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Miocene and its basement in sulphur-bearing areas of marginal part of the Carpathian Foredeep — a summary

The author summarized some problems of Miocene geology and largely characterizes the basement of the Miocene formation in native sulphur ore areas (northern, peripheral part of the Carpathian Foredeep) based on materials collected during extensive exploratory field research developed after the Second World War (see also B. Kubica, 1994).

INTRODUCTION

Miocene marine deposits infill the Carpathian Foredeep (southern Poland), a basin formed in the foreland of the Carpathian orogen during the Alpine orogeny. The Miocene deposits of the central part of the Carpathian Foredeep are as thick as a few thousand metres. However, northward, in the marginal part of the basin, the thickness of the Miocene deposits gradually decreases down to several metres. In this peripheral part (Fig. 1), the Miocene deposits transgressed basement composed of a complex pattern of Palaeozoic-Mesozoic tectonic structures which built up the Holy Cross Mts., Lublin and Silesia regions.

During field explorations in the Carpathian Foredeep carried out after the Second World War the Miocene was divided into the Tortonian (actually the Badenian) and Sarmatian units. Furthermore, the Badenian has been subdivided into the Baranów Beds, the Chemical Series and the *Pecten-Spirialis* Beds and the Sarmatian into: *Syndesmya* Beds and Unfossiliferous Beds. Geophysical methods (especially gravimetry and well-logging) were very helpful in exploration research. In general, they allowed documentation of the economically important areas as well as characterization of distinct depositional sequences within the formation.

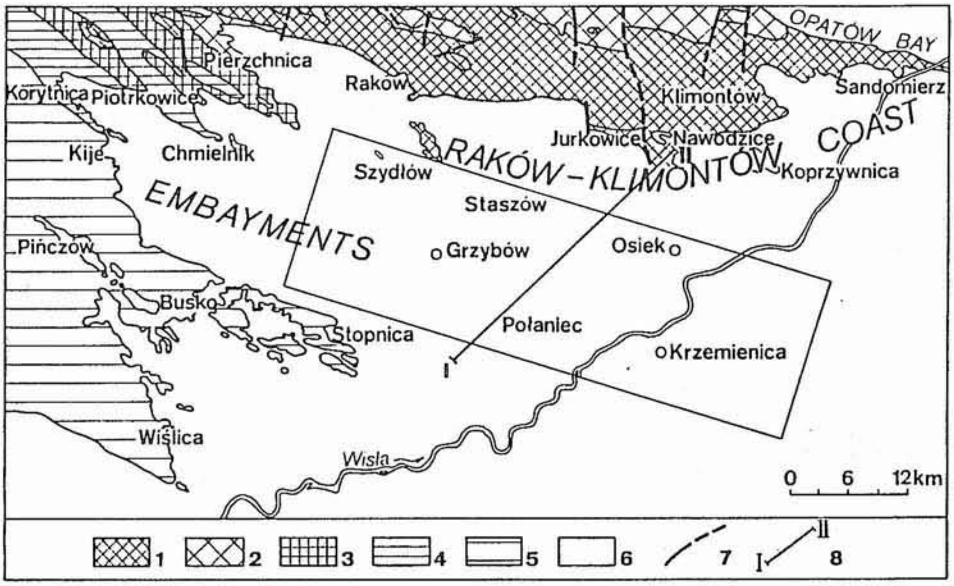

Fig. 1. Location of the area studied (marked) and extent of the marine Miocene in the northern part of the Carpathian Foredeep (after A. Radwański, 1969)

1 — Lower Palaeozoic, 2 — Upper Palaeozoic, 3 — Triassic, 4 — Jurassic, 5 — Cretaceous, 6 — Miocene, 7 — faults, 8 — cross-section (Fig. 2)

Lokalizacja obszaru badań (zaznaczono) i zasięg utworów morskiego miocenu w północnej części zapadliska przedkarpackiego (według A. Radwańskiego, 1969)

1 — dolny paleozoik, 2 — górny paleozoik, 3 — trias, 4 — jura, 5 — kreda, 6 — miocen, 7 — uskoki, 8 — przekrój geologiczny (fig. 2)

Collected materials established a detailed geological background of the area. New results allowed recognition of the geology of both the Miocene formation as well as the underlying basement on the southern border of the Holy Cross Mts. (see e.g. K. Kowalewski, 1958; K. Pawłowska, 1965; S. Pawłowski, 1970; Pawłowski *et al.*, 1965, 1985; B. Kubica, 1992). A summary of these extensive field researches are outlined in this work.

THE MIOCENE

STRATIGRAPHY

The Miocene series in the described area is represented (Tab. 1) by Badenian (formerly Tortonian) and Sarmatian deposits.

THE BADENIAN

The Badenian is represented mainly by the Baranów Beds, the Chemical Series and the *Pecten-Spirialis* Beds.

Table 1

Stratigraphy of the marine Miocene in the northern part of the Carpathian Foredeep

Epoch	Stage	Zone	Max. thickness [m]	Lithology	Biozones		Traces of volcanic activity
MIOCENE	SARMATIAN	Unfossiliferous Beds	3000	calcareous siltstone with thin intercalations of sands	plant debris	*Elphidium hauerinum*	
		Syndesmya Beds		calcareous siltstones, clay marls with calcareous marl intercalations	*Syndesmya reflexa, S. scythica, Hydrobia, Mohrensternia, Limnocardium lithopodolicum, L. subfitoni*	*Varidentella sarmatica, Cycloforina karreiovata, Anomalinoides dividens*	numerous intercalations of tuffites and bentonites
	BADENIAN	*Pecten-Spirialis* Beds	40	clay marls with calcareous marl intercalations	*Chlamys elyni, Ch.neumayri, Ch.lilli, Spiratella*	*Hanzawaia crassiseptata, Neobulimina longa, Radiolaria*	numerous tuffite intercalations
		Chemical Series	60	massive, laminated, crystalline gypsum, postsulphate limestones, native sulphur	plant debris, fish bones	*Elphidium delicatulum* (in clay intercalations)	occasional tuffite intercalations
		Ervilia Layer	0.1	sand and calcareous cocquina	*Ervilia pussilla, Modiola hoernesi*		
		Baranów Beds	120	sandstones with sand intercalations, *Lithothamnium* limestones and mudstones	*Amussium denudatum, Chlamys scissa, Ch. koheni, Ostrea cochlear, Venus multilamelata*	*Uvigerina costai, Orbulina suturalis, Heterostegina costata, Amphistegina lessonii*	tuffite intercalations

T h e B a r a n ó w B e d s . The regional and vertical distribution of facies within the Baranów Beds defines two distinct sedimentary sequences. They include: (1) a lower coaly complex of continental to marine-swamp environments developed at the depositional basin margin and, (2) an upper, relatively thick, sandstone-sandy terrigenous-biohermal complex which represents open marine siliciclastic-carbonate mixed environments.

The lower complex (formerly defined as Helvetian) consists of sandy-clayey and coaly facies intercalated by lignites and fossil soil horizons (see also J. R. Kasiński, M. Piwocki, 1994). This series contains a rich although monotonous, brackish-water macrofauna (bivalves and gastropods) and microfauna, which characterize well the Lower Badenian stage. The deposits are distinctly discontinuous and preserved in local depressions of the Miocene basement. The deposition of this complex is linked to Badenian sea level fluctuations at the beginning of the Miocene transgression. The transgressive sequence developed on relatively flat seaward edge. At that time the shoreward edge was occupied by numerous swamps with abundant, and characteristic flora and fauna.

These brackish-water deposits may locally overlap older Miocene units.

The lower complex of the shore-parallel facies grades upward into a much thicker upper one represented mainly by fine-grained and variously lithified sandy series. The upper complex often contains abundant *Lithothamnium* debris. In comparison to the previous subdivisions of the Tortonian (e.g. K. Kowalewski, 1958) it has appeared that instead of one continuous *Lithothamnium* horizon in the marginal part of the Carpathian Foredeep there are frequent bioherms which were formed at different times at different localities. The facies variations reflect a distinct sea-bottom topography induced by previous tectonic movements or intrabasinal structural deformation. Thus, these buildups overgrew the originally higher sea-bottom elevations and were simultaneously destroyed by wave and current action contributing significant amounts of organogenic debris to deposits elsewhere. The organogenic deposits are distinctly better developed in the eastern part of the investigated region where optimal environmental conditions for the growth of the coralline algae existed. Therefore, abundant algal buildups and the greatest thicknesses of the biohermal limestones developed there.

T h e *E r v i l i a* L a y e r . The sandy-organogenic complex of the Baranów Beds is overlain by the thin (usually below 10 cm in thickness) sandy, marly or carbonate *Ervilia* Layer. It commonly consists of mass occurrence of the bivalve *Modiola hoernesi* Reuss and *Ervilia pussilla* Phillippi.

T h e C h e m i c a l S e r i e s . This series is widespread in the Carpathian Foredeep and was extensively investigated for economic purposes. It sharply overlies the Baranów Beds and is represented mainly by sulphates (gypsum, anhydrite and dehydrite) as the host rocks for native sulphur-bearing or barren limestones.

Research on the evaporite unit significantly contributed to the geology of the region. With except the recognition of regional and vertical sulphate distribution and its characteristics (e.g. B. Kubica, 1972, 1992; S. Pawłowski *et al.*, 1985), there was found that around 300 m depth gypsum becomes partly dehydrated forming an intermediate diagenetic facies called dehydrite (B. Kubica, 1972, 1994) and in even deeper parts of the Carpathian Foredeep (around 500 m depth) it becomes converted into anhydrite (e.g. S. Pawłowski *et al.*, 1985; B. Kubica, 1992). In addition, some clay intercalations in the gypsum series contain various allochthonous inclusions (e.g. coalified plant remains, macro- and microfauna, tuffite interlayers), as well as a mass occurrence of *Elphidium delicatulum* Bermudez.

As to the economically important sulphur-bearing limestones, one of the fundamental problems was working out the bioepigenetic hypothesis of native sulphur origin in the Polish part of the Carpathian Foredeep (e.g. S. Pawłowski, 1965, 1968, 1970; S. Pawłowski *et al.*, 1965, 1979, 1985; B. Kubica, 1992). Firstly, there was found that some sulphate lithofacies have their strict lithological analogs in sulphur-bearing deposits which, for instance, preserved characteristic gypsum structures and textures (K. Pawłowska, 1962*b;* comp. also A. Gąsiewicz, 1994). Secondly, the collected data demonstrated a close relationship between the occurrence of sulphates on the one hand and elevated tectonic structures, accumulation of hydrocarbons and bacterial activity on the other. These favourable geological conditions were, according to the author, responsible for sulphate transformation into secondary (postsulphate) limestones and native sulphur mineralization. In summary, this approach led to the discovery of one of the world's largest native sulphur deposits.

The *Pecten-Spirialis* Beds. This series is of varying thickness (from a few to several metres thick) and represents the youngest Badenian unit. The *Pecten-Spirialis* Beds are well characterized by *Pecten* and other index fauna (e.g. S. Pawłowski *et al.*, 1985 with references therein). This unit, due to its widespread and stable stratigraphic position in the Carpathian Foredeep and characteristic lithological and faunistic features, was often used as an "index horizon" during field explorations.

THE SARMATIAN

The Badenian sequence grades upward into the thick, monotonous and clayey series of the Sarmatian. The Sarmatian deposits are subdivided into two distinct and thick complexes: the lower *Syndesmya* Beds, and the upper Unfossiliferous Beds. These units are very easily traced in logs.

The *Syndesmya* Beds. This clayey and marly series with limestone and tuffite intercalations is monotonous and contains upwardly decreasing open-marine macro- and microfauna still typical of the *Pecten-Spirialis* Beds. At the beginning, brackish conditions were established, the faunal assemblage consisted of a mass occurrence of bivalve-gastropod individuals, mainly *Syndesmya, Hydrobia* and *Mohrensternia.* The foraminiferal assemblage of the *Syndesmya* Beds was less dependent on facies variety in comparison to the macrofaunal one. For this reason, within the *Syndesmya* Beds it is possible to distinguish the following foraminiferal zones (from the base to the top of series): *Anomalinoides dividens, Cibicides lobaculus* and *Varidentella sarmatica.*

Unfossiliferous Beds. The *Syndesmya* Beds are overlain by a very thick complex composed of clayey and sandy siltstones sometimes with rhythmical sandy intercalations. It contains extremely rare macro- and microfauna, and common pyrite and marcasite aggregates. The lower part of this complex may be characterized by one foraminiferal zone (*Elphidium hauerinum*) only. This unit unconformably rests on the older unit and completes the Miocene.

The development of such a thick and impermeable cover composed of the Upper Badenian-Sarmatian clayey sequences was critical for the formation of sulphur ores. The sedimentary cover formed a natural autoclave where the transformation process could develop.

TECTONICS

Generally, the Miocene deposits rest on relatively flat (on a regional scale) basement composed mainly of Palaeozoic-Mesozoic sequences (described further in the text and also in the geological cross-sections of P. Karnkowski, 1994). The Miocene transgression developed gently due to a slow subsidence rate. However, the Late Alpine orogenic phases strongly influenced the pattern of Miocene deposition in the Carpathian Foredeep. Consequently, there were short periods of local emergence or sea-shallowing reflected by regional facies differences. The tectonic pulses are responsible for erosion of older units and thus stratigraphical gaps and unconformities developed and are especially numerous in the marginal part of the basin. Tectonic activity is also recorded by the presence of abundant tuffite intercalations, and caused the deposition of a thick, monotonous, terrigenous dominated series especially well developed during the Sarmatian. High tectonic mobility of the basin is responsible for the formation of a mosaic of tectonic blocks (numerous horsts and grabens) — comp. also e.g. S. Pawłowski *et al.* (1985). Especially intensive tectonic movements occurred at the Badenian/Sarmatian boundary and are recorded as an unconformity in many places of the foredeep (e.g. T. Osmólski, 1972; S. Pawłowski *et al.*, 1985; Z. Krysiak, 1985). This unconformity commonly separates the lower (Badenian) heavily faulted complex and the upper one (Sarmatian) which has been less intensively faulted and was mainly subjected to relatively large-scale deformation and subsidence. After this tectonic event, rapid subsidence began in the basin and the thick Sarmatian series could develop. A high and variable rate of subsidence is also documented by the unconformity recorded at the boundary between the *Syndesmya* Beds and the Unfossiliferous Beds (see e.g. S. Pawłowski *et al.*, 1985).

THE MIOCENE BASEMENT

STRATIGRAPHY

The Miocene basement is mainly built up of Precambrian, Palaeozoic and Mesozoic formations (Fig. 2). The basement is tectonically affected (folded and faulted) and composed of a mosaic of blocks. A complex arrangement of mutually displaced tectonic blocks induced the presence of many fault troughs where incomplete Palaeozoic-Mesozoic (till the Upper Jurassic) sequences have been preserved.

PRECAMBRIAN

Precambrian is represented by slightly metamorphosed clayey-silty complex composed of metaargillites and metaaleurites. It also contains thin interbeds of quartz sandstones with locally present carbonate interlayers. The rocks are commonly grey in colour but weathered they are from greenishgrey to cherry-red and often show blight tiger-like colouration. The complex is strongly tectonically disturbed, deeply inclined, compressed and cracked. According to geophysical data these rocks are of great thickness that is not exactly known. The Precambrian rocks in the eastern part of the Holy Cross Mts. and in the Fore-Carpathian Depression played an important role as old consolidated massif that controlled the palae-

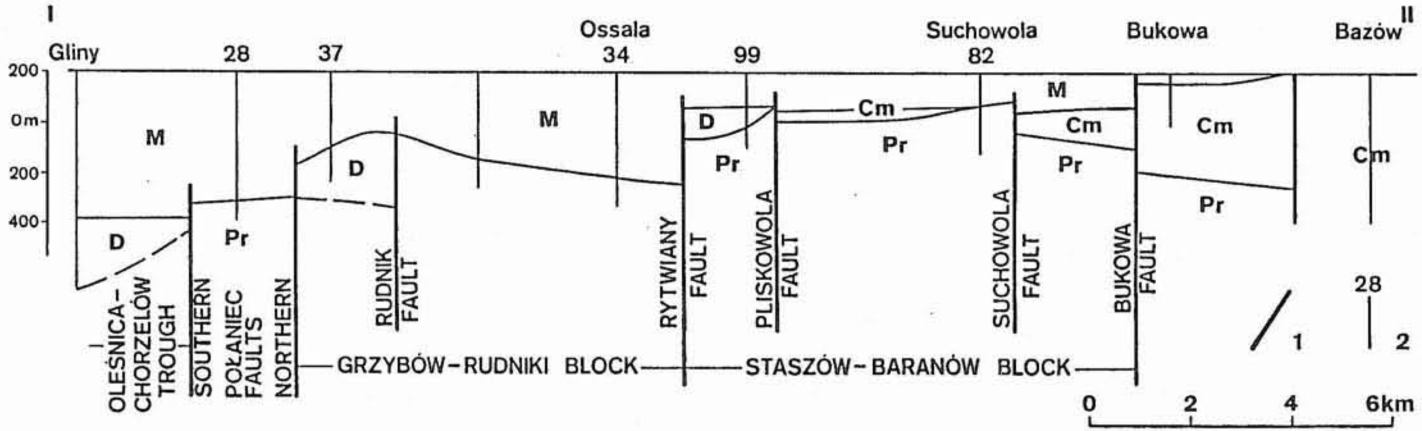

Fig. 2. Geological cross-section across the Miocene basement (for location see Fig. 1)
Pr — Precambrian, Cm — Cambrian, D — Devonian, M — Miocene; 1 — faults, 2 — boreholes
Przekrój geologiczny przez podłoże miocenu (lokalizacja na fig. 1)
Pr — prekambr, Cm — kambr, D — dewon, M — miocen; 1 — uskoki, 2 — otwory wiertnicze

ogeographic conditions and facies distribution of Palaeozoic deposits. For this reason the facies development differs from that of the northern part of the Holy Cross Mts. This relationship has already been noted by J. Czarnocki (1950) who has distinguished the northern (Łysogóry) and the southern (Kielce) subregions. In the northern part of the area (Fig. 1) near Suchowola, Osiek, Pliskowola (located in the Osiek region) and Gwoździec, Komorów (located in the Połaniec region) the Precambrian deposits are covered and by thin Lower Cambrian land suite. South of that area the Precambrian complex underlies Miocene deposits. Precambrian rocks occur in some structures such as e.g. the Brzozówka Anticline in which they built up the core with Middle Devonian limestones in the flanks or in the Połaniec Graben where they occur in the border zone of this graben.

CAMBRIAN

The contrast between the Precambrian and the Cambrian is seen both in lithology and tectonics. The Lower Cambrian series occurs in a narrow zone (in which it borders the Precambrian complex) and is represented by greywackes, sand-conglomeratic deposits with poorly sorted clastic material. Such lihology is typical in this area. The Cambrian rocks are folded and highly tectonically disturbed. The Precambrian-Cambrian unconformity varies within 30–40°.

Northward the younger and younger Cambrian members outcropped. The Cambrian rocks become fine-grained (without arenaceous sediments) and monotonous, and contain fossils.

DEVONIAN

Lower Devonian series (up to 145 m thick) are represented by mottled sandy mudstone facies with local tuffite intercalations. They rest almost flat but discordantly on the older, mainly the Lower Palaeozoic strata (described above). The Lower Devonian suite shows many analogs with the Lower Devonian sequence of the Kielce region and is completely different from marine Lower Devonian sequence recorded in the northern part of the Holy Cross Mts. and from the Old Red facies found in some boreholes of the Sandomierz region (with remains of the fish species *Pteraspis* and *Cephalaspis*).

Middle and Upper Devonian series developed as shallow-water carbonates built up carbonate ramps and platforms which contain reef limestones, lagoonal deposits, tidalites and sabkha complexes. Characteristic features of these deposits are, firstly, the presence of the brachiopod *Theodossia tanaica* Nalivkin which is not known from carbonate platform deposits of the Holy Cross Mts. area, and secondly, the development of the Fammenian series (defined on the basis of foraminifera) as carbonates.

CARBONIFEROUS

Collected field data suggest that the Lower Carboniferous was deposited concordantly on the Devonian. The Visean carbonate facies (Kohlenkalk) exhibits lithological features which are very similar to the underlying Fammenian carbonates (K. Pawłowska, 1979). The Visean was defined based on the foraminiferal fauna. Foraminiferal zones 10 through 12, according to the division of B. L. Mamet, B. S. Skipp (1970), have been reported (K. Pawłowska, H. Ozonkowa, 1985). At the end of the Middle Visean, age a thicker series of breccia, coarse-grained sandstones and conglomerates developed. Generally, the Lower

Visean (carbonates) distinctly differ in facies development from the Culm series (clastic) of the Holy Cross Mts. area.

PERMIAN

During the Permian the investigated area was land and therefore a thick (up to 330 m) series of sandstones and gravelly sandstones could develop. These sandy to gravelly continental facies were preserved in local depression of the basement (Wierzbica area). Great thickness (1370 m) of the Permian rocks is also noted by W. Moryc and H. Senkowiczowa (1968) in a local trough of the Carpathian Foredeep.

TRIASSIC

The Triassic suite is represented by a completely preserved section of the classic (in the German stratotype) development. It is divided into: Buntsandstein, Roethian, Muschelkalk, Keuper and Rhaetic.

The Buntsandstein is developed (up to 100–200 m thick) as a series of claystones and mudstones. In comparison to other regions of, the Holy Cross Mts., the Buntsandstein section is characterized by a low content of clastic facies (conglomerates, and coarse-grained or gravelly sandstones), a depletion in fauna and flora, lack of *Gervilleia murchisoni*, and also by local enrichment in esteriae, bone and floral debris. The Buntsandstein deposits resemble the section of the western part of the Holy Cross Mts. where they also unconformably overlie the Palaeozoic basement (K. Pawłowska, 1979).

The Buntsandstein deposits conformably grade into a successive unit (the Roethian sequence) developed as carbonates and marls and first appearance of *Costatoria costata* Zenker.

Muschelkalk deposits are developed as marine carbonates typical for the German stratotype correlatable with the western part of the Holy Cross Mts.

They are sharply overlain by the clastic sequence (sandstones and mudstones) of the Keuper. The transition is also marked by a change of faunal assemblages from open marine (Muschelkalk) to brackish macro- and microfauna and abundant flora. The latter consists of both unrecognizable and recognizable (Filicinae and Cycadinae) remains. The great thickness of the Lower Keuper, fossil index horizons, the presence of coaly clays and the boundary dolomite horizon, as well as the preserved and abundant microfauna and typical pollen spectra allow to correlation of this unit with the classic sections of the Fore-Sudetic Monocline and the Polish Lowland.

For the first time, opposite to the commonly assumed view of J. Samsonowicz (1929), the presence of Rhaetic deposits has been documented in the area described here (K. Pawłowska, 1979). The Rhaetic suite displays a bipartition. The lower part is clayey and defined by a bivalve *Unionites posterus* (Deffner et Fraas) and marine microfauna. The Upper Rhaetic series (K. Pawłowska, 1979), in comparison to the lower one, is represented by clastic facies such as coarse psammites, conglomerates and clay rollers. Slight sea-level fluctuations could have led to local facies differentiation and subdivision of these deposits into several lithological units. The Rhaetic suite dips 5–10° and, along with the Keuper, has been partly and irregularly eroded. Therefore, the Upper Rhaetic deposits rest with a distinct gap (comprising the Upper Keuper, the thick sequence of the Lower Rhaetic and probably the lowest part of the Upper Rhaetic) on the Lower Keuper deposits.

JURASSIC

The Jurassic suite is represented by the recognized Lower and Upper Jurassic sequences.

The Lower Jurassic (K. Pawłowska, 1962*a*) sequence is only known from some of the basement depressions (e.g. Grabki Małe Depression) where it is commonly preserved only fragmentarily. This sequence can be correlated with sections known from the northern part of the Mesozoic margin of the Holy Cross Mts. It is possible that in some fault troughs the Lower Jurassic deposits are covered by Middle Jurassic series.

The distribution of the Upper Jurassic sequence (white carbonates similar to the Oxfordian section of the southern margin of the Holy Cross Mts.) is also limited to the basement depressions and therefore it occurs only locally. From the east to the west of the region there have been found three areas where Jurassic rocks occur, they include: Grabki Małe – Wolica, Rudniki – Wymysłów and Krzemienica areas. The Upper Jurassic carbonates in the vicinity of Krzemienica represent the most southeastward extent of the southern border of the Holy Cross Mts. Because of a lack of any index fauna, it is difficult to precisely establish a stratigraphic (sub)division of these rocks within a general stratigraphic scheme.

TECTONICS

The successive sedimentary formations found in the basement under the Miocene have their own structural fabric. Some of these structural features have later been successively rejuvenated, especially during the final Late Alpine orogenic movements.

A discordant contact found between the Precambrian and the Lower Cambrian formation separates the more folded lower complex from the upper one which is less folded and consists of a lithologically different suite. At present stage of knowledge it cannot be excluded that this boundary may separate the uppermost Precambrian and the Lower Cambrian sequences and thus reflect tectonic activity at that time. A stratigraphic gap comprising the sedimentary series until the Devonian was connected with the emergence during the Caledonian orogeny.

The Precambrian formation is discordantly (almost flat) covered by the Lower Devonian. The presence of large intraformational conglomerates, breccias and slumps in the Lower Visean and a lack of the Upper Carboniferous may indicate tectonic activity of the basement and influence of the Variscan orogeny. Thus induced slight sea-level fluctuations could be responsible for the observed sedimentary structures. Fault movements connected with this orogeny could also be responsible for the formation of larger depressions and fault troughs in the basement where, in turn, clastic facies could accumulate during the Permian.

The Buntsandstein series generally masks any Palaeozoic structural fabric. However, the presence of basement elevations and depressions is reflected by both the thickness and facies differentiation of the section. Slightly inherited basement relief was finally equalized during the Roethian and Muschelkalk.

The Eocimmerian orogeny started with heavy erosion of older rocks and the emergence of the area and presented Upper Keuper deposition. As a result, the Upper Rhaetic series variously covers the Lower Keuper units or rests directly (in the eastern part of the area) on the Lower Palaeozoic sequence. In addition, there is probably a small discontinuity between the Lower and the Upper Rhaetic sequences, which can be inferred from the presence of a slight dip of the sequences and also from a disturbance, fracturing and brecciation associated with the faults. Later, after the Triassic, the whole sedimentary cover underwent intense denudation and therefore is only locally preserved.

Generally, the investigated area is disturbed by a complex fault network which has been rejuvenated during the Miocene. During the uppermost Precambrian and Cambrian, the area had undergone folding tectonics while later only movements connected with faulting tectonics occurred (comp. also M. Jarosiński, 1992).

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MIOCEN I JEGO PODŁOŻE NA OBSZARACH SIARKONOŚNYCH W BRZEŻNEJ STREFIE ZAPADLISKA PRZEDKARPACKIEGO — PODSUMOWANIE

Streszczenie

W pierwszej części artykułu omówiono niektóre problemy stratygrafii, tektoniki i wykształcenia facjalnego badenu i sarmatu brzeżnej części zapadliska przedkarpackiego, w drugiej zaś przedstawiono zarys budowy podmioceńskiego podłoża na obrzarze występowania złóż siarki rodzimej.

W budowie geologicznej podłoża miocenu biorą udział utwory najwyższego prekambru, częściowo dolnego kambru, dewonu, karbonu (facja wapienia węglowego), permu, triasu i jury. W historii geologicznej masyw prekambryjski wpływał na odmienny niż w Górach Świętokrzyskich rozwój późniejszych facji, granic zasięgów jednostek stratygraficznych, obecność luk depozycyjnych (np. brak utworów od ordowiku do częściowo dewonu), a także odmienny plan strukturalny (przeważnie tektonika dysjunktywna).