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On development of Middle Cambrian sediments in the Gdańsk Bay area

ABSTRACT: Stratigraphy and petrography of Cambrian sediments, mainly of Middle Cambrian, is presented from four boreholes (Białogóra 2, Żarnowiec 5, Władysławowo 4 and Krynica Morska 2) of the Gdańsk Bay area (northern Poland). On the basis of analysis of faunistical and lithofacial data, the sediments of Middle Cambrian were found to have been deposited in a zone close to a tidal flat (Łeba and Dębki formations) and in a sublittoral zone (Sarbsko and Osiek formations).

INTRODUCTION

The paper presents results of studies over sediments and fossils of Lower and Middle Cambrian on the basis of drill cores of some boreholes from the Gdańsk Bay area. Petrographic analyses were carried through by Teresa Przybyłowicz whereas biostratigraphic analyses by Wiesław Bednarczyk. Lithologic observations and conclusions dealing with a sedimentary environment were collected by both authors.

The paper supplements previous studies of one of the authors (Bednarczyk 1972, Bednarczyk & Turnau-Morawska 1975, Bednarczyk 1979) over the Cambrian of northern Poland and is limited to the cores received due to agreement on collaboration with the firms of Union of Petroleum Mining and Gas Industry.

The authors wish to give their acknowledgements to geologists and managers of survey firms at Piła and Wołomin and to managers of the Union of Petroleum Mining in Warsaw.

Lithologic and palaeontologic samples are stored in the archives of Laboratory of Stratigraphy, Institute of Geological Sciences Polish Academy of Sciences, Warsaw.

The studies were included in a problem "Geodynamics of Poland" — *MR I.-16.*

STRATIGRAPHIC AND PETROGRAPHIC DESCRIPTION OF THE CORES

The Cambrian sediments were described on the ground of four boreholes: Białogóra 2, Żarnowiec 5, Władysławowo 4, Krynica Morska 2 (Fig. 1). Thicknesses of Cambrian sediments and depths of their occurrence were defined on the ground of studies over lithologic and geophysic sequences. They are as follows:

borehole	thickness	depth	
Białogóra 2	278 m	2669.5—2948 m	(not bored through)
Żarnowiec 5	136.2 m	2727.0—2863.2 m	"
Władysławowo 4	355.2 m	2850.0—3205.3 m	"
Krynica Morska 2	296.5 m	2808.5—3104.0 m	"

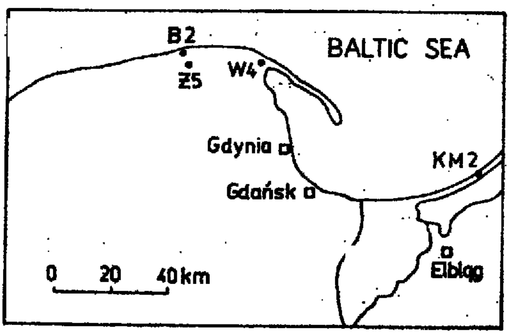


Fig. 1
Location of boreholes
B2 — Białogóra 2, Ż5 — Żarnowiec 5, W4 — Władysławowo 4, KM2 — Krynica Morska 2

A subdivision of Lower and Middle Cambrian into formations (Fig. 6) was done on the ground of stratigraphic-petrographic studies over cored pieces of borehole sections and analyses of geophysic profiles, referring to previous subdivision in this area of Bednarczyk & Turnau-Morawska (1975).

Within Lower and Middle Cambrian the following formations were distinguished: Łeba, Sarbsko, Dębki, Osiek and Białogóra formations.

ŁEBA FORMATION

The Łeba Formation was noted at the following depths:

borehole	depth	thickness	
Białogóra 2	2903—2948 m	45 m	partly bored through
Władysławowo 4	3122—3205.3 m	83.3 m	"
Krynica Morska 2	2974—3075.2 m	101.2 m total	

GENERAL REMARKS

The formation composes of alternated sandy, clayey and siltstone rocks of a prevailing gray-green colour. It contains glauconite grains that forms lamine making the stratification, parallel and oblique, more distinct. At the bottom of the formation there is an insert of coarse-grained sandstone with an admixture of chad fraction. In the upper part of the formation in boreholes Białogóra 2 and Krynica Morska 2 the claystones prevail over the sandstones; instead, in a borehole Władysławowo 4 the upper part composes of a sandstone with a dispersed glauconite and with less abundant interbeds of darkgray siltstones and claystone. Within the claystones there are locally concentrations of glauconite. There are also many traces of acting of Fodinichnia and Domichnia, the pipes of which are locally filled with sandy matter with glauconite.

In the section of Białogóra 2 the Łeba Formation composes of quartzic siltstones and claystones with interbeds of coarse-grained, almost conglomerate sandstones with numerous glauconite grains. In the lower part of the sequence there are claystones with intraclasts of glauconitic sandstone of parallel bedding. There are also thin inserts of sandy limestone. In this part of the section there are numerous Ostracoda within the claystones (*Hipponicharion eos* Mathew) and trilobites. The latter are preserved in fragments only. Usually hypostoma, cheek spines, free cheeks, cranidiums and pleurae occur. On the ground of them the species were defined as *Paradoxides oelandicus* Sjögren and *P. insularis* Westergård. Besides, the shells of *Hyolithes oelandicus* Holm were noted. The brachiopods are represented by fine shells of inarticulata of *Lingullella ferruginea* Salter and *Linnarssonia socialis* (Seebach). The latter two form locally concentrations creating the whole beds of dorsal as well as of ventral shells. But the ventral shells predominate. Sporadicly, but only within the siltstone inserts the shells of *Redlichella granulata* (Linnarsson) were noted.

In the upper part of the Łeba Formation where the sandstones predominate, there are local concentrations of cranidiums, hypostoma of *Paradoxides* ex gr. *oelandicus* Sjögren and *P. insularis* Westergård as well as shells of *Redlichella granulata* (Linnarsson). Traces of organic activity are quite rare within the rocks of this formation. They are represented only by habitable holes of Domichnia type. The formation ends again with clayey sediments with *Paradoxides oelandicus* Sjögren.

In the borehole Władysławowo 4 the Łeba Formation is mainly composed of sandstones with glauconite. Siltstones and claystones of this formation, usually darkgray, contain also glauconite — locally in considerable concentrations. Within claystone-siltstone interbeddings there are frequently intraclasts of sandstones with glauconite. The sandstone is usually sedimentary and biologicaly disturbed (Pl. 6, Fig. 2, Pl. 7, Fig. 2). Within it there are washing traces and erosive niches (Pl. 4, Fig. 1). There is a small-scale and large-scale cross bedding as well as flaser, lenticular and finewavy beddings (Pl. 4, Figs 1—2, Pl. 6, Fig. 1), underlined by darkgray clayey lamine with glauconite or with lamine of glauconite. Within the sandstone there are also many intraclasts of darkgray siltstone with glauconite. At the bottom of this formation there is a common small-scale cross bedding underlined by glauconite lamine (Pl. 4, Fig. 2, Pl. 5, Fig. 1, Pl. 6, Fig. 1, Pl. 7, Fig. 2). In the whole formation there are numerous traces of organic activity of at least three ischnocoenoses: Domichnia, Fodinichnia and Repichnia (Pl. 4, Figs 1—2, Pl. 5, Fig. 1, Pl. 6, Fig. 2, Pl. 7, Fig. 2). Among them *Diplocraterion* sp., *Spiroscolex spiralis* (Torell) (Pl. 1, Fig. 2), *Tigillites* sp. and *Sagittichnus* sp. were found. Locally on the bed surfaces there are traces resulting from segregation of $CaCO_3$ or due to tectonic and diagenetic processes e.g. *Creysonia* Walcott.

The Łeba Formation is similar in the borehole Krynica Morska 2. There, mainly vari-grained sandstones occur with dispersed glauconite grains but in the lower part of the formation there are mainly coarse-grained sandstones. Within the sandstones as well as in siltstones and claystones that form the sandstones interbeds, a glauconite is abundant the grains of which underline the cross bedding (Pl. 2, Fig. 1, Pl. 3, Fig. 1); also convolute and horizontal beddings are noted (Pl. 7, Fig. 1). Within the claystone there are numerous traces of *Bergaueria major* Palij, (Pl. 1, Fig. 1), *Gordia*? sp., *Planolites ballandus* Webby, *P. montanus* Richter, *Cyclomedusa*? sp. (Pl. 2, Fig. 2) and also Fodinichnia (Pl. 3, Figs 1—2). Locally on the surfaces there are structures resulting from current activity and waves.

MICROSCOPIC OBSERVATIONS

The sandstones possess psammitic and psammitic-aleuritic textures and usually, a direction structure. There are two distinct fractions: fine (usually 0.1—0.3 mm), with angular grains and being the basal sandstone fraction and also a coarser fraction (0.9—1.6 mm), with single chad grains up to 0.4 mm in diameter (borehole Władysławowo 4), well and very well rounded. The latter can be mainly found in the lower part of the formation where they locally form streaky concentrations (Pl. 5, Fig. 2) but also they can be chaotically dispersed within the sandstone (Pl. 22, Fig. 1). A quantitative mineral composition of the series is presented in the Table 1.

Quartz is the main detrital component; it puts out the light usually calmly, seldom in a wavy and a zonal way. Around some quartz grains there are regenerative coats (Pl. 19, Fig. 1), particularly well seen in these places where the grains are covered with a thin mantle of black and brown iron oxides and hydroxides.

Among the secondary components there are rare plates of muscovite, seldom of biotite of green and yellow-brown pleochroism as well as feldspars. Among the feldspars there is microcline, usually with a typical twin pattern and plagioclases of albite twin crystals belonging to the albite (Pl. 19, Fig. 2). Some feldspar grains are clear and have not been subjected to any transformations. Sometimes the feldspars are clouded and even they are corroded along the cracks by the carbonates (Pl. 20, Fig. 1). There are also carbonatized feldspar grains in which the feldspar remained in relics only (Pl. 20, Fig. 2) and locally, its grains are entirely replaced by carbonates. The feldspar grains are 0.1—0.2 mm large.

Sporadically there are pieces of fine-grained rocks as of a quartzitic siltstone, in places impregnated with iron oxides. There are also rare phosphate pieces or concretions composing of collophane and fine-grained quartz of aleuritic fraction (Pl. 21, Figs 1—2).

The sandstone cement is varying: locally it is a regenerated quartzic one that connects the quartz grains creating a quartzic mosaic. Locally the intergranular spaces are filled with calcite, usually with a fine-crystalline one but also with a more coarse — crystalline one (borehole Białogóra 2). In some parts of the sandstones their cement includes also locally the yellow-brown isotropic phosphates (collophane). Locally the cement composes of highly birefringent clayey minerals of illite type, creating also streaks and lenticles within the sandstones.

Glauconite is also a popular component of these sediments. It occurs in the whole formation in varying quantities (Table 1), either uniformly dispersed in the rocks or, as in the lower part of the formation, it is concentrated forming streaks, layers and lenticular agglomerations that make the direction structure more distinct. It is grass-green, fine-aggregated. It creates single isolated grains of oval and angular shapes (Pl. 22, Fig. 1). These single grains are of varying

Table 1

Mineral composition of Łeba Formation rocks (in volume per cent)

Borhole	Depth (m)	No. of sample	Quartz	Clayey minerals	Carbonates	Glauconite	Micas	Non transparent minerals	Heavy minerals	Feldspars	Siliceous fragments	Phosphates
Białogóra 2	2926.0—2929.5	25	35.8	56.2	0.8	3.8	1.0	2.1	0.1	—	—	0.2
	2926.0—2929.5	26	23.5	67.9	0.5	3.2	1.3	3.5	0.1	—	—	—
	2926.0—2929.5	27	40.9	50.3	2.8	2.7	1.0	1.8	0.2	—	—	0.3
	2929.5—2931.2	28	36.8	46.5	9.7	3.7	0.9	1.9	0.2	—	—	0.3
	2929.5—2931.2	29	59.2	7.1	3.0	12.5	—	1.5	—	—	—	16.7
	2933.0—2936.7	30	32.1	61.0	—	0.7	2.2	3.9	—	—	—	0.1
	2937.7—2940.0	31	16.2	75.9	0.3	1.1	1.8	4.5	0.2	trace	—	—
	2940.0—2944.0	32	15.7	74.0	0.3	1.2	2.4	6.4	—	trace	—	—
	2944.0—2948.0	33	7.9	82.8	—	1.6	1.5	6.2	trace	—	—	—
Władysławowo 4	3122.5—3125.0	25	48.3	41.4	0.7	5.0	1.5	0.6	0.5	2.0	—	—
	3155.8—3159.0	26	75.7	10.4	7.1	4.6	0.1	1.0	0.4	0.4	0.3	—
	3172.0—3173.0	28	83.7	3.2	1.0	10.7	0.3	0.6	0.5	—	—	trace
	3177.9—3179.1	30	72.9	—	7.2	15.2	0.6	0.3	0.7	2.3	0.8	—
	3190.1—3191.6	32	56.3	27.4	1.1	10.1	2.7	1.0	0.5	0.9	—	—
	3194.4—3195.8	33	84.5	3.0	3.5	6.0	0.5	0.1	0.3	1.8	0.3	—
	3198.1—3200.6	35	58.7	28.3	1.9	7.5	1.3	0.6	0.2	1.5	—	—
	3198.1—3200.6	36	61.0	5.3	2.2	27.7	1.9	0.8	0.1	1.0	—	—
	3203.7—3205.3	38	80.8	2.6	3.8	9.8	1.3	0.3	0.2	1.2	—	—
Krynica Morska 2	3062.2—3064.3	25	66.1	23.7	1.2	6.5	0.4	0.7	0.9	0.5	—	—
	3062.2—3064.3	26	77.6	0.6	8.2	11.5	0.6	0.7	0.8	—	—	—
	3072.6—3075.2	29	82.5	—	5.3	7.7	0.1	—	0.5	0.5		3.4

dimensions of 0.04—0.5 mm. Locally the glauconite grains are partially similar to the neighbouring quartz grains. But its granular form there are also glauconitic streaks in which its greater aggregates and agglomerations enter the intergranular spaces of a detrital matter and fill the integranular pores forming a cement (Pl. 22, Fig. 2, Pl. 23, Fig. 1). Occasionally there is a glauconite formed due to glauconitization of biotite plates. It is pale-green, with a conserved shape of a primary plate.

Among the heavy minerals there is a rounded zircon and green — olive tourmaline. Non-transparent minerals, iron oxides and sulphides (pyrite), form single grains and aggregate nodular agglomerations. They are dispersed within the rocks but sporadicaly they are concentrated together with zircon and tourmaline as thin streaks close to the glauconitic lamine.

Siltstone-claystone inserts have an aleuritic-pelitic texture and a direction structure, occasionally laminated — underlined by lamine or aleuritic lenticles with a greater content of quartz. The structure is also underlined by a direction arrangement of plates of muscovite and of greenish or brownish biotite as well as by streaks and agglomerations of a black organic matter, iron oxides and sulphides (pyrite or marcasite). Non-transparent minerals can be also found as dust, fine crystals and nodules, resulting in a gray-brown colour.

A brownish clayey matter composes mainly of clayey fine-scaly, highly birefringent minerals of the illite (what is proved by thermal analyses, Figs 2, 4—5, samples: *B2-28, 30, 31*; *W4-35*; *KM2-24*), of a distinct direction arrangement marked by an agreeable putting out of a light. Within the clayey layers there is

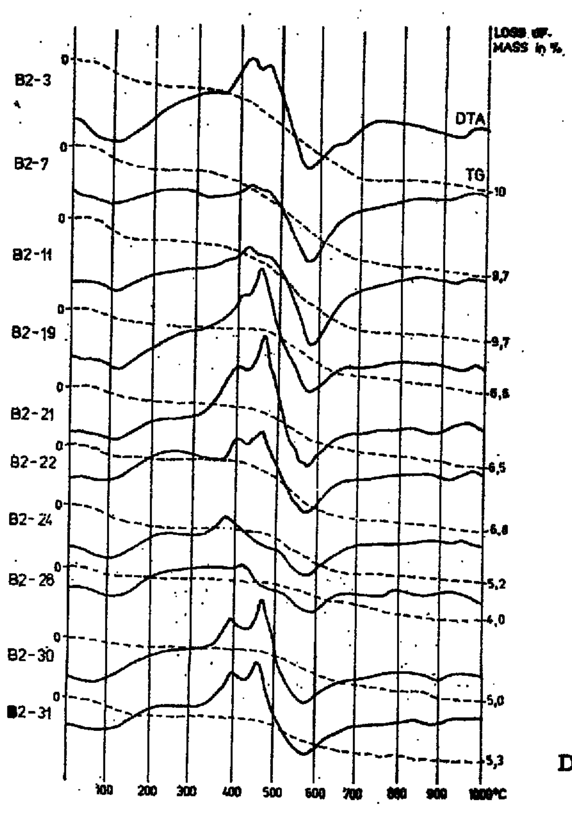


Fig. 2
Derivatograms of Cambrian sediments of borehole Białogóra 2
B2—3 etc. — sample number

a dispersed quartz as a quartz dust and very fine angular grains of 0.02—0.06 mm. Locally there are also well rounded quartz grains of a psammitic fraction, 0.2—0.9 mm (borehole Białogóra *2*, lower part of the Łeba Formation at a depth of 2940—2948 m).

Siltstone parts of these rocks have a clayey cement, locally a regenerated quartzic one. Their detrital composition is the same as of the sandstones already described (Table 1). Sharp-edged quartz is the main component, there is also a small admixture of twinned plagioclases and microclines as well as muscovite and biotite of a direction arrangement. Here and there the aggregate concentrations of carbonates are noted; in places they cement the quartz grains or form dispersed single crystals. The glauconite within these rocks forms either fine grains, 0.04—0.08 mm and more sporadicaly slightly greater ones: 0.1—0.2 mm, or it is contained within the rock matrix and does not form any distinct grains. These is also a glauconite formed due to glauconitization of micas.

Features of the glauconite found in the sandstone and in the siltstone-claystone series prove its partial autochthonous origin and some grains could get into the sediment in a half-plastic state, thus adapting its shape to the neighbouring quartz grains.

SARBSKO FORMATION

The Sarbsko Formation occurs at the depths:

borehole	depth	thickness
Białogóra *2*	2787 —2903 m	116 m total
Żarnowiec *5*	2855.5—2863.2 m	7.7 m partly bored through
Władysławowo *4*	2947 —3122 m	175 m total
Krynica Morska *2*	2948 —2974 m	26 m total

GENERAL REMARKS

The formation composes of alternated gray siltstones and darkgray claystones. Within the complex there are thin, of irregular thickness, inserts of lightgray fine-grained sandstone. At the bed surfaces there are abundant plates of muscovite. Numerous forms of Fodinichnia were noted. In the lower part of the formation there are inserts of lightgray limestones.

The Sarbsko Formation composes in a borehole Białogóra *2* mainly of darkgray claystones. Siltstones and sandstones are rare and occur only in inserts and thin interbeddings. Thin limestone inserts are typical there (depth 2849.2—2870.6 m); a glauconite as well as the phosphates are rare. Within the whole formation there are numerous fragments of trilobites: hypostoma, pleurae, cranidiums and pygidiums. The following species were noted: *Peronopsis fallax* (Linnarsson), *Triplagnostus praecurrens* (Westergärd), *Paradoxides oelandicus* Sjögren, *P.* ex. gr. *oelandicus* Sjögren, *P.* cf. *pinus* Holm and *P.* sp.

There are also many shells of *Hyolithes oelandicus* Holm and shells of brachiopoda inarticulata: *Lingulella ferruginea* Salter, *Linnarssonia socialis* (Seebach) and *Redlichella granulata* (Linnarsson). The latter ones are typical for the lower part of the formation in this section.

On the surfaces of siltstones and claystones there are abundant traces of Repichnia, Fodinichnia and Cubichnia (Pl. 9, Fig. 2).

In a borehole Żarnowiec *5* a part of the Sarbsko Formation was drilled only (7.5 m). It composes of a clyastone with numerous traces of organic activity, among which there are fine traces of Cubichnia (*Isopodichnus* sp., *Cyclomedusa*? sp.) (Pl. 8, Fig. 3) and Fodinichnia (*Planolites* sp.). In the lower part of the formation fine current marks of *Kineya* Walcott type were noted.

The Sarbsko Formation is represented in a section of Władysławowo *4* by typical darkgray siltstones alternated with sandstones of cross bedding as well as by darkgray claystones alternated with lightgray fine-grained sandstones of cross bedding too. The sandstone beds are frequently washed so, there are many load casted sandstone and siltstone within the claystone (Pl. 10, Fig. 1). The fossils within this formations are quite rare and badly conserved. There are only fragments of trilobites (pleurae, more rare cranidiums) i.e. of: *Ellipsocephalus lejostracus* (Angelin), *Paradoxides* sp. Single and fragments of carapaces of *Hipponicharion* sp. and some shells of *Lingulella* sp. are also noted. Instead, there are numerous organic traces of Repichnia, Fodinichnia and Pascichnia, among others: *Bifungites fezzanensis* Desio, *Gordia* sp. (Pl. 8, Fig. 1), *Planolites ballandus* Webby (Pl. 9, Fig. 1), *P.* sp. (Pl. 8, Fig. 5). There are also numerous prints of mud cracks, small faults resulting from sediment draining, traces of dragging and percussion (splinters). In the upper part of the formation there is but a cross bedding, also a parallel bedding made more distinct by clayey streaks.

In the section of Krynica Morska *2* the Sarbsko Formation includes a darkgray claystone with interbeds of gray, horizontally laminated siltstone. At the surface of siltstone beds there are single features of Domichnia type among *Tigillites* sp. Besides, on the surfaces there are prints of dragging and percussion (splinters). Ocassionally there are fragments of trilobites *Paradoxides*? sp.

MICROSCOPIC OBSERVATIONS

Clayey-siltstone rocks have an aleuritic-pelitic texture and a direction laminated structure. The lamine of greater content of aleuritic fraction alternate with clayey brown lamine. An illite is the main clay mineral within them (what

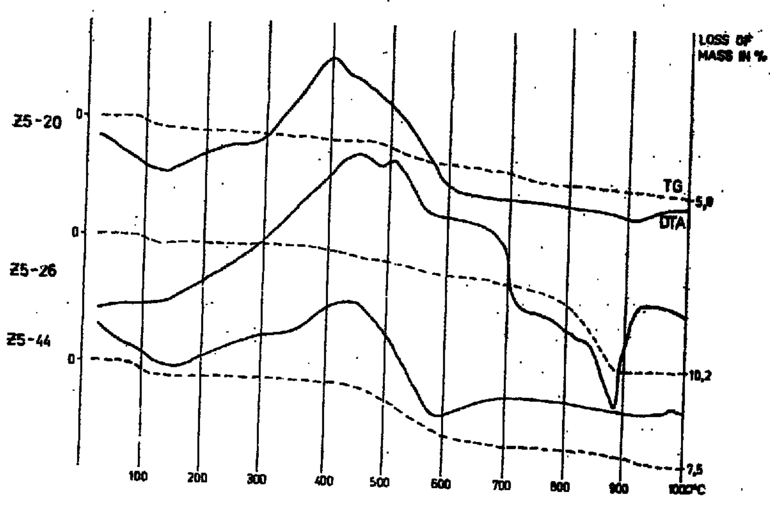


Fig. 3. Derivatograms of Cambrian sediments of borehole Żarnowiec *5*
Ż5—20 etc. — sample number

is proved by thermal analyses, Figs 2—5, samples: *B2-19, 21, 22, 24; Ż5-44; W4-20, 21; KM2-20, 23*). The lamine are accompanied by plates of muscovite and more seldom — of biotite. There is an insignificant admixture of scaly greenish minerals of low birefringence, belonging perhaps to a chlorite group. Clay minerals are tinged with a dusty brown pigment creating fine nodules or concentrated in thin streaks that also underline a direction structure of the rock. As proved by thermal analyses the pigment composes of organic matter and iron sulphides (pyrite or marcasite). There is a siderite too, usually strongly oxidated and creating fine spherolites of 0.04 mm, single or in small agglomerations (boreholes: Białogóra *2*, Żarnowiec *5*, Władysławowo *4*). Quartz of 0.02—0.04 mm is dispersed within the claystone but also, it forms thin streaks and lenticles.

In the lower part of the Sarbsko Formation the are single grains of green, fine-aggregated glauconite of 0.03—0.08 mm.

Within the claystones there are irregular wavy, frequently pinching lamine of siltstones and sandstones. Their texture is a pelitic-aleuritic-psammitic one. They compose of sharp-edged quartz of 0.02—0.1 mm grains. A cement of these rocks is generally a quartzic regenerated one. Clay minerals form also a certain admixture in the cement but they make thin streaks too. Locally there are fine, aggregated agglomerations of carbonates — calcite and single sideritic spherolites (borehole Żarnowiec *5*). Among the siltstone components of secondary importance there are muscovite and biotite and also accessory minerals as zircon and green tourmaline. Here and there one can find nodular agglomerations of iron oxides and pyrite.

Light-gray limestones creating inserts within the claystones (borehole Białogóra *2*) compose of colourless mosaic of cryptocrystalline carbonates — calcite.

Table 2

Mineral composition of Sarbsko Formation rocks (in volume per cent)

Borehole	Depth (m)	No. of sample	Quartz	Clayey minerals	Carbonates	Glauconite	Micas	Non transparent minerals	Heavy minerals	Phosphates
Białogóra 2	2796.0—2797.8	19	13.8	82.3	0.9	—	0.4	2.6	—	—
	2818.6—2821.6	21	13.5	79.9	0.3	trace	0.7	5.6	trace	—
	2842.9—2846.6	22	11.6	84.4	—	0.1	1.0	2.8	0.1	—
	2867.4—2870.6	23	25.5	—	71.9	0.4	0.3	1.1	0.4	0.4
	2887.6—2890.6	24	13.3	80.9	1.4	0.7	1.1	2.5	0.1	—
Władysławowo 4	2989.5—2992.0	20	30.3	61.6	3.6	0.2	3.2	0.6	0.5	—
	3047.0—3050.0	22	20.1	73.5	—	2.4	2.8	1.2	—	—
	3083.0—3087.0	23	34.4	58.5	—	2.9	2.1	1.8	0.3	—

Seldom only there are fine sideritic spherolites. In the carbonate matrix there are loosely arranged sharp-edged quartz grains of an even fraction of about 0.05 mm. Here and there the muscovite plates occur. There are quite numerous oval agglomerations of non-transparent minerals. Locally there are concentrations of glauconite of washed shapes, occurring amidst a carbonaceous matrix. Seldom phosphate pieces (collophane) occurs; they have a rod-shaped structure and are probably the organic remains.

A percentage content of mineral components within the claystones, siltstones and limestones is presented in Table 2.

DĘBKI FORMATION

The Dębki Formation was noted at the following depths:

borehole	depth	thickness
Białogóra 2	2709.0—2787.0 m	78.0 m total
Żarnowiec 5	2757.0—2855.5 m	98.5 m „
Władysławowo 4	2886.0—2947.0 m	61.0 m „
Krynica Morska 2	2816.5—2948.0 m	131.5 m „

GENERAL REMARKS

The formation composes of quartzic gray-beige and milky-white fine-grained sandstones with streaks and thin, several centimetres thick inserts of darkgray claystone, locally of a convolute bedding (Pl. 13, Fig. 2). On the bed surfaces there are abundant mica plates. In the upper part of the series there are clay balls and load casts (Pl. 14, Fig. 1). Here and there fine (about 2 mm) spots — rusty-brown agglomerations occur, evenly distributed within the rock (borehole Białogóra 2, Żarnowiec 5). In the borehole Żarnowiec 5 the pyrite crystals occur — they are dispersed within the rock but also they form larger agglomerations.

In the section Białogóra 2 the Dębki Formation composes of quartzic milky-white and gray-beige sandstones with streaks and thin beds of darkgray claystones or, with inserts of claystone of irregular thickness. Sandy load casts (Pl. 10, Fig. 2) and intraclasts were found. Locally within the sandstone there is a cross bedding underlined by thin claystone lamine. Within the claystone inserts and beds there are sandy intraclasts and sliding planes suggesting an occurrence of intra-bedding displacements (Pl. 12, Fig. 1). Locally, a fine-wavy, lenticular as well as convolute beddings were noted (Pl. 12, Figs 1—2, Pl. 13, Fig. 2, Pl. 14, Fig. 1) and on the bottom planes of the sandstone there were hieroglyphs of cracks formed due to sediment drying up, so-called mud fissures (Pl. 14, Fig. 2). The surfaces of that type are covered with a thin clayey matter. The clayey parts contain, sometimes large, abundant micaceous plates. The fossils noted within the sandstones are enormously poor and occur in pieces. They are represented first of all by trilobites (fragments of cranidiums, pleurae, fragments of free cheeks and cheek spines): *Paradoxides* sp. and *Ellipsocephalus* sp. On the sandstone surface there are ducts of Domichnia type, among others an escape structure of an unknown individual (Pl. 13, Fig. 1) and also, on the surfaces of the claystone beds there are Pascichnia (*Nereites cambrensis* Mac Leay, Pl. 12, Fig. 3) and features of Fodinichnia (Pl. 10, Fig. 2, Pl. 14, Fig. 1).

In the section of Żarnowiec 5 the Dębki Formation composes also of milky-white quartzic and gray-beige sandstones, locally interbedded with darkgray claystone and siltstone. On the bottom bed surfaces the load casts are noted. Within the sandstone there are clay balls and siltstone pieces of intraclasts. Similarly, within the claystones there are also sandstone intraclasts. In the lower part of the Dębki Formation there are sandstones of horizontal bedding. There is also a lenticular bedding. But in the upper parts of the section no bedding can be noted, perhaps due to reworking of the sediment by the bottom fauna. There are relatively many living tracks within the whole series. The are represented by various feeding types (Fodinichnia, Domichnia among others: *Planolites ballandus* Webby and *Monocraterion* sp.) (Pl. 17, Fig. 2). On the bottom surfaces of beds there are also float casts. Fossils are sporadic within the sediment and occur in pieces only. They include mainly cheek spines of *Paradoxides* sp.

In the section Władysławowo 4, localized farther to the east, the Dębki Formation composes of typical milky-white sandstones with horizontal, wavy and lenticular beddings, usually disturbed by the Fodinichnia assemblages (Pl. 14, Fig. 3). A horizontal bedding is also underlined by lamine and streaks of darkgray claystone. Within the interbeddings of this claystone there are also sandstone intraclasts. But a horizontal bedding there is also a convolute bedding and a small-scale cross bedding (Pl. 15, Fig. 1). The sandstone intraclasts have also a cross bedding. Claystones within the sandstone are of secondary importance and contain many fine plates of mica. On the bed surfaces there are abundant living tracks of Fodinichnia among which *Planolites ballandus* Webby, *P. montanus* Richter were determined (Pl. 15, Fig. 2, Pl. 8, Fig. 4); features of Domichnia (*Tigillites* sp.) and structures similar to *Biformis* sp. are more rare.

In the last mentioned, most eastward section of Krynica Morska 2, the Dębki Formation is twice thicker. It is represented by typical milky-white or beige-gray sandstones interbedded with darkgray claystone or siltstone. Within the sandstone there is a convolute and a horizontal flaser bedding (Pl. 11, Fig. 1) whereas, in some parts of the section there are cloudy structures. The claystones contain sandstone intraclasts. On the bed surfaces there are washing and dragging tracks as well as prints of bottom fauna action: of *Planolites ballandus* Webby (Pl. 11, Fig. 2). Many load casts were noted and on some surfaces — the hieroglyphs of drying fissures (mud cracks). In the upper parts of the section there are flat, elliptic siltstone or claystone balls.

MICROSCOPIC OBSERVATIONS

In the lower part of the formation there are fine-grained and even-grained sandstones of very uniform and well selected fraction. Most grains are included in the fraction of 0.1—0.3 mm. In the upper part of the section the grains are of a less uniform size and there is an admixture of grains of the fraction of 0.4—1.0 mm, in the borehole Krynica Morksa 2 — of a chad fraction of 1.4—1.6 mm. These coarser grains are evenly distributed within the basal sandstone fraction but locally, they create streaky agglomerations. The sandstone structure is not oriented and there is a local trend to the arrangement of the quartz grains with their longer axes in the same direction. They are almost monomineral (Table 3). The detrital matter contains almost entirely the quartz grains that interfinger one another. Some grains are covered with a very thin brown coat reflecting their shape. They have generally rounded corners and the grains of the coarser fractions are even oval.

The sandstones have mainly a quartzic cement, completely regenerated, that forms a quartzic mosaic together with the detritic quartz.

Within these rocks there are almost everywhere the carbonates — calcite and siderite creating agglomerations and groups filling the intergranular spaces

Table 3

Mineral composition of Dębki Formation (in volume per cent)

Borehole	Depth (m)	No. of sample	Quartz	Clayey minerals	Carbonates	Baryte	Micas	Non transparent minerals	Heavy minerals
Białogóra 2	2709.0—2709.8	1	92.7	—	4.1	1.4	—	0.8	1.0
	2712.8—2714.3	3	38.5	60.2	0.6	0.4	0.2	0.1	trace
	2726.0—2727.5	4	91.6	7.4	0.8	—	—	—	0.2
	2728.7—2730.7	5	92.3	—	6.1	0.8	—	0.3	0.5
	2732.0—2734.5	7	54.5	39.7	1.4	—	2.0	1.5	0.9
	2732.0—2734.5	8	40.2	53.0	4.4	—	0.8	1.5	0.1
	2734.5—2736.5	9	94.7	0.4	4.8	—	—	—	0.1
	2740.5—2742.0	10	91.5	—	4.4	—	0.3	2.4	1.4
	2754.5—2754.8	11	21.7	75.3	—	—	1.3	1.3	0.4
	2756.2—2757.6	12	83.4	6.3	8.6	—	0.4	0.5	0.8
	2757.6—2759.1	13	90.9	1.3	5.3	—	0.3	1.0	1.2
	2762.3—2763.8	14	86.5	—	9.1	—	1.5	1.6	1.3
	2763.8—2765.3	15	91.2	—	7.9	—	0.3	0.2	0.2
	2763.8—2765.3	16	48.7	47.1	0.4	—	0.8	1.6	1.4
	2771.0—2772.7	17	91.2	0.9	4.3	—	trace	2.1	1.5
	2781.6—2782.6	18	93.9	1.1	3.4	—	0.6	0.7	0.3
Żarnowiec 5	2780.5—2781.5	34	73.5	—	23.5	—	—	2.1	0.9
	2786.3—2787.6	36	63.1	30.9	1.7	—	3.1	—	1.2
Władysławowo 4	2942.1—2946 4	16	82.3	11.6	3.9	—	0.4	1.0	0.8
Krynica Morska 2	2819.6—2824.5	6	71.8* 27.5**	—	0.7	—	—	—	—
	2824.5—2830.2	8	80.2	12.3	5.2	—	1.2	0.3	0.8
	2824.5—2830.2	9	43.3	53.6	—	—	1.8	0.7	0.5
	2824.5—2830.2	12	74.6*—19.1**	—	6.0	—	—	—	0.3
	2845.0—2846.0	15	81.8	10.1	2.8	—	4.2	0.7	0.4
	2861.0—2863.5	18	76.4	8.8	12.8	—	1.1	0.3	0.6

*) detriti. quartz
**) regenerate quartz

in a spotty way. Locally, a siderite forms small spherolites and very fine rhomboedric crystals, usually intensively oxidized. A siderite was not noted in a borehole Krynica Morska 2. Instead, in a borehole Białogóra 2 there is locally a barite (in small quantities) that occurs in the intergranular spaces.

These sandstones contain too plates of muscovite and green biotite. Among the accessory minerals well rounded zircons and tourmalines are noted. There are rounded grains and nodular agglomerations of non-transparent mineral (iron oxides and sulphides).

A quantitative mineral composition of the sandstone is presented in Table 3.

Within these rock parts in which there are clayey lamine and streaks, there is a direction structure (Pl. 23, Fig. 2). There is also an increased content of aleuritic fraction (0.04—0.1 mm) and a content of pelitic and clayey matter considerably increases within the cement.

Clayey lamine that are wavy stratified pass into thin streaks or they widen forming the lenticles. There are also isolated clayey balls. Clayey fragments compose mainly of illite (Figs 2, 5, samples *B2-3, 7, 11; KM2-5, 16, 19*). An insignificant admixture is also created by slightly birefringent minerals, perhaps belonging to the minerals of kaolinite or chlorite? groups. Within the claystones there are frequently thin muscovite plates, up to 0.6 mm large and arranged in

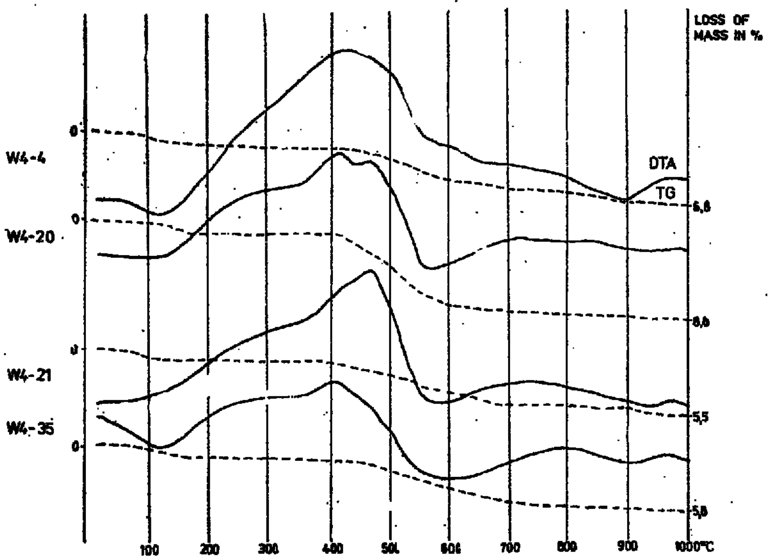


Fig. 4. Derivatograms of Cambrian sediments of borehole Władysławowo 4
W4—4 etc. — sample number

agreement with the bedding. A small admixture within these beds is created by a quartzic pelite. Here and there there is a fine-aggregated calcite and a brown siderite, occurring in fine-crystalline agglomerations, seldom of spherolitic shapes but also as rhomboedric crystals evenly distributed within the rock. A clayey matter is brown or black due to a content of pigment in very fine nodules and very thin streaks. As proved by thermal analyses it composes of organic matter and iron sulphides (pyrite, marcasite). At the contact of clayey and sandy fragments there is a local concentration in streaks of non-transparent minerals and also of zircon and tourmaline (borehole Białogóra *2*).

OSIEK FORMATION

The Osiek Formation was found at the following depths:

borehole	depth	thickness	
Białogóra 2	2690—2709 m	19 m total	
Żarnowiec 5	2727—2757 m	30 m „	
Władysławowo 4	2861—2886 m	25 m „	
Krynica Morska 2	2808—2816.5 m	8.5 m „	(together with Upper Cambrian)

The rocks of this formation were cored only in the boreholes of Żarnowiec 5 and Władysławowo 4.

GENERAL REMARKS

The Osiek Formation composes of darkgray siltstones with claystone interbeds as well as interbeddings of claystones with thin inserts of fine-grained, lightgray sandstone. On the surface of clayey beds there are tracks of organic acting. There are also fragments of trilobite carapaces and brachiopode shells. Within the rocks a pyrite occurs in dispersed crystals and concretions.

In the section of Żarnowiec 5 the Osiek Formation is represented by darkgray claystones and siltstones with interbeds of gray sandstones. Within claystones and siltstones there is frequently a dispersed pyrite, locally in larger rod-shaped aglomerations on bed surfaces and float casts resulting from a water turbulence due to wind blows (*Kineya simulans* Walcott, Pl. 18, Fig. 3). There are also abundant living tracks of Repichnia and Fodinichnia. Among them there are: *Planolites, Gordia, Saggitichnus, Cochlichnus* (Pl. 18, Fig. 4). The sandstone has a horizontal bedding. At the contact of the sandstone with a claystone there are erosive niches filled with sandy matter. At the sandstone bottom surfaces there are load casts and float casts. The rocks of this formation contain relatively abundant but only fragments of trilobite carapaces and shells of inarticulata. Such species were determined as: *Peronopsis fallax* (Linnarsson), *P. pusilla* (Tullberg), *Paradoxides paradoxissimus* Wahnleberg, *P.* cf. *paradoxissimus* Wahl., *P.* sp. *Lingulella ferruginea* Salter. There are also rest and moving tracks of trilobites: *Merostomichnites, Dipliichnites*? sp. and *Cruziana* sp. (Pl. 18, Figs 1, 2).

In the section Władysławowo 4 the Osiek Formation includes the siltstones alternated with darkgray claystones. The borders between claystones and siltstones are sharp but concordant; no washing traces are noted. Within the claystones there are fine concretions of pyrite and abundant plates of micas. Lightgray fine-grained sandstones within the claystones are of secondary importance. The sandstone beds have washing traces on their surfaces as erosive niches filled with clayey matter. Within the claystones there are intraclasts of that sandstone. Within the sandstones as well as within a claystone-siltstone series there are abundant living tracks of Fodinichnia type (*Planolites* sp.) or rest tracks of trilobites — *Rusophycus* sp. (Pl. 17, Fig. 1) or other problematic tracks as *Granularia*? sp., *Bifungites* sp. (Pl. 16, Fig. 2). Locally there are beds full of fragments of trilobite carapaces and of fine shells of inarticulata. *Paradoxides* sp. and *Lingulella* sp. are noted within them.

MICROSCOPIC OBSERVATIONS

The siltstones have most frequently a direction structure underlined by clayey streaks. Sharp-edged and badly rounded quartz grains, 0.02—0.08 mm large, interfinger locally with one another creating a quartzic mosaic but also they occur loosely within a matrix; the latter composes of clayey matter of illite type with a small admixture of scaly, pale-green, slightly birefringent minerals that probably belong to the chlorite group. Locally, the cement composes of micritic carbonates that create fine aggregates or fill the intergranular spaces, or they are mixed with clayey minerals and form a marly rock matrix. A thermal analysis proves a calcite to be the main component of carbonates, with an admixture of dolomite (Fig. 3, sample *Ż5-26*). Seldom within the siltstone there are muscovite plates up to 0.08 mm large, usually oriented. Sporadicaly fine-aggregated agglomerations of washed outlines, maybe glauconitic? ones, were noted. These rocks contain in the upper part of the section, numerous globules and nodules of black, non--transparent organic matter; they are generally concentrated creating thin streaks together with a clayey matter. Among the components that pigment the rock, there is also a pyrite in dispersed very fine crystals or in greater streaky agglomerations and several millimetre thick oval concretions.

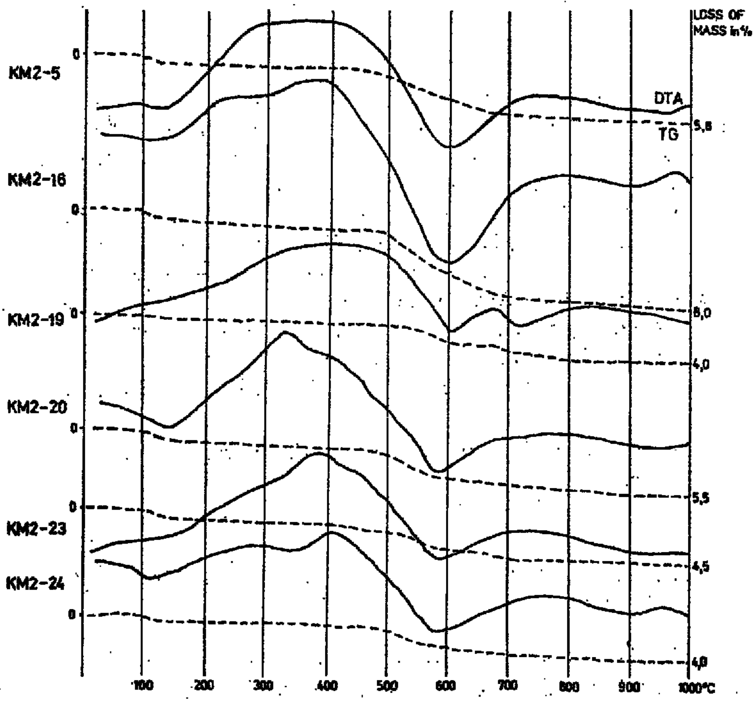


Fig. 5. Derivatograms of Cambrian sediments of Krynica Morska *2*
KM2—2 etc. — sample number

The claystones that accompany the siltstones, are brown and compose generally of illite (Figs 3—4, samples *Ż5-20, W4-4)* of direction arrangement of scales. Among them a small admixture of pale-greenish minerals is noted — perhaps of a chlorite group. Locally, within the claystones there are fine aggregates of micritic carbonate. The carbonates in the lower part of the section are more abundant, creating then a marly claystone. The claystones usually contain an admixture of quartz, 0.02—0.04 mm large, dispersed or in small streaky agglomerations.

The sandstones that form thin inserts within the claystones, have a non--direction structure and are vari-grained. They compose mainly of the fraction

Table 4

Mineral composition of Osiek Formation rocks (in volume per cent)

Borehole	Depth (m)	No. of sample	Quartz	Clayey minerals	Carbonates	Glauconite	Micas	Non transparent minerals	Heavy minerals
Żarnowiec 5	2728.2—2730.0	18	73.1	—	17.7	1.3	3.1	3.6	1.2
	2738.0—2742.0	23	58.9	9.0	20.2	—	—	11.4	0.5
	2742.0—2746.0	25	66.5	1.6	26.8	—	0.2	1.7	3.2
Władysławowo 4	2861.0—2862.0	1	84.7	—	4.3	1.5	3.6	4.6	1.3
	2870.6—2873.6	3	67.0	—	29.3	—	—	3.6	0.1

0.2—0.3 mm but single grains are up to 1 mm. The quartz grains are well and very well rounded (Pl. 24, Fig. 1). Carbonates — coarse-crystalline or fine-crystalline calcite are usually a typical cement of these sandstones. Some parts of these sandstones have a regenerated quartzic cement. But, within some sandstone inserts a clayey cement predominates. A pyrite that is abundant within that series, forms oval concretions and fills the intergranular pores within the sandstones but locally, it forms thin streaks creating a cement. Single organic remains built of phosphates are also noted. Among the heavy minerals there are well rounded zircons, yellow-green tourmaline and sometimes rutile, undergone to leucoxenization. In a borehole Żarnowiec 5 there were streaky concentrations of these minerals at a depth of 2778 m and 2743 m; they occurred within a pyrite matrix (Pl. 24, Fig. 2).

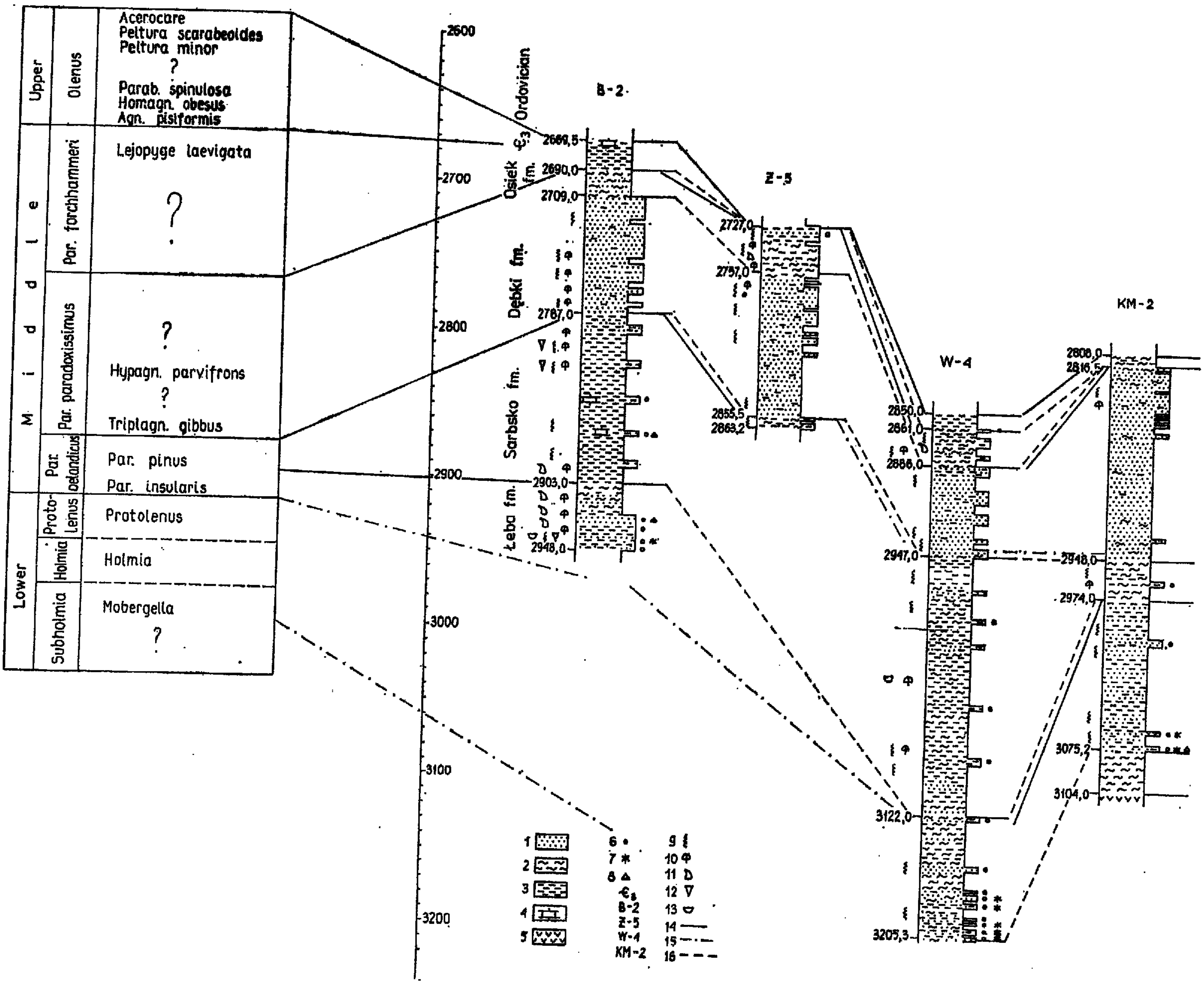
A quantitative mineral composition of these sandstones and siltstones is presented in Table 4.

BIOSTRATIGRAPHY AND CORRELATION OF THE SECTIONS

On the ground of fossils, first of all trilobites, and lithologic similarities as well as stratigraphic succession of lithostratigraphic formation defined in previously described sections in the Łeba region (Bednarczyk & Turnau-Morawska 1975), in the boreholes presented in this paper the sediments of Lower and Middle Cambrian were distinguished. Within the Middle Cambrian two zones and three subzones were noted (from the bottom):

	subzone H. parvifrons
Zone Paradoxides paradoxissimus	
	subzone P. pinus
Zone Paradoxides oelandicus	
	subzone P. insularis

Stratigraphy and lithology of the Cambrian sediments



1 — sandstone, 2 — siltstone, 3 — claystone, 4 — limestone, 5 — crystalline rocks, 6 — glauconite, 7 — feldspars, 8 — phosphates, 9 — trace fossils, 10 — trilobites, 11 — brachiopodes, 12 — hyolithes, 13 — ostracodes, 14 — zone and subzone boundary, 15 — inferred stratigraphic boundary, 16 — lithostratigraphic unit boundary
C_3 — Upper Cambrian, *B-2* — borehole Białogóra 2, *Ż-5* — borehole Żarnowiec 5, *W-4* — borehole Władysławowo 4, *KM-2* — borehole Krynica Morska 2

LOWER CAMBRIAN

Lower Cambrian in the sections described in this paper was notea only in a borehole Władysławowo *4* and in a borehole Krynica Morska *2* (Fig. 6).

In the borehole Władysławowo *4* the Cambrian was not drilled through but in the borehole Krynica Morska *2* a crystalline bedrock was reached. Due to uncomplete coring only the sediments of the Łeba Formation were noted. The Łeba Formation accessible to observations contains only the living tracks as habitable ducts of the Domichnia type and burrows of the Fodinichnia type; creeping tracts of Repichnia are more rare.

MIDDLE CAMBRIAN

Zone Paradoxides oelandicus in the mentioned sections of the Gdańsk Bay area is represented by upper sequences of the Łeba Formation and by sediments of the Sarbsko Formation. Undoubtedly, in the most eastward part of the area this zone composes also of the lowermost parts of the Dębki Formation (Fig. 6).

In a section Białogóra *2* the zone Paradoxides oelandicus includes also the rocks occurring within the interval from 2787.0 to 2948.0 m. The lower border of the zone is unknown in this section as the borehole was ended at the last of the mentioned depths. The upper limit is arbitrary defined along the border between the Sarbsko and the Dębki formations (Fig. 6).

The subzone Paradoxides insularis ends in the section at a depth of 2903.0 m and its upper limit is at the same time the border between the Łeba and the Sarbsko formations.

The upper subzone pinus is represented in the described section entirely by the rocks of the Sarbsko Formation. A thickness of the sediments of the subzone P. pinus equals 116 m. A thickness of the subzone P. insularis is unknown as only its 45 m long sequence is known.

In a section Żarnowiec *5* the zone Paradoxides oelandicus was distinguished on the ground of lithologic similarities and succession of lithostratigraphic formations of Cambrian of the Łeba region. It is probably represented by the top part of the Sarbsko Formation there (depth: 2855.5 m to 2863.0 m). But the living tracks of Fodinichnia and Cubichnia type, no index fossils of the zone oelandicus were found.

The zone Paradoxides oelandicus in a section Władysławowo *4* is represented by the sediments of the Sarbsko Formation occurring in the interval from 2947.0 to 3122.0 m. A thickness of the rocks of that zone is then equal 175 m. On the ground of comparison with the section

Białogóra *2* and other sections of the Łeba region (Bednarczyk & Turnau-Morawska 1975, Lendzion 1976) this section can be accepted to contain also the uppermost parts of the Łeba Formation. So, the border between Lower and Middle Cambrian in this borehole can be defined by the limit within the top parts of the latter formation (Fig. 6).

Due to slightly differentiated fossil assemblage neither the insularis nor the pinus subzones were distinguished in the section Władysławowo *4*.

In a section Krynica Morska *2* the zone Paradoxides oelandicus is mainly represented by the sediments of the Sarbsko Formation. The limits of the zone cannot be precisely defined as no fossils were found. The lower border of the zone was accepted at a depth of 2974.0 m whereas the upper border occurs within the bottom part of the Dębki Formation (Fig. 6). The zone Paradoxides paradoxissimus in the sections of the Gdańsk Bay region is represented, similarly as in the Łeba region, by the rocks of Dębki and Osiek formations (Bednarczyk & Turnau-Morawska 1975).

In a section Białogóra *2* it includes a sequence from 2690.0 m to 2787.0 m. A thickness of the zone is about 97 m.

The zone was best described in a section Żarnowiec *5*. Similarly as in the previous section it is represented by two formations: Dębki and Osiek ones, enclosed in the interval from 2727.0 to 2855.5 m. Best documentation is collected for the upper part of the zone represented by the Osiek Formation. Occurrence of the species *Peronopsis pusilla* (Tullberg) proves a presence of the equivalents of the subzone Hypagnostus parvifrons, typical for the upper part of the zone paradoxissimus. It supports then the previous conclusions of the age of the Osiek Formation, resulting after all from the stratigraphic succession (Bednarczyk & Turnau-Morawska 1975 *).

Occurring of the zone Paradoxides paradoxissimus in a section Władysławowo *4* results from lithologic similarities and lithostratigraphic succession of the Middle Cambrian. As in the other sections, it is composed of the rocks of the Dębki and the Osiek formations, found at depths from 2861.0 to 2947.0 m. Its thickness is then equal about 90 m.

The zone Paradoxides paradoxissimus was distinguished in a borehole Krynica Morska *2* on the same basis as in the previous section. But it cannot be excluded that due to changes occurring at the border of Middle and Upper Cambrian, starting from the zone Paradoxides forchhammeri (Bednarczyk 1972, Bednarczyk & Turnau-Morawska 1975, Lendzion 1976), a sedimentary basin was remodelled. Thus, a stratigraphic

* a thickness of the sediments of the zone paradoxissimus is equal about 128 m there.

scheme constructed on the ground of the sections for the Łeba region, cannot be applied for the eastern part of the Gdańsk Bay area and for the other part of the Peribaltic Depression. The depth at which both these formations occur was fixed for the interval from 2816.5 to 2948.0 m. A thickness of the sediments of these two formations is then equal 131.5 m. It is only slightly varying from the thicknesses of these formations so, their age and stratigraphic position can correspond with the accepted assumptions.

The uppermost Middle Cambrian in the sections of the Łeba region composes of glauconitic sandstones of the Białogóra Formation (Bednarczyk & Turnau-Morawska 1975, cf. also horizon *1* of subcomplex *VIIIb*, Topulos 1979). Lately received fossil fauna, coming from the equivalents of this formation in the section Hel *IG-1* proves that this formation represents the zone Paradoxides forchhammeri (Lendzion, *personal information*).

But the section Hel *IG-1* the sediments of this formation should be expected in the Gdańsk Bay region in a borehole Władysławowo *4*. In other boreholes of the Łeba region as well as of the Gdańsk Bay region, the sediments of this formation could be washed before the Ordovician transgression or during the Upper Cambrian (Bednarczyk 1979).

At the end of this chapter one should record that the sediments of Upper Cambrian were not found in the described sections due to uncomplete coring (Fig. 6). Geophysical data suggest that the Upper Cambrian occurs in a typical clayey-limestone sequence and small thickness in the sections Białogóra *2* (about 10 m) and Władysławowo *4* (about 8 m, cf. Topulos 1979). In other sections only thin fragments could be conserved, similarly as noted in the eastern part of the Peribaltic Depression (Lendzion 1976, Szymański 1976).

REMARKS ON SEDIMENTARY ENVIRONMENT AND PALAEOGEOGRAPHY

LOWER CAMBRIAN

An origin of the sediments of the Łeba Formation was presented in the paper of Bednarczyk and Turnau-Morawska (1975). This formation, noted in the described boreholes, supports the previous conclusions of its marine origin. On the ground of data from the section Krynica Morska *2* in which its thickness equals about one third of a total thickness of the Cambrian sediments in this borehole and basing on informations from previous papers, one can suppose that the Łeba Formation contains the equivalents of the zones Mobergella, Protolenus and Paradoxides insularis (Fig. 2, Bednarczyk 1972, Bednarczyk & Turnau-Morawska 1975, Lendzion 1976, Areń & Lendzion 1978).

During the first accumulative phase of the sediments of the Łeba Formation, in the area of the Gdańsk Bay, sandy deposits prevailed — locally coarse-grained or even conglomeratic ones. Well rounded grains of a chad fraction occur within the rocks as streaks and single grains. Accompanying pebbles of phosphate rocks (cf. also Bednarczyk & Turnau-Morawska 1975) prove that the matter of this part of the formation came from washed lower, older horizons of Cambrian. Within the whole formation there are considerable quantities of glauconite, autochthonous as well as allochthonous one. The glauconite builds locally the cement but it also forms grains that got into the sediment in a semi-plastic state. Also the phosphates that accompany the glauconite, form a cement but the pieces of phosphoritized organic remains were noted too. But glauconite and phosphates there are also small quantities of feldspars within the sediments. Generally speaking, a poor mineral composition of the rocks of the Łeba Formation, a predominating part of quartz and fine-grained fraction of most of the formation rush to a conclusion that the alimentary area was peneplenized and localized quite far from the sedimentary basin or, the detrital material that is also included into the older sediments, was many a time redeposited (cf. also Jaworowski 1979).

The sedimentation within the basin was slow and interrupted by many sedimentary breaks. A sedimentary disorder is proved by a presence of authochthonous glauconite formed undoubtedly in a zone of bottom movements, occurrence of numerous glauconitic laminations and streaky concentrations of heavy minerals and non-transparent minerals. A segregation resulting from the mineral weight allows to expect an activity of bottom currents caused by waves. An occurrence of alternations of a psammitic fraction, usually well sorted, and of a pelitic fraction proves a small deposition rate and an existence of sedimentary breaks. Small-scale and large-scale cross bedding, with trough, flaser, wavy and convolute beddings included, suggests a sedimentation at low stream power during a small transport intensity. Particularly a presence of flaser and wavy beddings, connected with ripple--marks, may speak for an increased deposition of sandy and siltstone--clayey matter, typical for the area of a tidal flat (Reineck & Wunderlich 1968, Gradziński & al. 1976). This opinion is not contradicted by an occurrence of a convolute bedding that is locally noted in an intertidal zone (Reineck & Singh 1973). These conclusions agree well with opinions of Jaworowski (1979) who assumed for the turn of Lower and Middle Cambrian a sedimentary environment in that area for an intertidal zone or below a tidal flat.

The environment was probably unfavourable for evolution of a benthonic fauna. Continuous reworking, deposition and washing of a sediment was neither favourable for conservation of carapaces and living tracts nor for existence. Therefore, the tracts are relatively rare within the sandy sediments and more abundant within the clayey interbeds typical for the periods of a sedimentary peace. An analysis of ichnocoenoses proves that they developed usually at the border of a sublittoral and littoral zone (sensu Seilacher 1967).

MIDDLE CAMBRIAN

The environment of an interrupted sedimentation lasted, as underlined before, also at the beginning of Middle Cambrian. But, already during a deposition of the sediments of a subzone Paradoxides pinus there was a change in sedimentary conditions. The sediments of the successive Sarbsko Formation (Bednarczyk & Turnau-Morawska 1975, Fig. 6) reflect a sedimentary peace. Within the claystone-siltstone rocks of this formation no autochthonic glauconite occurs whereas an allogenic glauconite is rare and comes probably from washing and reworking of the underlying rocks of the Łeba Formation. This bedding of the sediments (wavy, parallel and convolute one) may suggest an occurrence of a still shallow reservoir. But the basin was still fed by a fine-grained sandy matter. In the isolated more shallow parts of the basin, inserts of limestones were formed. A fauna in the reservoir was relatively rich and differentiated what is suggested by agglomerations of its carapaces and numerous living tracts as ichnocoenoses of Repichnia, Cubichnia and Fodinichnia types. The benthonic fauna was represented by trilobites, ostracods and Hyolitha. It included also the mud-digesting animals and most Brachiopoda inarticulata.

In result of agglomerating the organic remains and its decomposition, in some parts of the reservoir the reducing environment occurred. It is proved by pyrite and fine sideritic spherolites as well as by a black colour of clayey-siltstone sediments. This fact influenced probably a distribution of the fauna within the reservoir. In its eastern part the fauna was found to be rare whereas in the western part — relatively rich. The eastern more shallow, littoral (propably) part of the reservoir contained also more sandy sediments and the biostructures of the Domichnia type, cross and horizontal bedding and claystone intraclasts within the sandstones suggesting a possibility of a sliding separation of the claystones. In the western part of the area the reservoir was deeper what is proved by an occurrence of Agnostidae. In effect, the sediments of the Sarbsko Formation were deposited in the environment of a certain depth and sedimentary stability, in a probable sublittoral zone at slightly changing coastline (zone Cruziana, Seilacher 1967, Crime 1970, Frey & al. 1975). An alimentation of the sediment came probably from the intensively peneplenized, uplifted areas of the present Baltic Shield.

During a sedimentation of the successive Dębki Formation (zone Paradoxides paradoxissimus, Fig. 6), the shallow-water sedimentary conditions prevailed with a predominant sedimentation of sandy rocks. The sandstones of the Dębki Formation are fine — grained and even--grained, they are well washed and contain segregated as well as rounded monomineral grains. A segregation of the matter and its rounding support the presented conclusion. Among the additional evidence there are ripple-marks and streaky agglomerations of heavy minerals. These phenomena suggest a shallow reservoir of great turbulence of waters. Numerous clayey lamine and inserts reflect short periods of sedimentary breaks resulting from tidal movements. Due to dying out the fauna and their decomposition the reducing conditions could locally occur, resulting in formation of pyrite and syderite. At the end of accumulation of the sediments of the Dębki Formation there was an activation of a submarine erosion. It caused an occurrence of flat, elliptic clayey balls and a chad fraction within the sandstones.

In the whole section of the Dębki Formation there are usually different types of bedding: small-scale cross, horizontal flaser lenticular and fine-wavy ones and within the claystone series — a convolute one. At the same time load casts, intraclasts and mud cracks were noted. Such features of the sediments of this formation can be interpreted as the features of sediments of a littoral zone or even, of a tidal flat (Reineck & Singh 1973). As the sediments contain the biostructures Fodinichnia and Domichnia, the Dębki Formation can be supposed to have originated in the zone Scolithus-Glossofungites (Seilacher 1967, Frey & al. 1975). This zone occurred, as proved by a distribution of the sediments of the Dębki Formation, along the southern edge of the present Baltic Shield.

A change of a sedimentary environment was again noted during a deposition of sediments of the Osiek Formation (Fig. 6). At that time mainly the siltstone-clayey, occasionally marly and limestone sediments were deposited. The borders between the siltstone and claystone beds are distinct and do not show any disturbances. Only the sandstones are accompanied by washing traces as, among others the erosive niches. The sandstone beds have usually a horizontal bedding. On the bottom surfaces there are load and float casts (*Kinneya simulans* Walcott), suggesting a water movement resulting from wind blows. These facts prove that the reservois was not deep.

Concluding from the conserved carapaces and living tracts, the conditions were favourable for the organisms. A benthonic fauna is abundant and varying, with trilobites and inarticulata. Among ichnofauna an ichnocoenosis of Repichnia, Fodinichnia and Cubichnia is the most popular; Domichnia is more rare and occurs in the eastern part of this area. This fact suggests the conditions typical for a sublittoral zone (Cruziana; Seilacher 1967). In more deeper and isolated parts of the reservoir animal remains have been collected so, reducing conditions were created producing pyritic impregnations and concretions. A reservoir coastline at that time was not subjected to any greater changes and the alimentary area occuppied the elevated areas of north-western part of the East European Platform similarly, as at the turn of Lower and Middle Cambrian (Sikorska 1979).

At the end of Middle Cambrian, in a zone Paradoxides forchhammeri, there was a return to a slow and intermittent sedimentation, expressed by an agglomeration of sand-glauconitic sediments of the Białogóra Formation (Bednarczyk & Turnau-Morawska 1975). Locally, there were emergencies or breaks in sedimentation due to submarine erosion (Bednarczyk 1972, Lendzion 1976). In result of these phenomena an occurrence of the Białogóra Formation is limited to the Łeba Elevation and the western part of the Peribaltic Syneclise.

UPPER CAMBRIAN

During Upper Cambrian, in a slightly deeper reservoir the clayey--limestone facies predominate with a poor (in species and genera but locally occurring in large concentrations) fauna assemblage of trilobites, brachiopods, conodonts and ostracods (Bednarczyk 1979) as well as with an ichnofauna of *Helminthopis* sp.

The sections of Cambrian of the northern Poland are strictly connected with the Cambrian sections of Scandinavia but first of all, of Bornholm (Poulsen 1963), Scania (Thorslund 1960) and the Öland Islands where beach sediments occur (Hessland 1955). But they are different for their greater thickness. Many faunistical similarities of the Cambrian in the described area are known with the Cambrian of the Holy Cross Mts (Orłowski 1975) but it differs from the latter by its almost six times smaller thickness.

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WIESŁAW BEDNARCZYK & TERESA PRZYBYŁOWICZ

ROZWÓJ OSADÓW KAMBRU W REJONIE ZATOKI GDAŃSKIEJ

(Streszczenie)

Na podstawie materiałów z czterech wierceń: Białogóra *2*, Żarnowiec *5*, Władysławowo *4* i Krynica Morska *2* (fig. 1) oraz w nawiązaniu do wcześniejszych prac pierwszego z autorów (Bednarczyk 1972, 1979, Bednarczyk & Turnau-Morawska 1975), a także do publikacji innych autorów (Jaworowski 1979, Lendzion 1976, Areń & Lendzion 1978, Sikorska 1979, Szymański 1976, Topulos 1979) wydzielono w profilach kambru tych wierceń formacje: łebską, sarbską, dębkowską i osiecką.

Występujące w stropowych partiach formacji łebskiej skamieniałości (trylobity, brachiopody bezzawiasowe, małżoraczki i hyolity) pozwoliły udokumentować obecność podzony Paradoxides insularis, a w skałach formacji sarbskiej podzony Paradoxides pinus. Fauna zawarta w osadach formacji dębkowskiej, a w szczególności w iłowcach i mułowcach formacji osieckiej umożliwiła wydzielenie zony Paradoxides paradoxissimus, a w niej podzony Hypagnostus parvifrons (fig. 6).

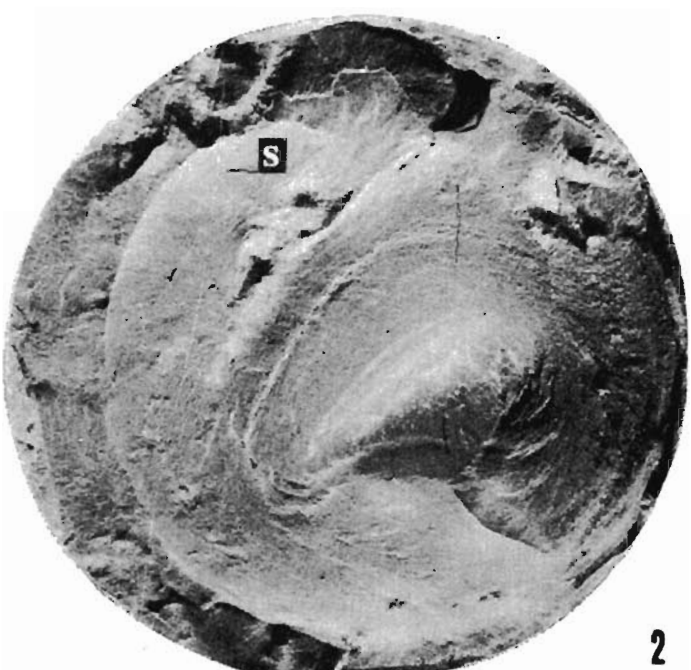
Szczegółowa analiza petrograficzna (fig. 2—5, tab. 1—4 i pl. 19—24) oraz analiza struktur sedymentacyjnych i zespołów ichnofauny (pl. 1—18), wykazała, że na obszarze obecnego wyniesienia Łeby i w rejonie Zatoki Gdańskiej osady formacji łebskiej (dolny kambr i najniższy kambr środkowy) tworzyły się w strefie litoralnej, między lub niżej równi pływowej (zona Glossofungites sensu Seilacher 1967).

W czasie akumulacji skał formacji sarbskiej (kambr środkowy) dominowały warunki morza głębszego, odpowiadające strefie sublitoralnej (zona Cruziana op. cit.). Ponownie warunki sedymentacji litoralnej w kambrze środkowym przypadły na okres sedymentacji formacji dębkowskiej (strefa równi pływowej, zona Skolithos-Glossofungites), a warunki sedymentacji sublitoralnej (zona Cruziana) na okres akumulacji formacji osieckiej.

Pod koniec kambru środkowego na omawianym obszarze jak również na obszarze syneklizy perybałtyckiej doszło do spłycenia zbiornika sedymentacyjnego, a nawet do lokalnych wynurzeń. W związku z tymi zjawiskami piaskowce formacji białogórskiej reprezentujące zonę Paradoxides forchhammeri napotkano jedynie w kilku punktach m.in. w wierceniu Białogóra *1* i Hel *IG-1*.

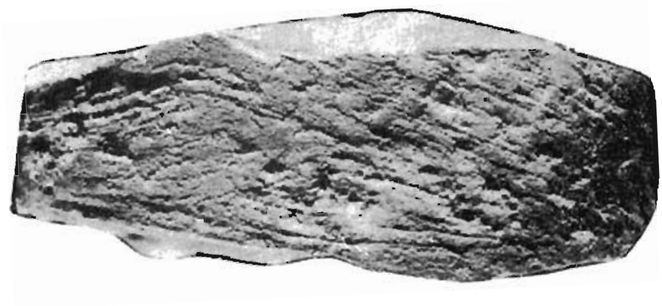
W epoce kambru górnego obszar tu omawiany pokrywało morze dość głębokie, lecz jak wynika z analizy skamieniałości (trylobity, brachiopody zawiasowe, małżoraczki, konodonty i ichnofauna m.in. *Helminthopsis* sp.) odpowiadające strefie niższej sublitoralnej z pogranicza zony Cruziana-Zoophycos. Sedymentacja właściwa dla tej strefy przetrwała zapewne bez większych zmian do tremadoku, gdyż ponowne ruchy wznoszące i związana z nimi luka sedymentacyjna miały miejsce przed wczesnym arenigiem (zona Prioniodus elegans, Bednarczyk 1979).

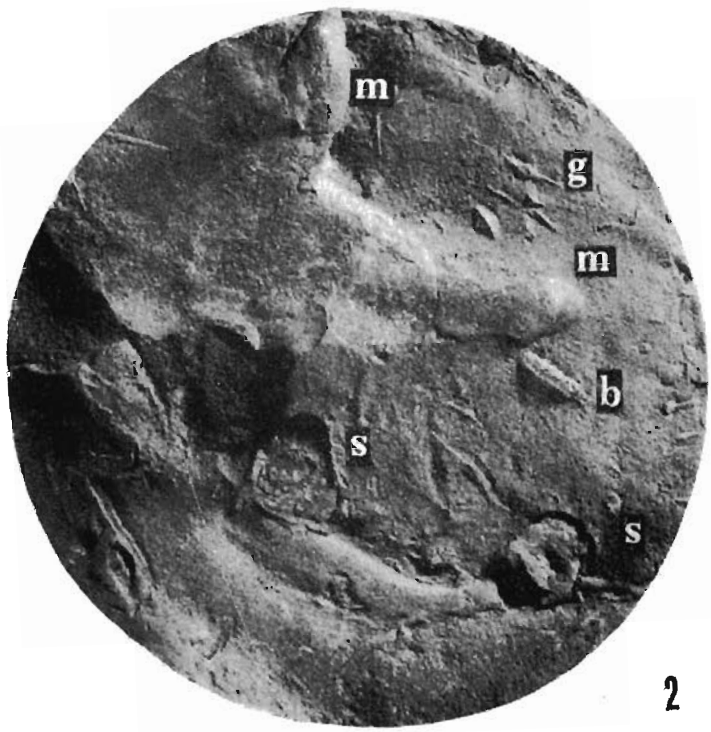
1



2

1 — *Bergaueria major* Palij, 1976; borehole Krynica Morska *2*, depth 3062.1—
—3064.0 m; Łeba Formation, Lower Cambrian; × 3.
2 — *Spiroscolex spiralis* (Torell, 1870); Władysławowo *4*, 3198.1—3200.6 m; Łe-
ba Fm., Lower Cambrian; × 1.5.





1 — Small-scale through cross-bedding emphasized by glauconitic laminations; Krynica Morska 2, 3072.6—3075.2 m; Łeba Fm., Lower Cambrian; × 1.5.

2 — The same specimen, bottom surface view; *s* — *Cyclomedusa?* sp., *g* — *Gordia?* sp., *m* — *Planolites montanus* Richter, 1937, *b* — *Planolites balandus* Webby, 1970; × 1.5.

1

2

1 — In the upper part of the drill core pink, coarse-grained sandstone is visible; in the lower part one a sandstone with cross-bedding emphasized by glauconitic laminations is observable. Within clayey part of the drill core — exichnia structures: Krynica Morska 2, 3062.1—3064.3 m; Łeba Fm., Lower Cambrian; × 1.5.

2 — Sedimentary deformation, load casted ripplemark with preserved cross-lamination emphasized by glauconite. Within sandstones the tubes of endichnia, within claystones exichnia-fodinichnia; Krynica Morska 2, 3062.1—3064.3 m; Łeba Fm., Lower Cambrian; × 1.5.

1

2

1 — Intraclasts of claystones are embedded of the glauconitic sandstone; outwashed surface of sandstone, minute load casts and fodinichnia structures within claystone; Władysławowo *4*, 3184.0—3185.5 m; Łeba Fm., Lower Cambrian; × 1.5.

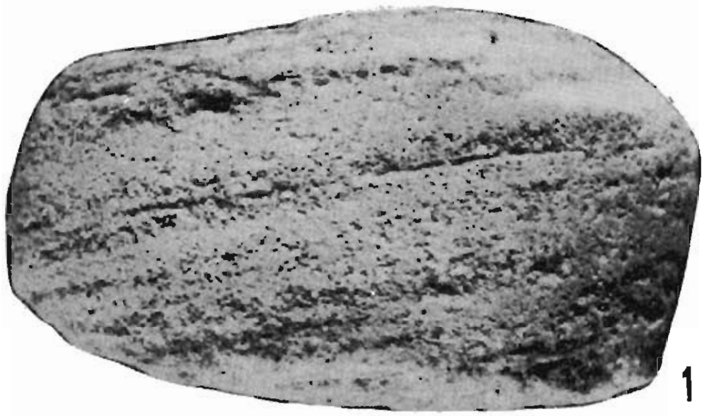
2 — Flaser small-scale cross-bedding within glauconitic sandstone; lenticular bedding is visible in the lower part of drill core; Władysławowo; *4;* 3173.0 ——3174.6 m; Łeba Fm.; × 1.5.

1

2

1 — Trough, small-scale cross-bedding emphasized by glauconitic laminations, within clayey part load casted ripplemarks and tubes of fodinichnia are visible; Władysławowo *4*, 3194.4—3195.8 m; Łeba Fm., Lower Cambrian; × 1.5.

2 — Streaky accumulated grains of quartz within claystone of Łeba Formation; Władysławowo *4*, 3203.7—3205.3 m; Lower Cambrian; × 1.5.



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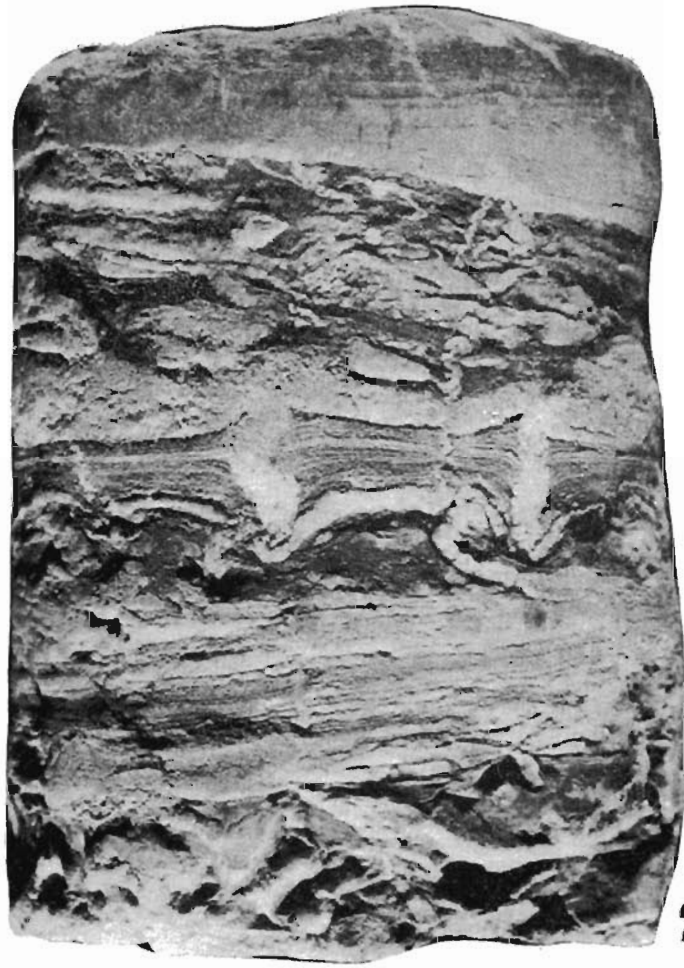
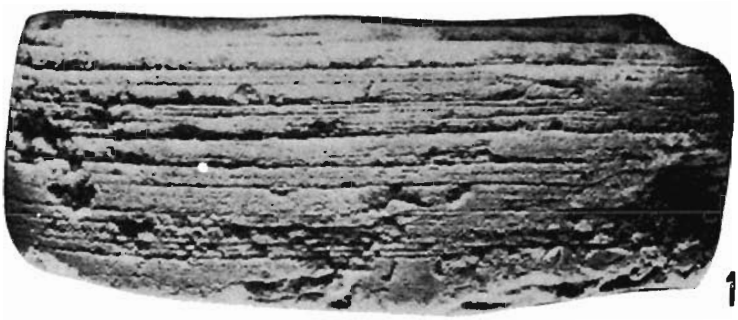


2

1 — Large-scale cross-bedding in the glauconitic sandstone; Władysławowo 4, 3190.1—3191.6 m; Łeba Fm., Lower Cambrian; × 1.5.

2 — In the upper part of drill core flaser, horizontal, slightly wavy bedding, bioturbation structures of Teichichnus and load-casts in the lower part; Władysławowo 4, 3172.0—3173.0 m; Łeba Fm., Lower Cambrian; × 1.5.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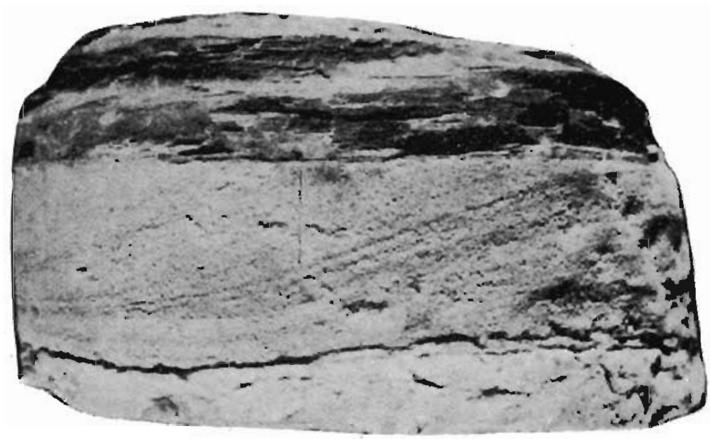
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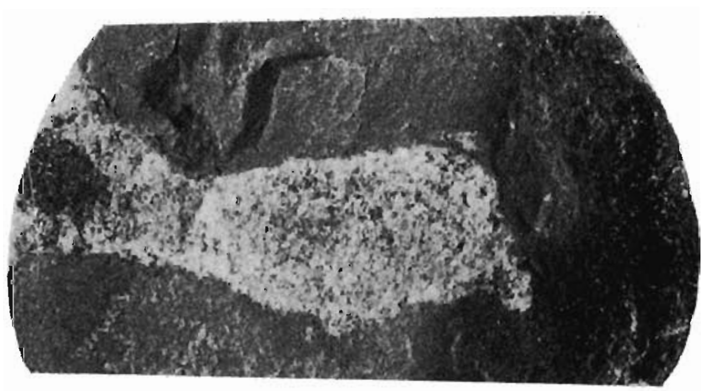
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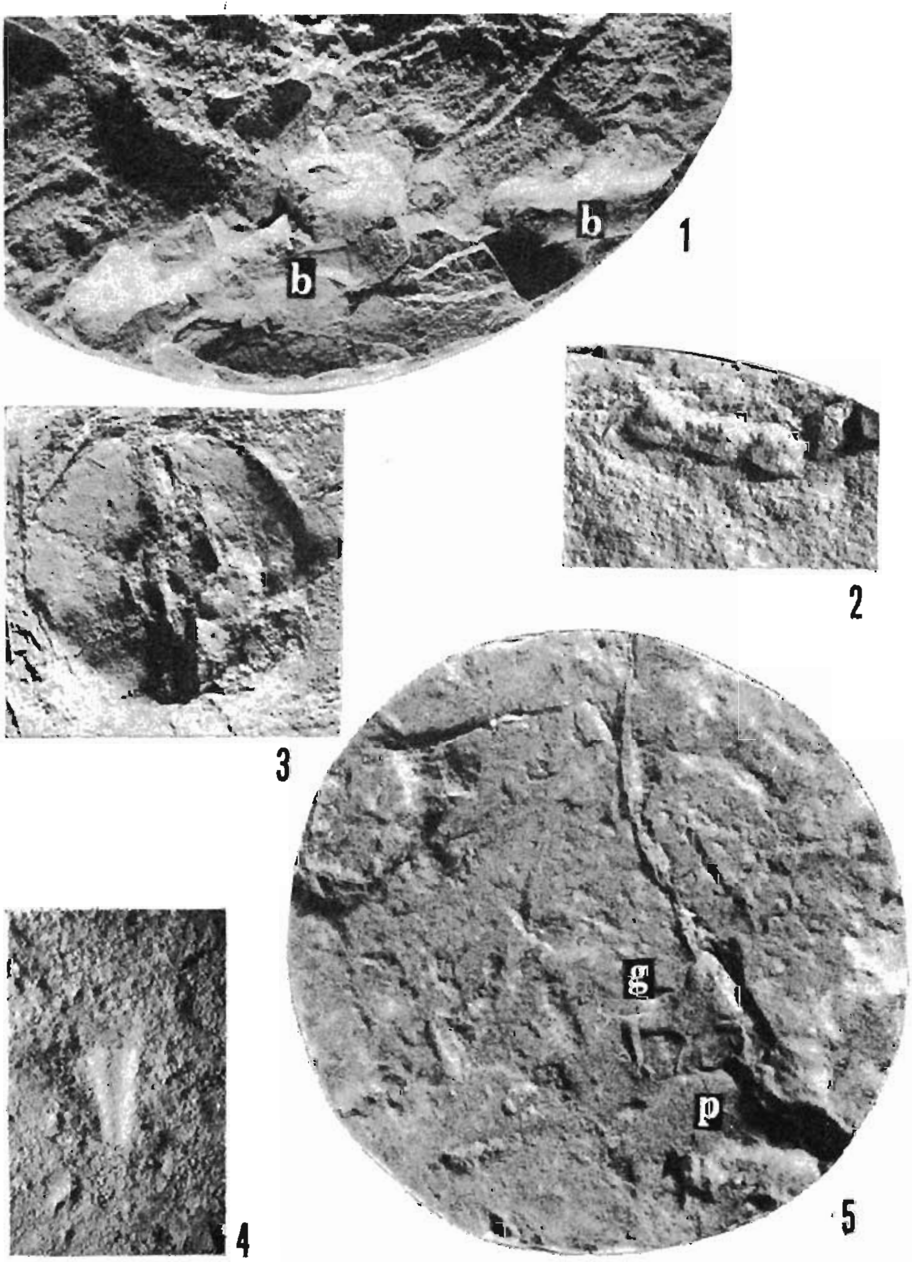
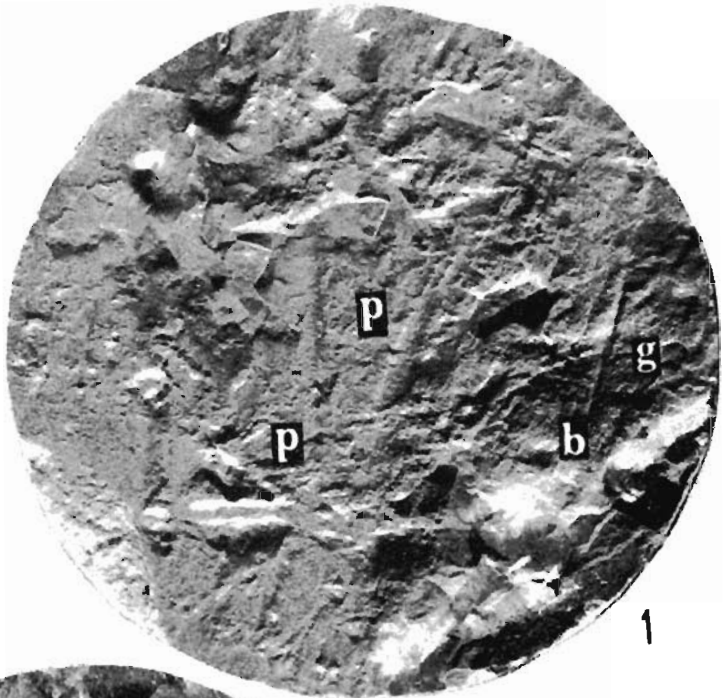
1 — Horizontal lamination in the glauconitic sandstone; Krynica Morska *2*, 3062.1—3064.3 m; Łeba Fm., Lower Cambrian; × 1.5.

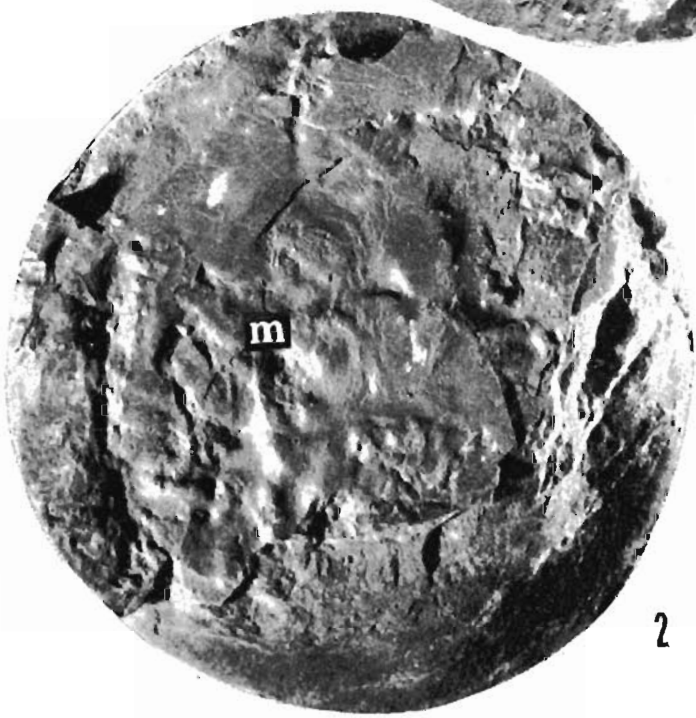
2 — Flaser, small-scale cross-bedding in the lower part of drill core load casts and bioturbation structures; Władysławowo *4*, 3173.0—3174.6 m; Łeba Fm., Lower Cambrian; × 1.5.

3 — Intercalation of sandy limestone in the mudstone; Białogóra *2*, 2940.0—2944.0 m; Sarbsko Fm., Middle Cambrian; × 1.5.



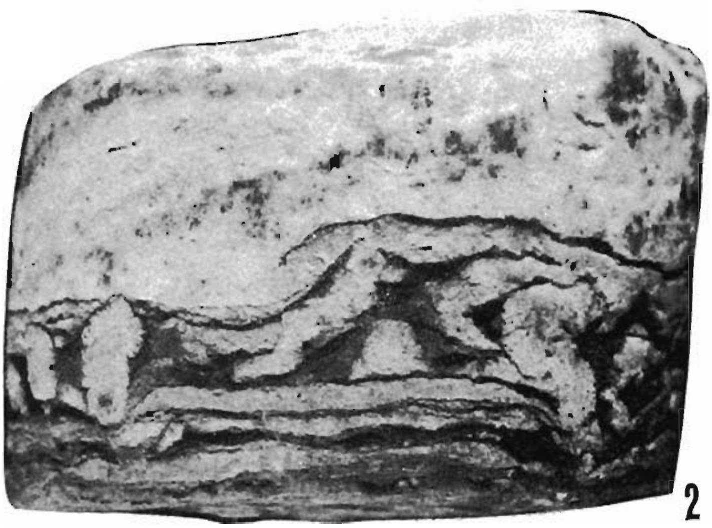
1 — *Bifungites fezzanensis* Desio, 1940 (b), and *Gordia* sp. (× 9); Władysławowo *4*, 2989.5—2992.0 m; Sarbsko Fm.; × 1.5.
2 — *Isopodichnus?* (Rusophycus) sp.; Żarnowiec *5*, 2858.7—2859.7 m; Sarbsko Fm.; × 3.
3 — *Cyclomedusa?* sp.; Żarnowiec *5*, 2858.7—2859.7 m; Sarbsko Fm.; × 4.
4 — Problematic hipichnia; Władysławowo *4*, 2886.4—2888.5 m; Dębki Fm., Middle Cambrian; × 3.
5 — *Planolites* sp. (p) and *Gordia* sp. (g); Władysławowo *4*, 2969.9—2971.9 m; Sarbsko Fm.; × 1.5.





1 — *Bifungites fezzanensis* Desio (b), *Planolites ballandus* Webby (p), and *Gordia?* sp. (g); Władysławowo *4*, 2989.5—2992.2 m; Sarbsko Fm.; × 1.5.
2 — *Merostomichnites?* sp. (m); Białogóra *2*, 2867.4—2870.6 m; Sarbsko Fm.; × 1.5.

1



2

1 — Load casts of sandy ripplemarks, cross-bedding and tubes of fodinichnia are visible within claystone of Sarbsko Fm.; Wladyslawowo *4*, 3006.5—3008.0 m; × 1.5.

2 — Sandy load casts structures; Białogóra *2*, 2717.0—2718.0 m; Dębki Fm.; × 1.5.

1

2

1 — Horizontal lamination and load casts; Krynica Morska *2*, 2824.6—2830.2 m; Dębki Fm.; × 1.5.
2 — *Planolites ballandus* Webby; the same specimen; × 1.5.

2

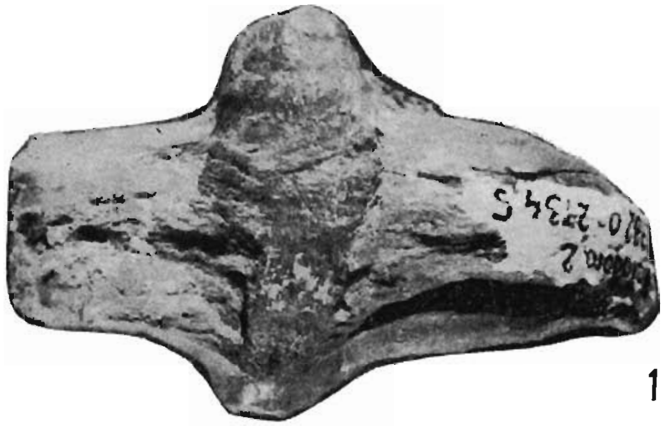
3

1

1 — Intraclasts of sandstone and mudstone and lenticular bedding in the Dębki Fm.; Białogóra 2, 2712.8—2714.3 m; × 1.5.

2 — Small-scale cross-bedding; in the lower part of drill core intraclasts of mudstone; Bialogóra 2, 2715.5—2717.0 m; Dębki Fm.; × 1.5.

3 — *Nereites cambrensis* Mac Leay, 1839; Białogóra 2, 2754.8—2756.0 m; Dębki Fm.; × 1.5.



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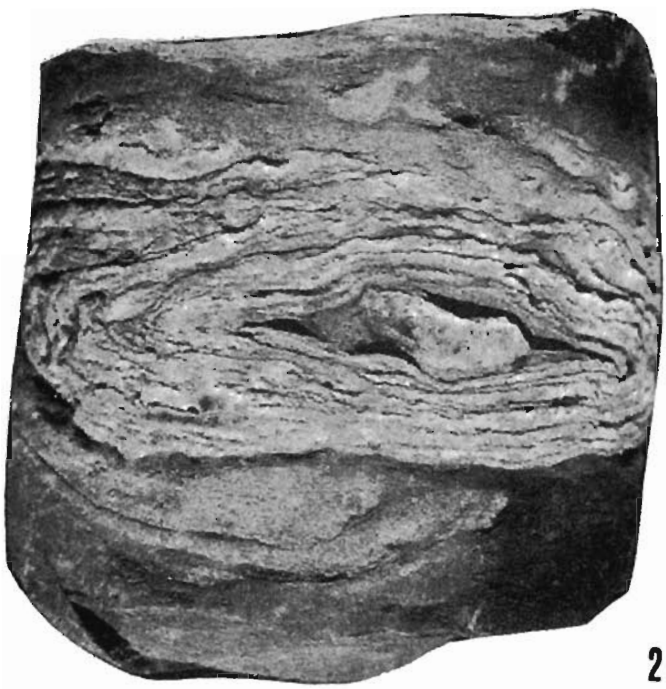
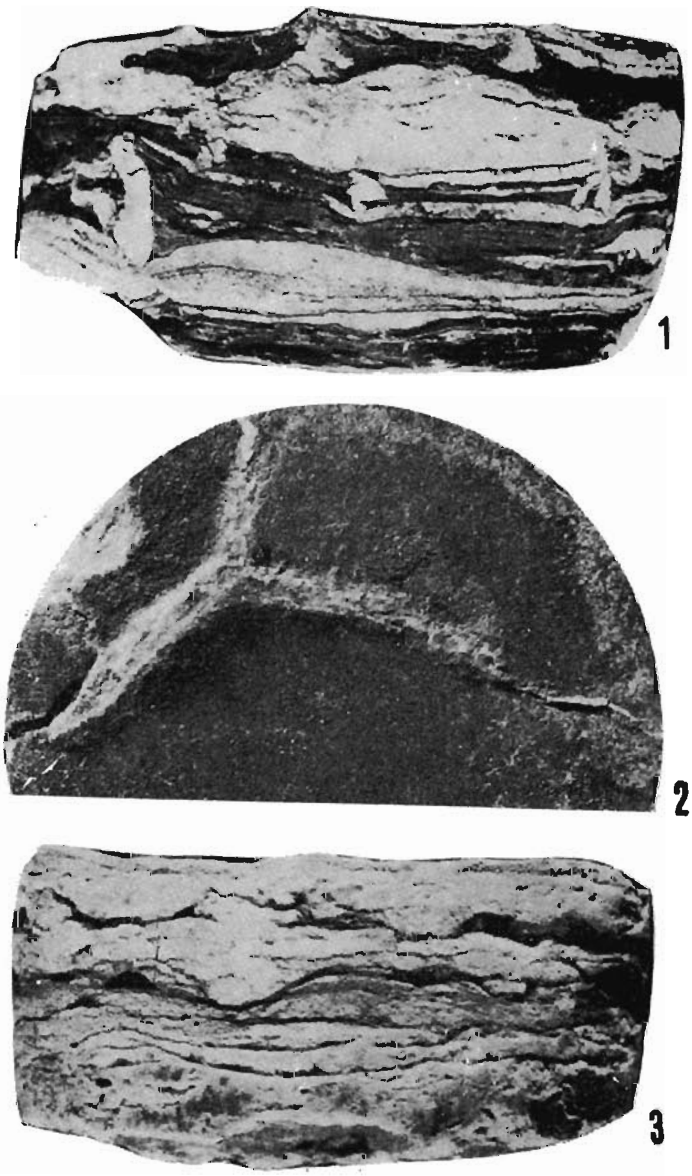


2

1 — Escape structure of an unknown organism in mudstone of Dębki Fm.; Białogóra *2*, 2732.0—2734.5 m; × 1.5.

2 — Fold-like sedimentary structure; in the upper part of the drill core minute load casts; Białogóra *2*, 2717.0—2718.8 m; Dębki Fm.; × 1.5.

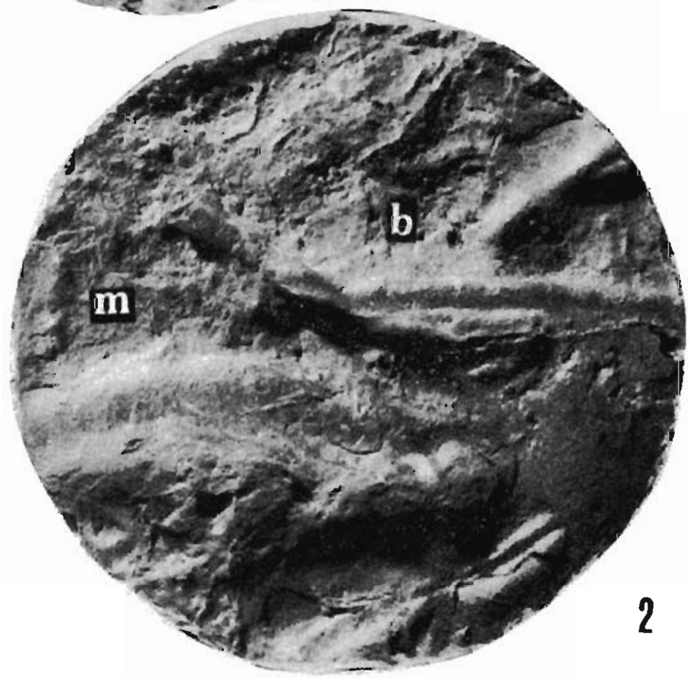


1 — Load casts and wavy bedding; Białogóra *2*, 2754.8—2756.0 m; Dębki Fm.; × 1.5.

2 — Mud cracks; Białogóra *2*, 2756.2—2757.6 m; Dębki Fm.; × 1.5.

3 — Wavy bedding passing to lenticular-bedding, bioturbation structures; Władysławowo *4*, 2886.4—2888.5 m; Dębki Fm.; × 1.5.

1



2

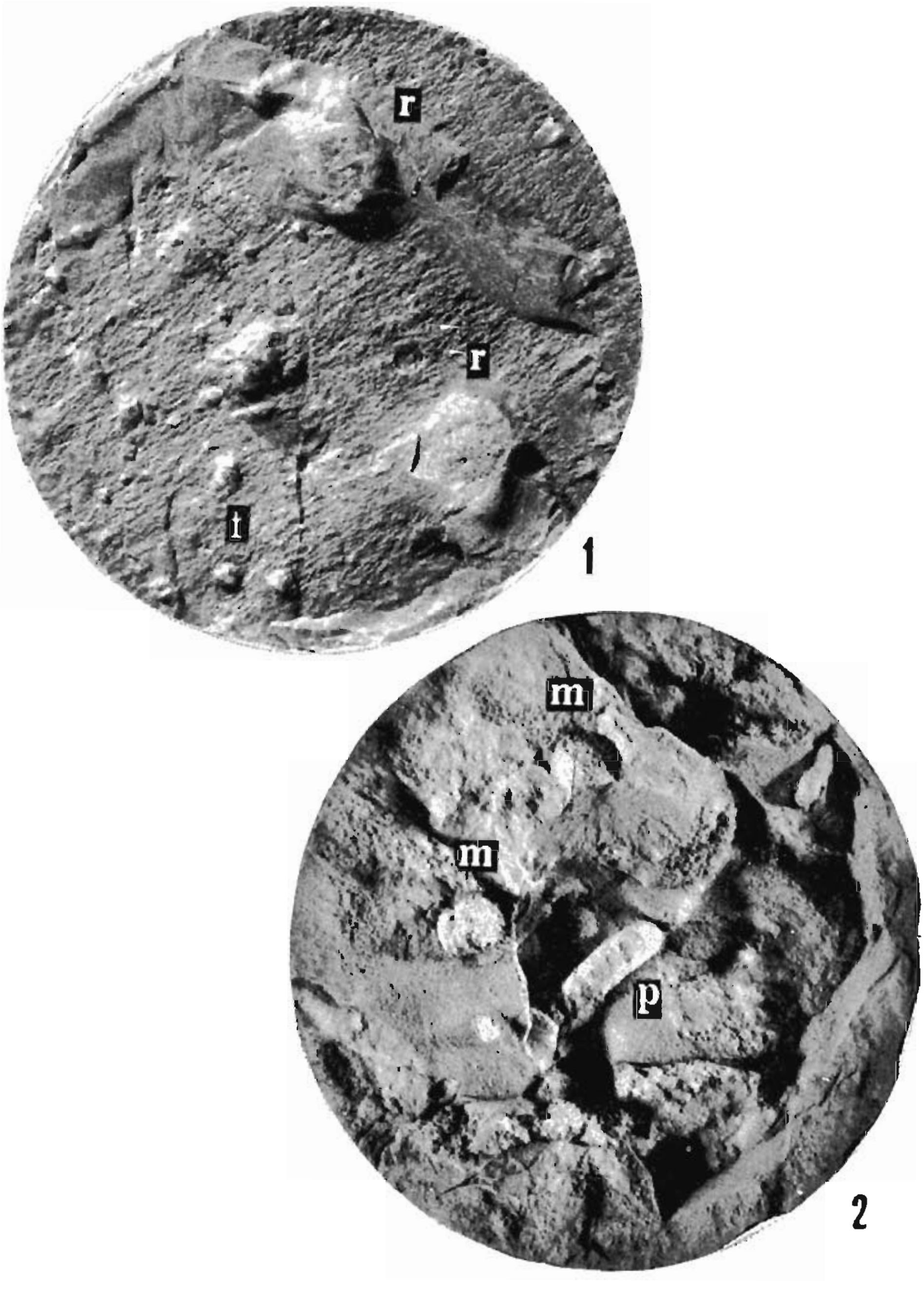
1 — Lenticular-bedding and small-scale cross-bedding, load casts in alternating claystone and sandstone; Władysławowo *4*, 2886.4—2888.5 m; Dębki Fm.; × 1.5.
2 — *Planolites ballandus* Webby (b) and *P. montanus* Richter (m); Władysławowo *4*, 2942.1—2946.4 m; Dębki Fm.; × 1.5.

1

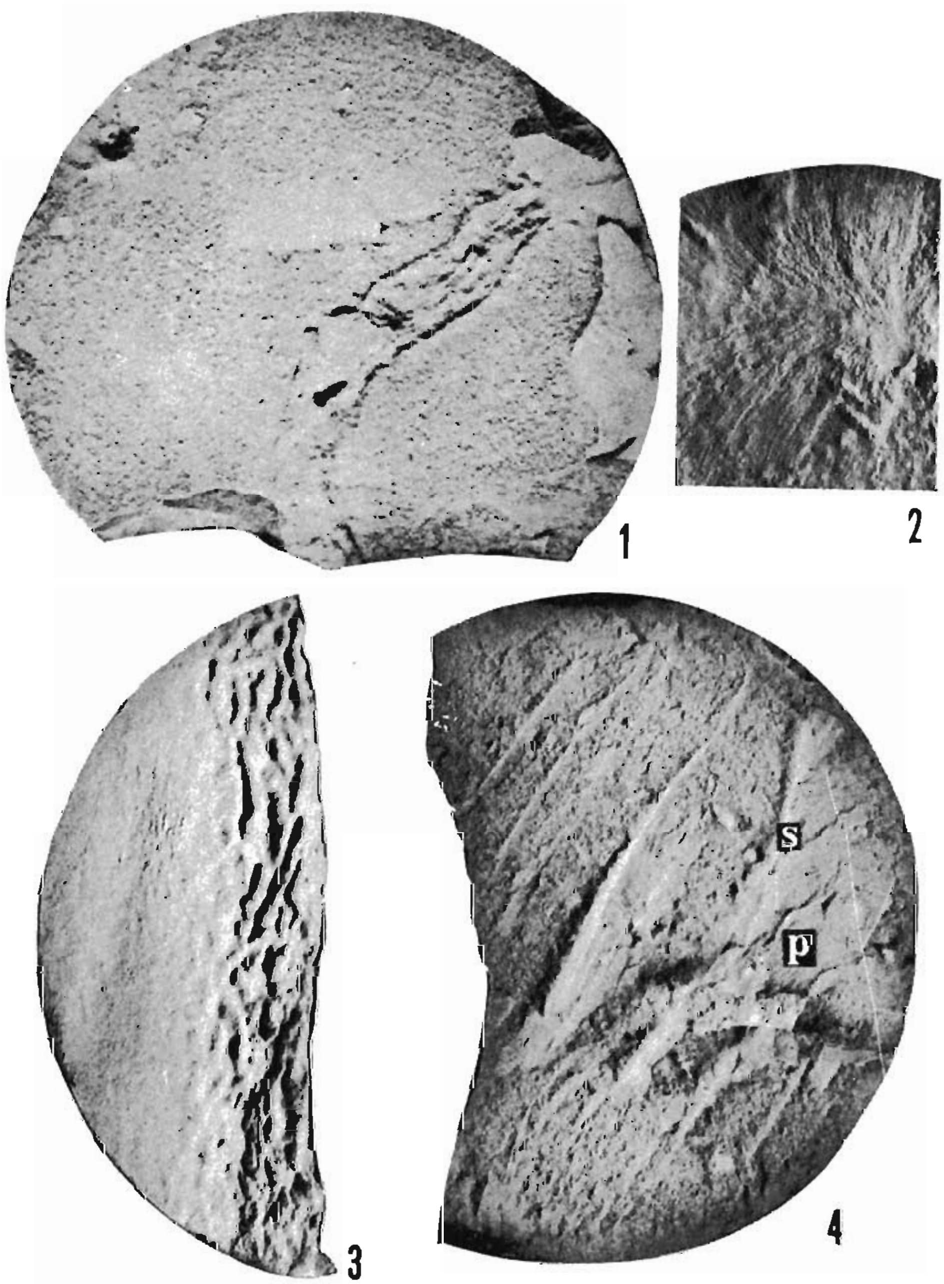
2

3

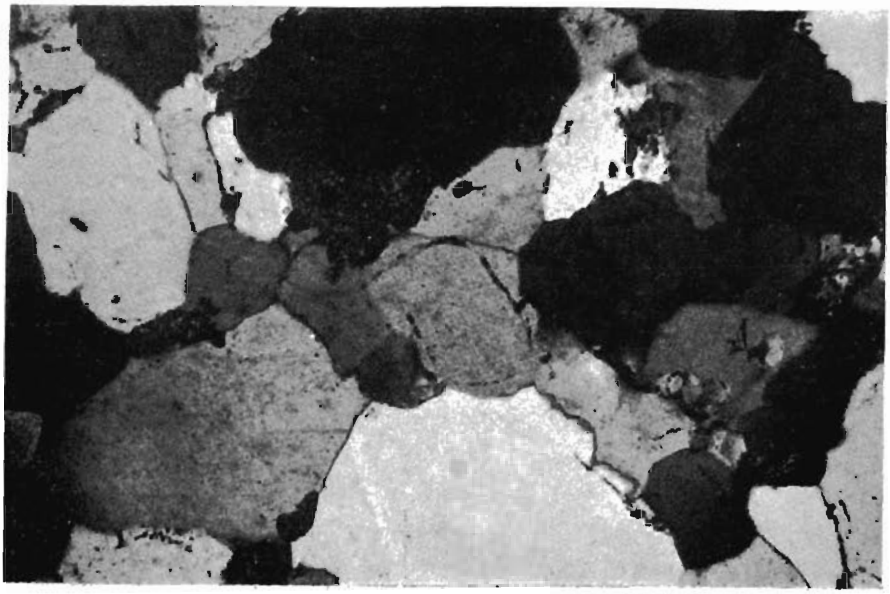
1 — *Lorenzinia?* sp.; Władysławowo *4*, 2870.6—2873.6 m; Osiek Fm., Middle Cambrian; × 2.
2 — *Kouphichnium?* sp.; Władysławowo *4*, 2870.6—2873.6 m; Osiek Fm.; × 3.
3 — Fragments of carapaces of trilobites within the claystone of Osiek Fm.; Władysławowo *4*, 2870.6—2873.6 m; × 3.



1 — *Rusophycus* sp. (r) and *Tigillites* sp. (t) in medium-grained sandstone; Władysławowo *4*, 2870.6—2873.6 m; Osiek Fm.; × 1.5.
2 — *Monocraterion* sp. (m) and *Planolites* sp. (p); Żarnowiec *5*, 2786.9—2787.4 m; Dębki Fm.; × 1.5.



1 — *Cruziana* sp.; Żarnowiec 5, 2727.0—2728.2 m; Osiek Fm.; × 1.5.
2 — *Merostomichnites?* sp.; Żarnowiec 5, 2738.0—2742.0 m; Osiek Fm; × 2.
3 — *Kinneyia simulans* Walcott, 1914; Żarnowiec 5, 2742.0—2746.0 m; Osiek Fm.; × 1.5.
4 — *Planolites* sp. (p) and *Sagittichnus* sp. (s); Żarnowiec 5, 2730.0—2731.1 m; Osiek Fm.; × 1.5.



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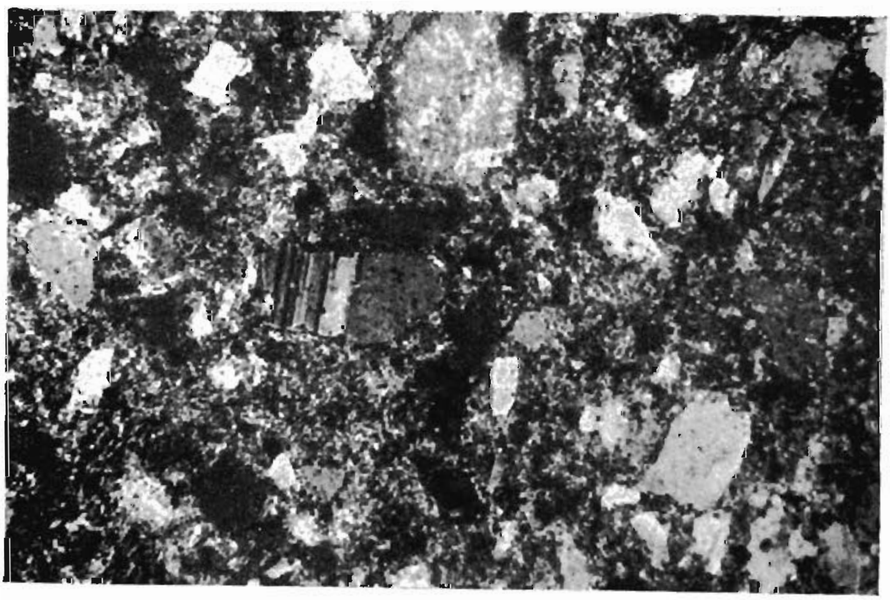
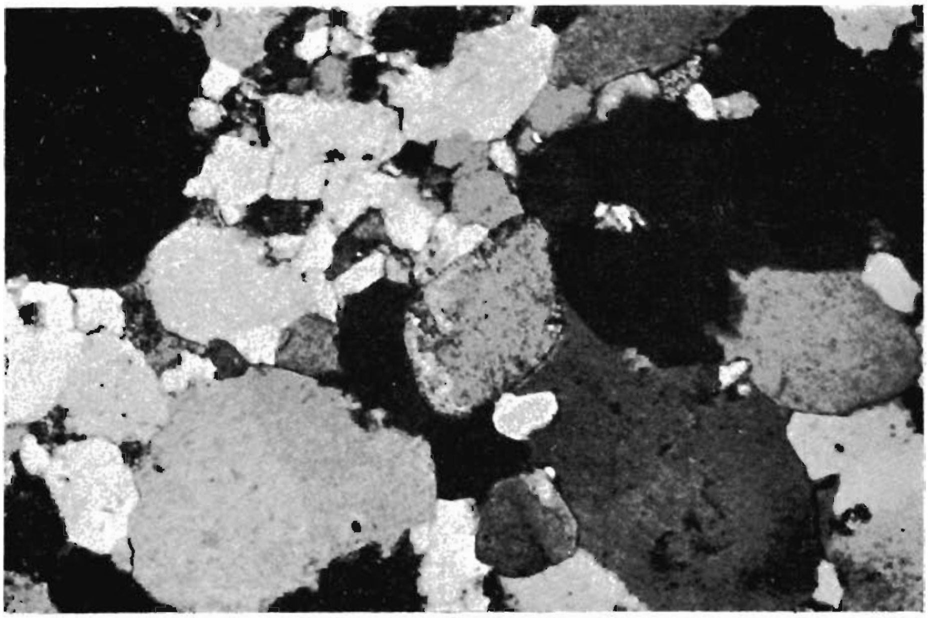


2

1 — Quartz with regeneration rim in quartzitic sandstone of Łeba Fm.; Władysławowo *4*, 3174.6—3175.9 m; sample *29*; nicols crossed; × 50.

2 — Plagioclase in the sandstone with clayey cement; Łeba Fm.; Władysławowo *4*; 3122.1—3125.0 m; sample *25*; nicols crossed; × 150.



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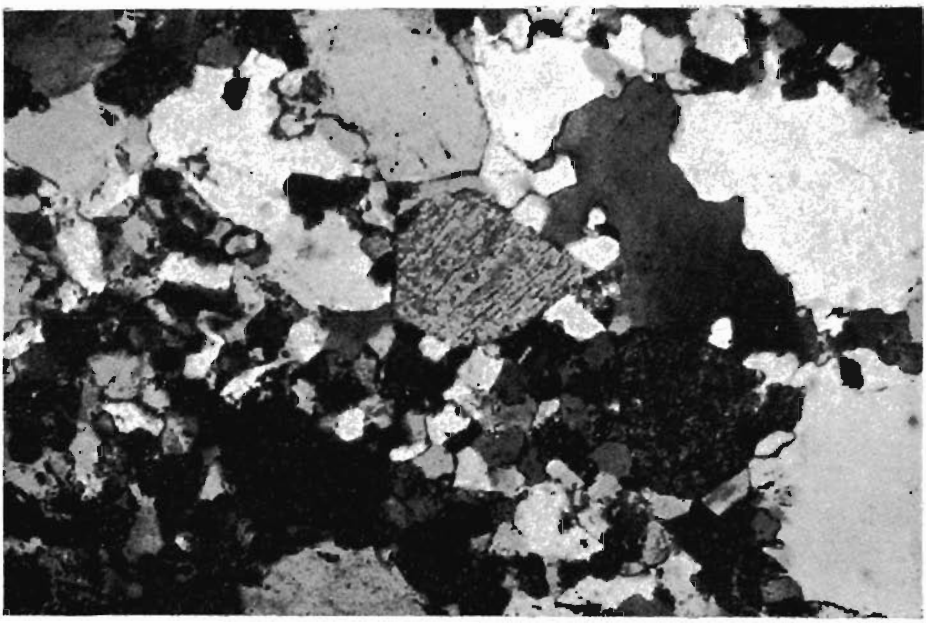
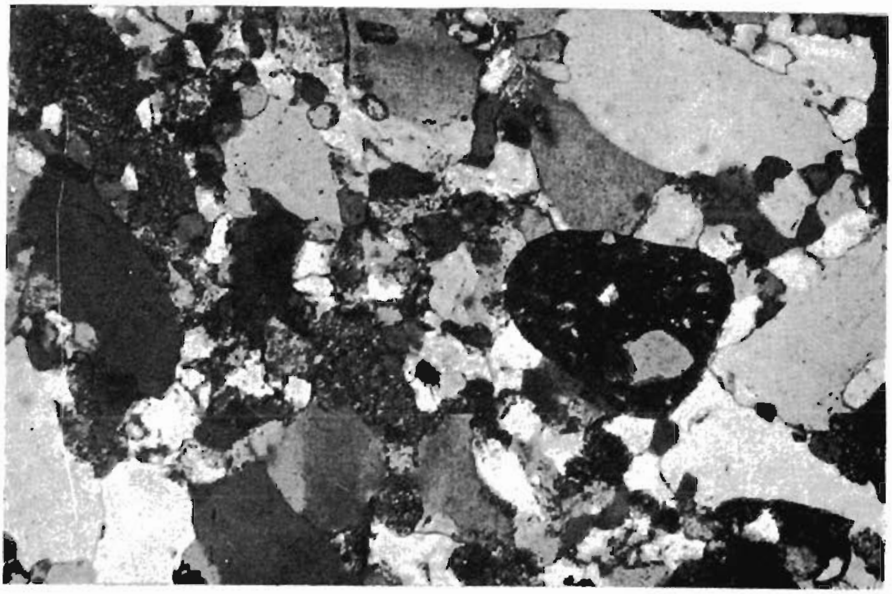


2

1 — Feldspar carbonized from margins of grain in the sandstone of Łeba Fm.; Krynica Morska *2*, 3072.6—3075.2 m; sample *29;* nicols crossed; × 60.

2 — Carbonized grains with preserved relic of feldspar in the sandstone of Łeba Fm.; Krynica Morska *2*, 3072.6—3075.2 m; sample *29;* nicols crossed; × 60.



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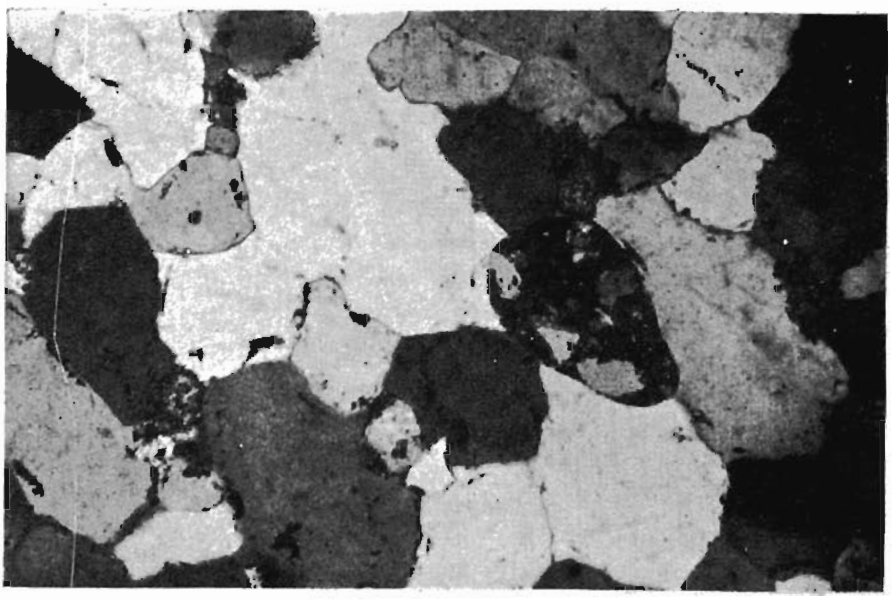
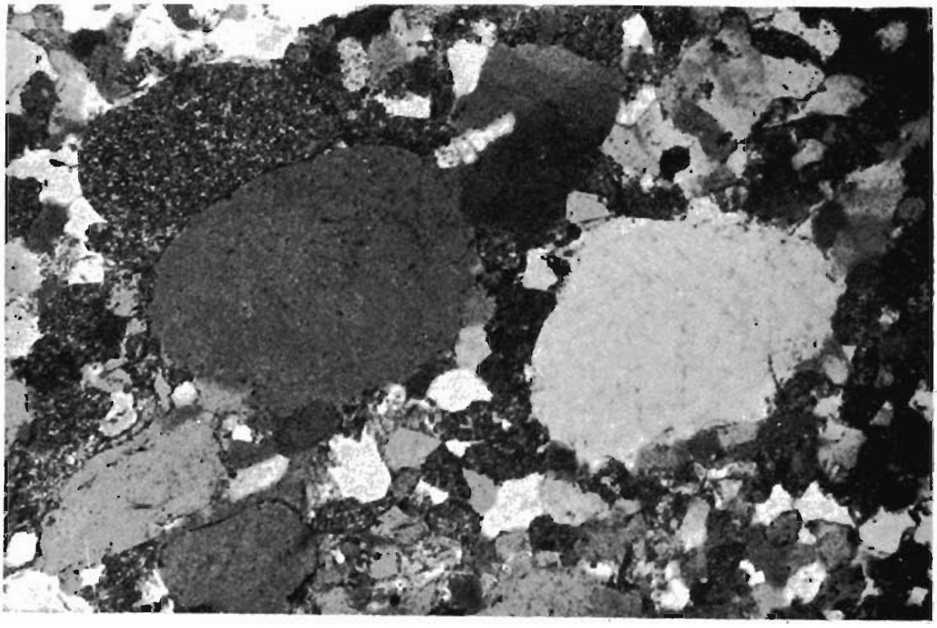


2

1 — Phosphoritic remnants in the sandstone of Łeba Fm.; Krynica Morska *2*, 3072.6—3075.2 m; sample *29;* nicols crossed; × 60.
2 — Phosphoritic remnants in the sandstone of Łeba Fm.; Władysławowo *4*, 3174.6—3175.9 m; sample *29;* nicols crossed; × 60.



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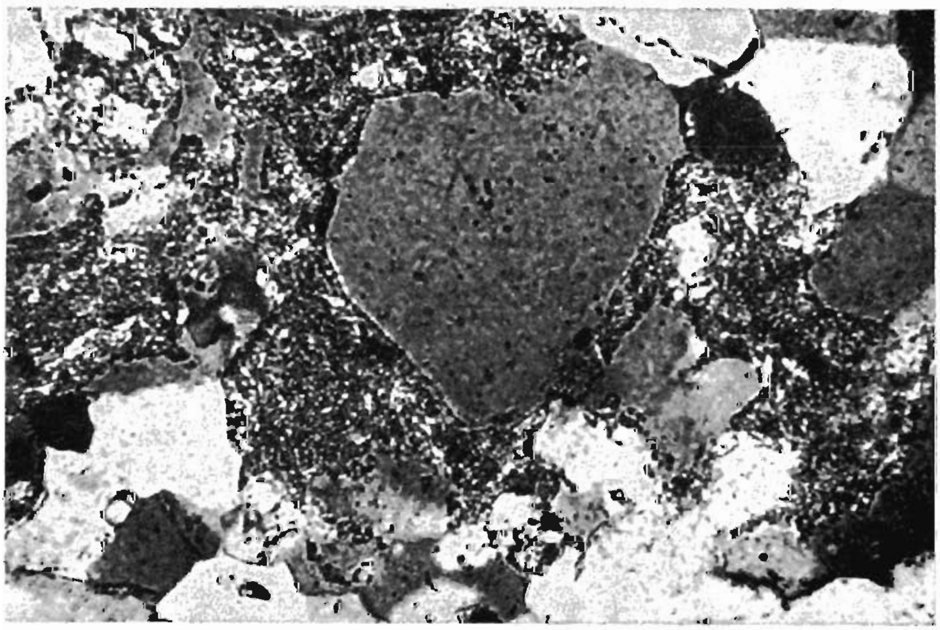
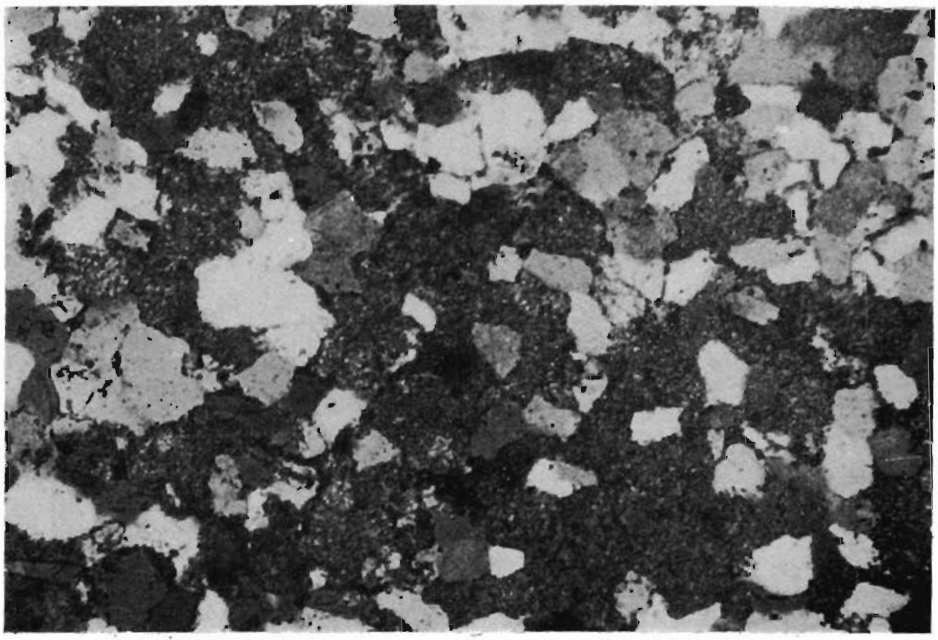


2

1 — Vari-grained sandstone of Łeba Fm.; in fine-grained matrix of sandstone large grains of quartz and glauconite are visible; Władysławowo *4*, 3203.7—3205.3 m; sample *38;* nicols crossed; × 60.

2 — Quartzitic sandstone of Łeba Fm.; around the grains of quartz a glauconite is visible. Locally it forms a cement of sandstone; Krynica Morska *2*, 3062.2—3064.3 m; sample *26;* nicols crossed; × 160.



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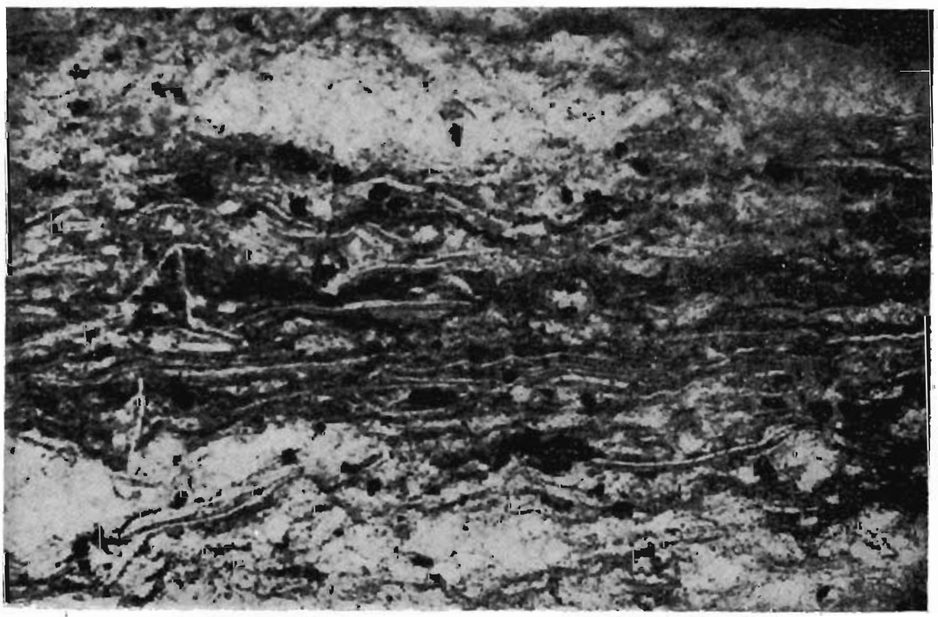
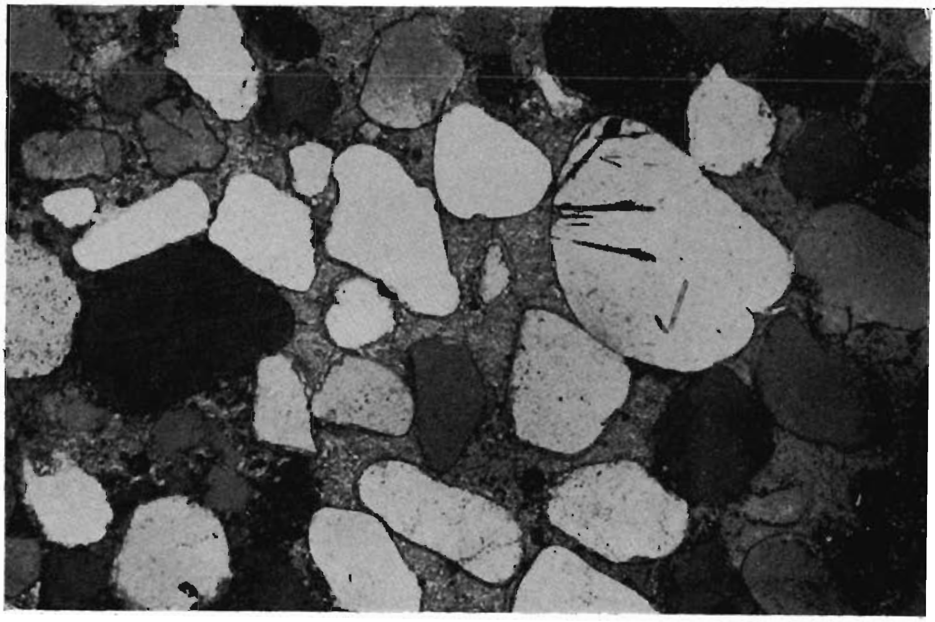


2

1 — Sandstone with glauconitic cement; Łeba Fm.; Władysławowo 4, 3194.4—3195.8 m; sample *34*; nicols crossed; × 50.

2 — Sandstone with laminated structure; agglomeration of plates of micas; Dębki Fm.; Krynica Morska *2*, 2840.2—2842.4 m; sample *14*; nicols parallel; × 60.



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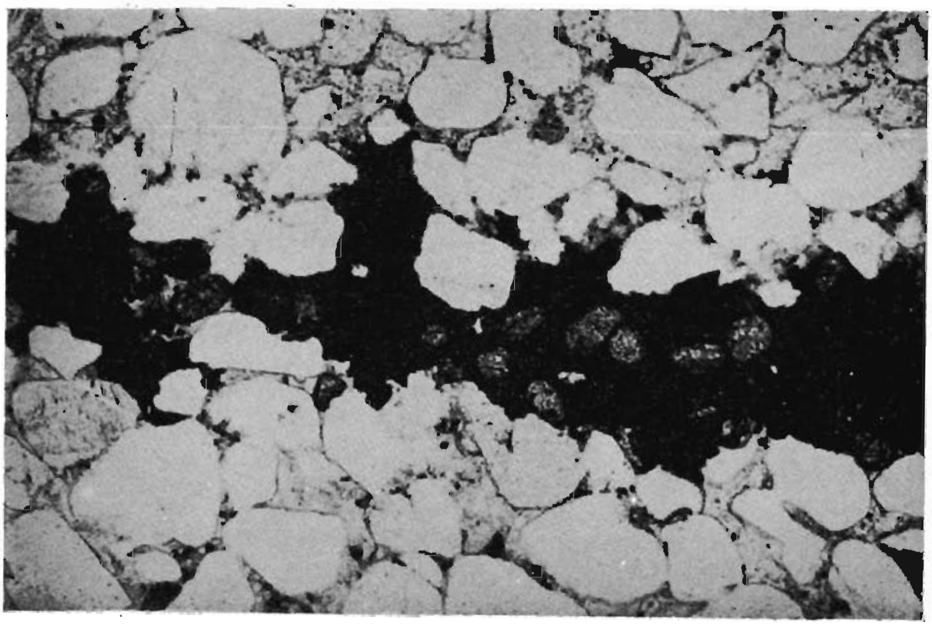

2

1 — Quartzitic sandstone with the carbonates creating a cement; Osiek Fm.; Żarnowiec 5, 2742.0—2746.0 m; sample 25; nicols crossed; × 60.
2 — Streak of pyrite with the grains of zircon in the quartzic sandstone and with the carbonates creating a cement: Osiek Fm.; Żarnowiec 5, 2742.0—2746.0 m; sample 25; nicols parallel; × 60.