of the Carpathian Foredeep was closely related to the transgressive/regressive megacycle during Badenian/Sarmatian se-


a
1
2
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transgressive marine cycles
c
cycles of barrier migration
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G
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CYCLES HIERARCHY
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cycles of barrier migration
lagoonal/thelmatic cycles

dimentation. Most of those deposits are known from the Kłodnica/Trzydnik Formations (the latter one correlates with the bottom part of the Baranów Formation). The phytogenic deposits occurred during the Late Karpatian/Early Badenian period (W. Nowak, 1984). Phytogenic sedimentation was related to the early trangressive stage of the sequence, when the Central Paratethys marine trangression reached the Polish part of the Carpathian Foredeep. It progressed from the west through Moravia to Upper Silesia and from the east to the Holy Cross Mts. foreland (R. Ney *et al.*, 1974; G. Hamor, 1988).

The Karpatian/Badenian marine trangression invaded areas with a variety of basement geological and palaeogeomorphological settings. The erosional valley systems, some of which were extremely deep (e.g. the Racibórz – Koźle – Wawrzyńcowice – Nysa valley, S. Dyjor *et al.*, 1977), were the entrances of the transgression. Low geomorphological gradient made long-distant penetration along the valley axes possible. A system of dismembered embayments, similar to the present Dalmatian coast, developed along the southern margin of the Holy Cross Mts. (A. Radwański, 1969, 1973). Due to very gentle bottom inclination, even a small sea level oscillation caused extensive coastline migration. Because of limited contact with the open marine basin, mostly as the result of the development of bar systems, water salinity changed from normal marine values to those typical of brackish- and fresh-water conditions. This process was especially fast in the valleys discharged by larger rivers. Detailed position of coastline is difficult to identify.

Large areas were only temporarily placed in sedimentary conditions favourable for phytogenic accumulation, in which the water table oscillated around the depositional surface. However, the dynamic equilibrium between the subsidence of the basin bottom and increasing thickness of accumulated rock (a precondition for thick peat accumulation, A. Bouroz, 1960), could persist for relatively short times only. For this reason, the lignite seams in the Carpathian Foredeep are nowhere as thick as in the Polish Lowland area. They usually have relatively high ash content (Tab. 1) and change vertically and laterally into coaly/clayey middlings.

Fig. 4. Results of analysis of sedimentary cyclicity of the lignite-bearing association within the Trzydnik and Chomentów basins: typical sedimentary sequences (a), frequence of typical sequences (b, d), Markov transitions (c, e) (a and b — after J. R. Kasiński, 1986)

L i t h o l o g i c a l u n i t s : A — gravelly sand, B — sand, C — silt, D — clay, E — coaly clay, F — lignite, G — marly clay, H — marl, I — limestone; s e d i m e n t a r y s e q u e n c e s : 1 — barrier-lagoonal, 2 — lagoonal-thelmatic, 3 — deltaic, 4 — distributary channel, 5 — crevasse splay; s e d i m e n t a r y e n v i r o n m e n t s : a — lagoon, b — barrier front, c — barrier body, d — vegetated lagoon, e — prodelta, f — delta front, g — distributary channel, h — meander bar, i — outwash, levee, crevasse, j — alluvial plain, k — overgrown alluvial plain, l — distal crevasse splay, m — distributary crevasse splay; other explanations see Fig. 3

Wyniki analizy cykliczności sedymentacji asocjacji brunatnowęglowej w basenach Trzydnika i Chomentowa: typowe sekwencje sedymentacyjne (a), frekwencja typowych sekwencji (b, d) i przewidywane przejścia według modelu Markowa (c, e) (a i b według J. R. Kasińskiego, 1986)

W y d z i e l e n i a l i t o l o g i c z n e : A — piasek ze żwirem, B — piasek, C — mułek, D — ił, E — ił węglisty, F — węgiel brunatny, G — ił marglisty, H — margiel, I — wapień; s e k w e n c j e s e d y m e n t a c y j n e : 1 — barierowo-lagunowa, 2 — lagunowo-bagienna, 3 — deltowa, 4 — kanałów rozprowadzających, 5 — glifów krewasowych; ś r o d o w i s k a s e d y m e n t a c y j n e : a — laguna, b — czoło bariery, c — bariera, d — zarastająca laguna, e — prodelta, f — czoło delty, g — kanały rozprowadzające, h — odsypy meandrowe, i — odsypy nieruchome, wały brzegowe, glify krewasowe, j — równia zalewowa, k — bagna na równi zalewowej, l — część dystalna glifu krewasowego, m — część rozprowadzająca glifu krewasowego; pozostałe objaśnienia jak na fig.3

Proximal parts of the embayments in the foreland of the Holy Cross Mts. were in fact lagoonal in their character, more or less separated from the open basin by sand barriers (J. R. Kasiński, 1986; J. K. Dyląg, J. R. Kasiński, 1994).

Sedimentary conditons within peat-forming lagoons changed quickly, as evidenced by: (1) the alternations of thin beds containing marine, brackish, fresh-water and continental faunas (K. Kowalewski, 1930, 1958*a*; J. Czarnocki, 1932*a*, 1933; W. Krach, 1958; S. W. Alexandrowicz, 1963; S. Pawłowski *et al.*, 1985) and (2) the presence of the brackish/near-shore ichnofossil *Ophiomorpha nodosa* Lundgren below coal benches (A. Radwański, 1973). In locally separated parts of the basin without any fresh-water supply, hypersaline sedimentary conditions, similar to recent sabkha systems (C. R. Handford, 1991), could persist. As the transgression rate decreased, deltas developed; delta lobes transgressed into lagoonal areas.

SEDIMENTARY MODEL OF LIGNITE DEPOSITS

Only two lignite deposits have been identified in the Polish part of the Carpathian Foredeep and both of them were exploited in the past. There are: (1) the Trzydnik deposit, located at the southern margin of the Lublin Upland and (2) the Chomentów deposit, located in the former Korytnica Embayment, developed on the southern slope of the Holy Cross Mts. Detail palaeogeographical and sedimentary reconstructions have been done only for these two lignite deposits at the northern margin of the basin for the Trzydnik deposit (J. R. Kasiński, 1986; A. Bossowski *et al.*, 1988), and the Chomentów deposit (J. K. Dyląg, J. R. Kasiński, 1994).

Sedimentary analysis of both the areas mentioned above included: (1) preparation of thickness relation lithofacies maps, (2) frequency analysis of different kinds of cyclic sequences, and (3) analysis of sedimentary cyclicity based on the Markov model.

Thickness relation of clastic sediments to total pelitic and phytogenic ones has been a base of construction of the maps. This relation indicates relative energy of the sedimentary environment and it allows differentiation of areas of quiet sedimentation (limnicum, thelmaticum) from those of extensive transport of clastic material (fluvial tracts, delta distributary channels etc.).

Five basic cyclic sequences related to varied sedimentary conditions (Tab. 2) have been distinguished in profiles of the lignite-bearing association (Fig. 4a).

Few lithological elements have been defined in borehole profiles of this association. They are as follows:

A — gravel and sandy gravel,
B — sand,
C — silt,
D — clay,
E — coaly middlings,
F — lignite,
G — marly clay,
H — marl,
I — limestone.

Both the difference matrices (Tab. 3, 4) were tested with the chi-square test according to the Bilinsley's function. The calculated values of the chi-square coefficient many times exceeded the critical value at the 95% confidence level in every case (P. Bilinsley, 1961). It justified that the sedimentary succession was repeatible and it realized the Markov model in both the studied areas (Fig. 4c, e).

TRZYDNIK AREA

The area of the Trzydnik deposit is located on the south-west slope of the Lvov – Lublin Trough upon the Palaeozoic platform near its north-west boundary. The Neogene lignite-bearing association developed during latest Karpatian and Early Badenian (Moravian) on basement consisting partly of the Upper Cretaceous and partly of Oligocene marine deposits. Top surface of the association has been established at the bottom of Badenian carbonate marine deposits consisting of *Lithothamnium* limestones, marls and marly clays (M. Brzezińska, 1961).

The basement of the lignite-bearing association is flat with a shallow depression elongated in the NNW–SSE direction in the central part: the lignite-bearing sediments are thickest there. Two large clastic lithosomes developed in that area: (1) the elongated lithosome in the southeastern part and (2) the tripartite lithosome in the northern part (Fig. 6a). The southeastern lithosome is evidenced in whole profile of lignite-bearing sequence and the northern one in its uppermost part only. The three lobes of the northern lithosome extend exactly along the structural foundations: the central major lobe infills the depression, the two other ones are related to structural directions in the Neogene basement (T. Janicki *et al.*, 1986).

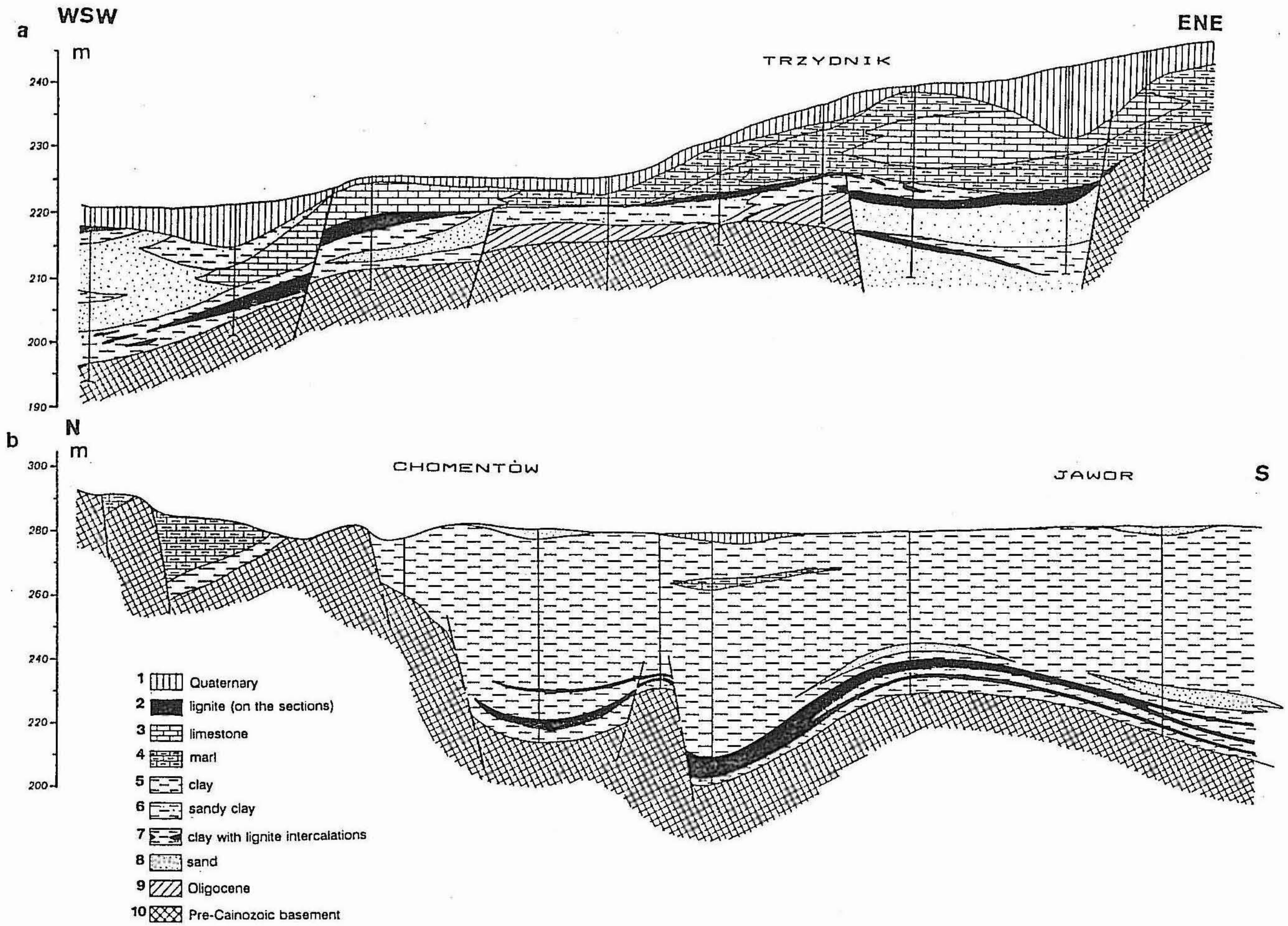
Sediments of the interlobe areas consist of clay, marl and lignite; the last ones predominate in the central part of the area. "Symmetrical" and coarsening-upward sequences with thick clastic members predominate, but coarsening-upward sequences with thin clastic members and fining-upward sequences are also relatively frequent (Fig. 4b).

The Markov difference matrix of transitions in the Trzydnik area (Tab. 3) shows the heterogenous character of sedimentary processes (Fig. 4c). The succession of these litho-

Table 2

Sedimentary sequences of the lignite-bearing association and their palaeoenvironmental relations

Sequence type	Environments
Coarsening-upward with thick clastic member	Barrier/lagoonal
"Symmetrical", fine-grained	Lagoonal/thelmatic, prodelta
Coarsening-upward with thin clastic member	Deltaic
Fining-upward with thick caustobiolithic member	Meandering river
Coarsening-upward with sporadical thin clastics	Crevasse splay


a
WSW
ENE
m
TRZYDNIK
240
230
220
210
200
190
b
N
m
CHOMENTÓW
JAWOR
S
300
280
260
240
220
200
1 Quaternary
2 lignite (on the sections)
3 limestone
4 marl
5 clay
6 sandy clay
7 clay with lignite intercalations
8 sand
9 Oligocene
10 Pre-Cainozoic basement

logical units, which are most essential for the Markov model (more than 0.20 average value in difference matrix d_{ij}), in order of their frequency, looks as follows:

GIG	IGI	HGI	HIG	AGI
AHG	BHG	DBH	GIH	CBH
DBC	AHI	BHI	IHG	CDB
EDB	BCB	CBC	EFE	FEF

CHOMENTÓW AREA

The Chomentów deposit is located on the southern slope of the Holy Cross Mts. The Neogene lignite-bearing association fills in the elongated Neogene Korytnica Embayment. The foundations of this embayment are Jurassic; the embayment itself formed at the same time as the phytogenic deposits of the Trzydnik basin. The top surface of the lignite-bearing association has been established at the bottom of the Badenian clayey/carbonate marine deposits, consisting there of clays, marly clays and marls.

The basement of the lignite-bearing association within the valley area was flat, but it was limited with two slopes orientated NW–SE.

Phytogenic and clayey sediments predominate in the proximal part of the embayment, but the sand content increases towards the distal part (Fig. 6b).

Table 3

Markov difference matrix of the Trzydnik deposits

d_{ij} =

	A	B	C	D	E	F	G	H	I
A	.00	–.01	–.01	.01	–.01	.01	.02	.03	–.01
B	–.17	.00	.25	.36	–.06	.08	–.15	–.03	–.19
C	–.12	.14	.00	.06	–.04	–.04	–.07	–.12	–.11
D	–.04	.08	.07	.00	.08	.00	–.16	–.22	–.13
E	–.12	.03	.02	–.02	.00	.21	–.04	–.12	–.13
F	–.10	–.01	–.05	–.04	.19	.00	.00	–.10	–.11
G	.19	–.10	–.14	–.12	–.04	.00	.00	.36	.56
H	.29	.29	–.04	–.05	–.01	–.02	–.01	.00	.11
I	.06	–.11	–.10	–.11	–.10	–.07	.50	.20	.00

Fig. 5. Geological cross-sections across Trzydnik (a) and Chomentów (b) sedimentary basins
Przekroje geologiczne przez baseny sedymentacyjne Trzydnika (a) i Chomentowa (b)
1 — czwartorzęd; 2 — węgiel brunatny; 3 — wapień; 4 — margiel; 5 — ił; 6 — ił piaszczysty; 7 — ił z wkładkami węgla brunatnego; 8 — piasek; 9 — oligocen; 10 — podłoże podkenozoiczne

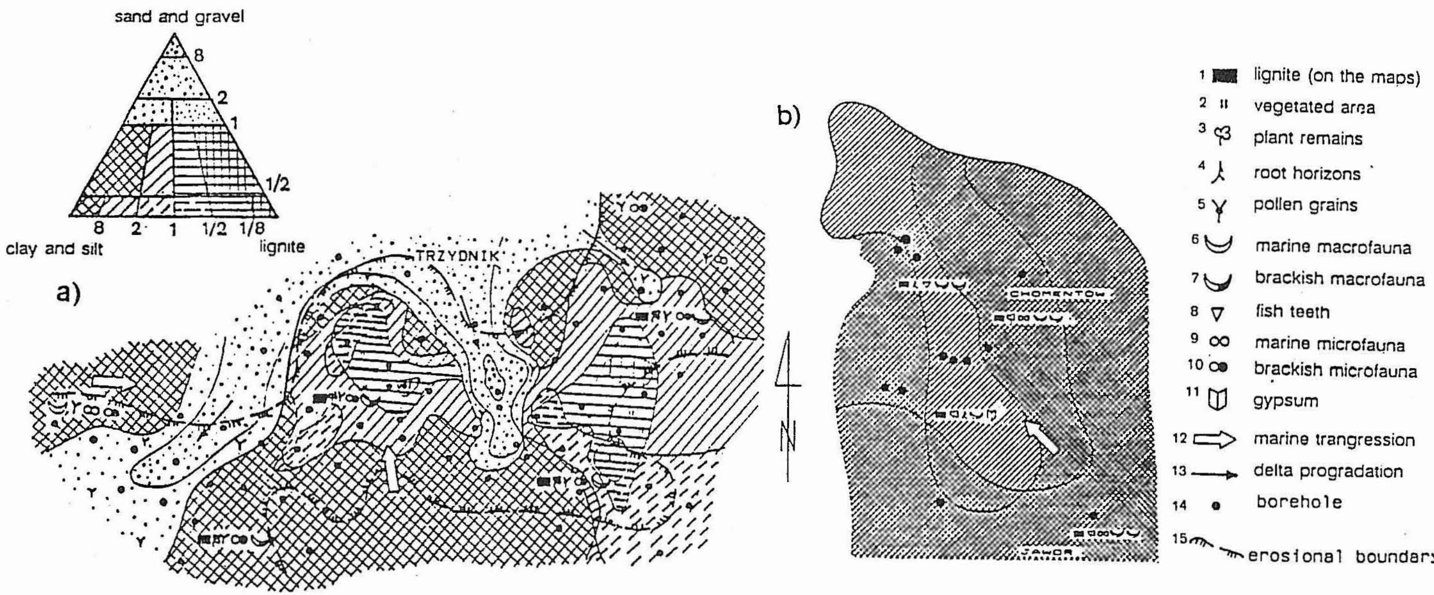


Fig. 6. Thickness relation maps of Trzydnik (a) and Chomentów (b) sedimentary basin

Mapy stosunków miąższościowych w basenach sedymentacyjnych Trzydnika (a) i Chomentowa (b)

1 — węgiel brunatny; 2 — obszary wegetacji; 3 — szczątki roślin; 4 — poziom korzeniowy; 5 — ziarna pyłku; 6 — makrofauna morska; 7 — makrofauna brakiczna; 8 — zęby ryb; 9 — mikrofauna morska; 10 — mikrofauna brakiczna; 11 — gips; 12 — transgresja morska; 13 — progradacja delty; 14 — otwór wiertniczy; 15 — granica erozyjna

Table 4

Markov difference matrix of the Chomentów deposits

		A	B	C	D	E	F	G	H	I
	A	.00	.00	.00	.00	.00	.00	.00	.00	.00
	B	.00	.00	.11	–.14	–.13	–.01	–.13	–.03	–.01
	C	.00	.32	.00	–.11	–.14	–.13	–.13	.17	.24
d_{ij} =	D	.00	.08	.19	.00	.04	.06	.40	.10	.48
	E	.00	–.07	–.07	–.15	.00	.36	–.07	–.10	–.01
	F	.00	–.01	–.14	–.18	.33	.00	–.18	.10	–.01
	G	.00	–.05	.01	.03	–.02	–.11	.00	.30	.24
	H	.00	–.10	–.10	–.25	–.16	–.13	–.16	.03	.00
	I	.06	–.11	–.10	–.11	–.10	–.07	.50	.20	.00

The sediments of other parts of the area consist of clay, marl and lignite; the last one predominates in the central part of the area. "Symmetrical" sequences predominate but coarsening-upward sequences with thick clastic members are also frequent (Fig. 4d). Numerous thin lenses, intercalations, and imprints of gypsum occur among marly clays and are also present in coal (J. Czarnocki, 1956). It is assumed that they are of primary origin (not proven), and might be evidence of local hypersaline conditions.

The Markov difference matrix (Tab. 4) documents more homogenous sedimentation in the Chomentów area (Fig. 4e) than in Trzydnik. Succession of these lithological units, which is essential for the Markov model (more than 0.20 average value in difference matrix d_{ij}) in order of their frequency, looks as follows:

HGD	EFE	FEF	IGD	BCD
IDG	HFE	BCB	CBC	DGD
GDC	HCD	HEF	IEF	EFD

DISCUSSION ON SEDIMENTARY ENVIRONMENT

Two kinds of cyclic sequences predominate in the areas of huge phytogenic sedimentation along the northern margin of the Carpathian Foredeep. There are symmetrical sequences and coarsening-upward sequences with thick clastic members; these are interpreted as lagoonal/thelmatic and barrier cycles (Tab. 2). These two types of sequences make up the substantial part of the lignite-bearing association and are of 51.1 and 29.2%, respectively (total 80.3%), of all measured sequences in both Trzydnik and Chomentów.

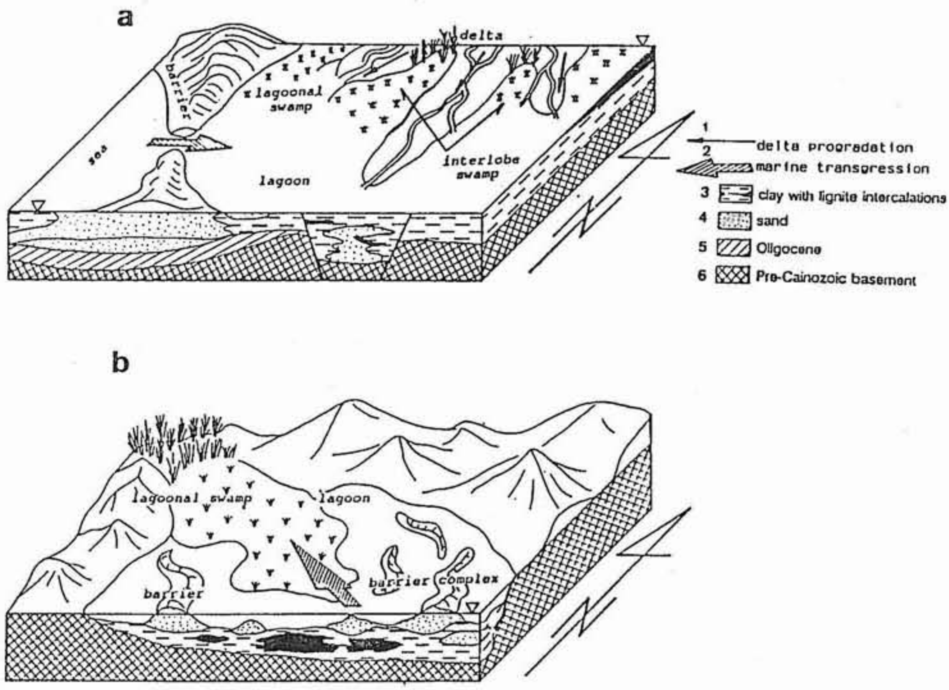


Fig. 7. Models of sedimentary environments of Trzydnik (a) and Chomentów (b) sedimentary basin
Modele środowisk sedymentacyjnych w basenach sedymentacyjnych Trzydnika (a) i Chomentowa (b)
1 — progradacja delty; 2 — transgresja morska; 3 — ił z wkładkami węgla brunatnego; 4 — piasek; 5 — oligocen; 6 — podłoże podkenozoiczne

The sedimentary sub-basin of the Trzydnik lignite deposit became a lagoon only during the first stage of marine transgression. This lagoon had been separated by a sandy barrier to the west and was supplied by fresh-water from the north. Faunal composition in the lagoon was different than the open sea outside the barrier: brackish species (*Hydrobia, Modiola, Modiolaria* — K. Konior, 1948) occurred in the lagoon only. Huge phytogenic accumulation developed in the central part of the basin, but in the marginal parts, vegetation was hampered by influx of terrigenous clay, probably related to prodelta development. Reed phytocoenoses definitely dominated the whole ecosystem of the lagoon, as is evidenced by micropetrographic composition of coal which is primarily made up of eu-ulminite originating from reed and herb plants (K. Matl, M. Wagner, 1991)

During the next stage of the basin development, the tripartite delta invaded the northern part. This change of character in sedimentation probably resulted from local lowering of the transgression rate. The western delta lobe covered the sandy barrier, while both other lobes covered lagoonal deposits. The deltaic clastic deposits reached extreme thickness in the central part of the basin, where continuous synsedimentary subsidence resulted from deposit loading. Pelitic and phytogenic sedimentation persisted in the remaining area. The area of vegetation decreased due to the extensive progradation of the prodelta. However,

Table 5

Geological and mining properties of the Trzydnik and Chomentów lignite deposits

Parametre	Trzydnik	Chomentów
Reserves and coal resources [thousand Mg]	723	600
Average coal thickness [m]	2.8	1.0
Extend coal thickness [m]	4.4	5.0
Average overburden thickness [m]	9.8	15.0
Overburden ratio	3.5	15.0

reed vegetation persisted in interlobe embayments and even swamp forest developed locally in their proximal parts.

The next change of character of sedimentation was related to the next transgression fluctuation; marine sediments covered the lignite-bearing association, ending the transgression.

Sedimentation in the Chomentów area was more homogeneous. The development of the lignite-bearing association was related only to a single stage of lowering of transgression rate. The lagoon originated in the proximal part of the Korytnica Embayment (Fig. 6b) and the rich vegetation found favourable conditions there. The accumulations of fresh-water fauna (*Helix, Planorbis, Pupa* — J. Czarnocki, 1956) demonstrate frequent stages of water refreshment. However, at times, the lagoon was not supplied with fresh-water, and those times hypersaline conditions probably led to occurrences of sedimentary gypsum in clays and coal.

The differences in the sedimentary evolution of the Trzydnik and Chomentów sub-basins can be seen on the lithofacies map and in the results of frequency analysis and Markov analysis. Areas of barriers and deltas have been outlined on the thickness relation maps as the areas dominated by clastic sedimentation (Fig. 4c, d). The number of distinguishable cyclic sequences (Fig. 4b) shows that the deltaic sequences were a significant depositional element in the Trzydnik sub-basin (15.0% of all measured sequences in that area), while they were considerably less common in the Chomentów basin composing 5.7% of all sequences only (Fig. 4e). The results of the Markov chain analysis show that there were most convincing differences between the two basins: four major assemblages of sedimentary transitions were defined in the Trzydnik area (Fig. 4c) and three assemblages only — in the Chomentów area (Fig. 4e).

LIGNITE OCCURRENCE

Lignite resources occur along the northern margin of the foredeep only in small areas near Chomentów, Trzydnik and Sandomierz (J. Czarnocki, 1932*a*; K. Konior, 1948; T. Bar, 1958; B. Taszek, 1961). Two small lignite deposits — Trzydnik and Chomentów — are

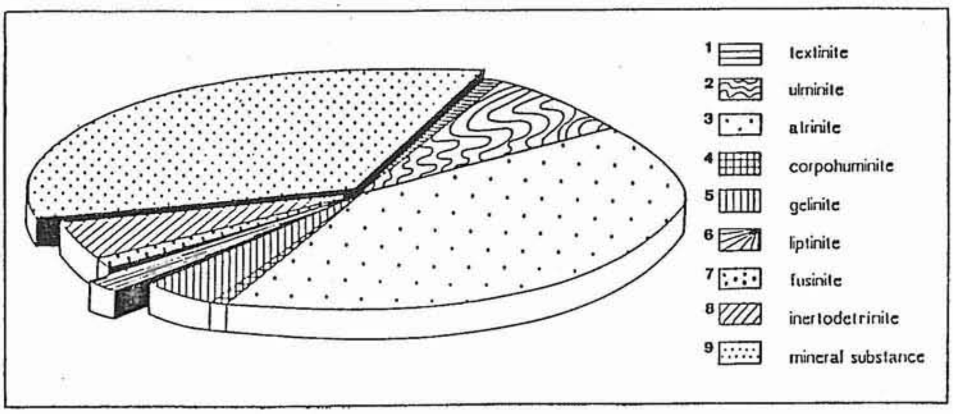


Fig. 8. Maceral composition of the Trzydnik lignite (after K. Matl, M. Wagner, 1991)
Skład macerałowy węgla brunatnego z Trzydnika (według K. Matla, M. Wagnera, 1991)
1 — tekstynit; 2 — ulminit; 3 — atrynit; 4 — korpohuminit; 5 — żelinit; 6 — liptynit; 7 — fuzynit; 8 — inertodetrynit; 9 — substancja mineralna

located there (Tab. 5). Both of them are lenticular deposits with a single lignite seam. The Chomentów deposit was open for a short time before 1914 and during the period 1940–1944. The Trzydnik deposit was exploited during the period 1959–1960; the richest part of the deposit, where the overburden was less than 8 m thick, was excavated at that time.

In other areas, the intercalations and lenses of lignite occur deeper and they do not have any economic value (S. Pawłowski *et al.*, 1985) despite their thickness, because their overburden ratio does not fulfil the economic criteria. The coal seams, described as thick ones in some borehole profiles, may be finally thinner and uneconomic ones, according the results of chemical and technological analyses. The Kichary 1 borehole profile (Fig. 9) may be a good example.

Lignite occurs in the lower part of the profile of the lignite-bearing association. It forms intercalations and lenses only, rarely thicker than 1 m, within coaly claystones and siltstones. Thicker seams, up to 7.8 m, are known locally in Upper Silesia and in the Sandomierz – Tarnobrzeg area but are not very widespread.

COAL QUALITY

The lignite of the Carpathian Foredeep is at the hypolignite stage of coalification and belongs to the group of soft lignite with peat-like texture. It is mostly detrital lignite with a small addition of xylitic detrite and with a high content of carbominerite, mainly carbo-argillite (T. Kruszewski, 1969; K. Matl, M. Wagner, 1985, 1991). The few analyses of lignite from the eastern part of the described area prove that this is an energetical coal, generally with high ash content. The high sulphur content of this lignite (Tab. 6) is the characteristic feature of a paralic coal. The lignite of Wolhyn and Podole (Ukraine) is similar to the one discussed above in its chemical characteristics (N. Zieleznova *et al.*, 1983).

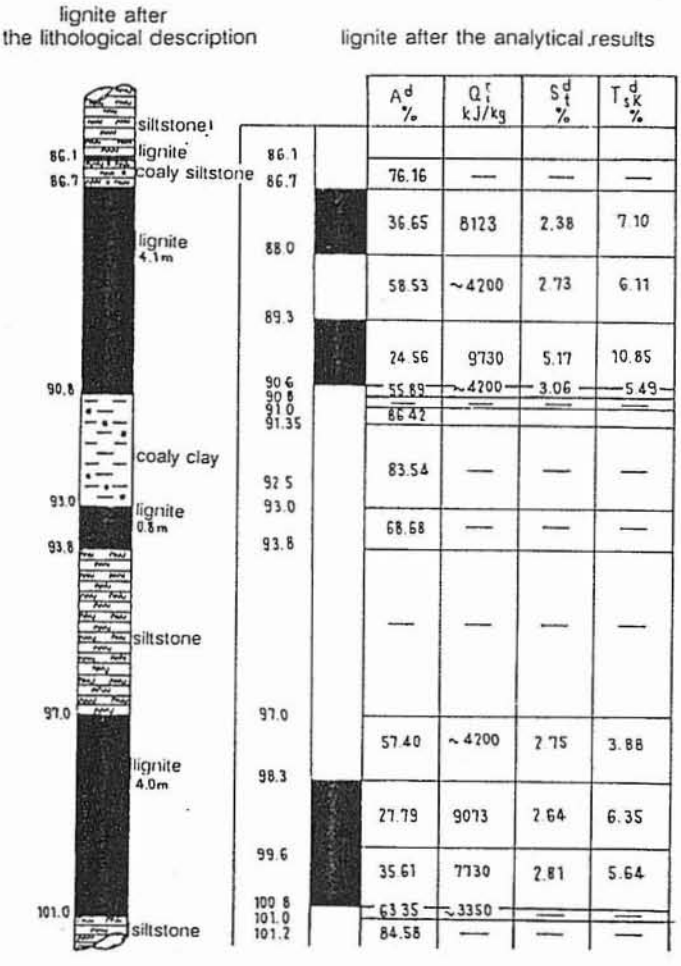


Fig. 9. The "false" thickness of lignite (described in borehole profile) and the "real" one (after results of analyses) in the Kichary 1 borehole — an example of interpretation difficulties
„Fałszywa" (podawana w profilu otworu) i „rzeczywista" (według wyników analiz) miąższość węgla brunatnego w otworze Kichary 1 jako przykład trudności interpretacyjnych

Petrological analyses, which were done only for the Trzydnik lignite (T. Kruszewski, 1969; K. Matl, M. Wagner, 1985, 1991), showed that the described lignite consists mostly of attrinite and ulminite with addition of gelinite (Fig. 8). Accesory macerals are of the inertinite and liptinite groups.

Table 6

Geological and mining properties of the Carpathian Foredeep lignite

Parametre	Trzydnik deposit	Chomentów deposit	Sandomierz area	Volhyn and Podole
Calorific value of raw coal (moisture 50%) Q_i^r [MJ/kg]	7.5	7.2	8.8	8.3
Ash content in dry coal A^d [%]	29.6	32.5	28.2	27.5
Total sulphur in dry coal S_t^d [%]	3.6	–	3.2	3.0
Tar content in dry coal T_{sK}^d [%]	≤ 11.7	–	7.5	–
Volatile matter in dry-ash free condition V^{daf}[%]	–	–	54.3	–
Bitumen content in dry coal B^d [%]	–	–	2.5	–

CONCLUSIONS

1. Origin of phytogenic deposits is closely related to the transgressive and regressive stages of Badenian-Sarmatian time.

2. The lignite-bearing association developed mostly along the northern margin of the Carpathian Foredeep and in its foreland, in areas with only slightly inclined bottom surfaces.

3. Phytogenic deposits are common within the Lower Badenian transgressive sediments along whole northern margin of the Carpathian Foredeep. Regressive Middle Sarmatian phytogenic sediments occur in the western part of studied area, in Upper Silesia. The thin, barren, brackish intercalations in the eastern part of the basin probably correlate to this complex.

4. The character of sedimentation of the lignite-bearing association depends mostly on allocyclic mechanisms (sea level changes), but autocyclic mechanisms (local subsidence) might also have had local influence on thick deltaic sedimentation in the Trzydnik basin.

5. Morphology of the basin bottom determined where phytogenic accumulation in large areas of valleys, increased in the southern slopes of the Holy Cross Mts., were particularly favourable place for the widespread peat-bog development.

6. Coals of the Carpathian Foredeep occur mostly in the form of thin layers and lenses. Thicker benches are usually deeper and therefore, they have practically no economic value.

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SEDYMENTACJA WĘGLONOŚNA W NEOGENIE ZAPADLISKA PRZEDKARPACKIEGO

Streszczenie

Geneza osadów fitogenicznych w zapadlisku przedkarpackim wiąże się ściśle z mioceńskim transgresywno-regresywnym cyklem rozwojowym tego basenu. Omawiane osady występują w postaci nieregularnego pasa wzdłuż północnego obrzeżenia zapadliska i na jego północnym przedpolu, w najniższej części formacji osadowej miocenu, w ścisłym związku z facjami transgresywnymi. Na obszarze Górnego Śląska osady fitogeniczne występują także w najwyższej części sekwencji cyklicznej, gdzie są związane z facjami regresywnymi.

Transgresja morza dolnobadeńskiego wkraczała na zróżnicowany morfologicznie obszar południowego stoku Gór Świętokrzyskich. Warunki szczególnie uprzywilejowane panowały w licznych zatokach rozwiniętych na przedłużeniu osi dolin (wybrzeże typu dalmatyńskiego), gdzie ze względu na niewielkie nachylenie dna doliny nawet nieznaczna zmiana poziomu morza powodowała zalanie lub ustąpienie wód ze znacznych obszarów. Na północnym obrzeżeniu zapadliska powstały wówczas jedyne dwa złoża węgla brunatnego: Trzydnik i Chomentów, położone w polskiej części tego basenu; są to złoża typu paralicznego. Osady węglonośne zawierają liczną faunę, o przewadze brakicznej. Główną rolę w rozwoju sedymentacji fitogenicznej autorzy przypisują zatem mechanizmom allocyklicznym.

Analiza cykliczności sedymentacji wskazuje, że sedymentacja asocjacji brunatnowęglowej rozwijała się w środowisku barierowo-lagunowym i miała charakter jednorodny. Jednak w niektórych rejonach (złoże Trzydnik) na sekwencję barierowo-lagunową nakładała się sekwencja osadów deltowych, świadcząc o lokalnej aktywności mechanizmów autocyklicznych.

Osady fitogeniczne zapadliska przedkarpackiego są reprezentowane przez miękkie węgle brunatne oraz drobnodetrytyczne osady z drobnodyspersyjną substancją węglistą typu humusowego. Do utworów fitogenicznych można także zaliczyć licznie występujące poziomy gleb kopalnych z uwęglonymi korzeniami roślin. Węgle brunatne powstały głównie z roślinności szuwarowej i zielnej, o czym świadczy duży udział euulminitu w składzie maceralnym węgla. Znacznie mniejszy udział wśród roślinności torfotwórczej miały fitocenozy lasu bagiennego.

Węgle brunatne są wykształcone w postaci cienkich pokładów, przeławiceń i izolowanych soczew o miąższości rzadko przekraczającej 1 m i poza północnym obrzeżeniem zapadliska leżą zwykle dość głęboko. Z tych powodów przeważnie nie spełniają kryteriów bilansowości i nie mają znaczenia gospodarczego.