BULLETIN DE L'ACADÉMIE
POLONAISE DES SCIENCES
Série des Sciences de la Terre
Volume XIX, No. 3, 1971
Published in September 1971

GEOLOGY

Cyclic-sedimentary Subdivision of the Rhaetian of the Polish Lowlands

by

W. GRODZICKA-SZYMANKO

Presented by W. POŻARYSKI on February 26, 1971

Summary. In the shallow, epicontinental Upper Triassic basin, which occupied vast parts of Polish Lowlands (Fig. 1), successive ingressions entering from the Alpine geosynclinal basin are marked. At the same time, paleotectonic modifications of the sedimentary basin, extensive and variable in time, took place. Cyclic changes of the diastrophism were of universal character, although not identical as to its content, and are reflected in the vertical lithological sequence of sediments, showing great regularity in their horizontal range at the same time. These changes also led to occurrence of local gaps, particularly numerous in the upper stage of the Upper Triassic — in the Rhaetian, The rhythmic sequence of marine and non-marine sediments is accepted as basic criterion for detailed stratigraphical division of the Rhaetian cyclothems: RI_1, RI_2, RII_1 and RII_2. The lithological characteristics of sediments, their structural pattern and vigorous development of terrestrial flora (Fig.3) typical for transition periods in stratigraphy of the Upper Triassic, enable us to assume that the upper boundary of the Rhaetian should be located between the cyclothems RIII and RL.

The deep boreholes recently drilled in the area of the Polish Lowlands revealed that the classic exposures and the previously known drilling profiles of epicontinental Rhaetian do not represent a complete stratigraphic succession.

The abundant well-logging material obtained within the research project of the Geological Institute, Petroleum Industry and Non-Ferrous Ore Industry of Poland made possible the attempt at a detailed subdivision of the Rhaetian in virtue of cyclic-sedimentary criteria, established on the most complete profiles from the region of Silesia and the eastern Sudetic forefield, and on their regional correlations in the Polish Lowlands. Concise results of this attempt are presented in the paper.

In consequence of the investigations performed it was found that the vertical position of certain previously known lithological units is — after establishment of complete correlations — different from that hitherto assumed. This is the case, for example, of the "Woźniki limestones" (Fig. 2, Pl. III, IV) and "Lisów breccia" (Fig. 2), previously discussed by Samsonowicz [27] and Różycki [25] and more recently by Znosko [34] and Szyperko [29].

A more detailed division of the Rhaetian was made by Różycki [26] for the region of Kujawy, Znosko [34] for the area between Cracow and Wieluń, and Dadlez [4—6] for Western Poland and the Mazurian District. According to the views held at that time, these authors accepted the age of Rhaetian deposits as Lower Jurassic.

In 1962, the International Colloquium in Luxemburg passed several regulations; one of them including the Rhaetian developed in the German facies into the Triassic, as its uppermost stage; moreover, the *Equisetites gracilis* Horizon (the lowest part of the *Thaumatopteris schenki* Zone according to Troedsson [30]), should be considered as the lowermost zone of the Lower Jurassic.

The results of further studies revealed that the vertical range of the Rhaetian stage is still controversial in the opinions of various authors (cf. [6, 11]). The lower boundary of the Rhaetian is basically univocal and distinct. Many of the authors draw that boundary above the Upper Gypsum Level within the Upper Gypsum Keuper (the German equivalent of that zone is "Heldburggips" [26, 11, 9].

The upper boundary of the Rhaetian and the Rhaetian/Lower Jurassic boundary are still open questions. Many authors from various parts of Europe have been discussing these problems (e.g. [2, 3, 6, 9, 11, 14—16, 18, 20, 24, 28, 30—32]).

The lower boundary of the Rhaetian and its correalation with Alpine Rhaetian facies were demonstrated by Pearson [21] at the Symposium on the Triassic rocks of Britain, London, 1968.

The subdivision of the Rhaetian into the Lower (*Posterus*) and Upper (*Contorta*) Zones was made by Kopik during his studies of the Polish Lowlands [11] and in the Holy Cross Mts [12] with reference to German, Swedish and English paleontological studies. This subdivision was based on the occurrence of the pelecypod, *Unionites posterus*, and ostracods of the genus *Rhombocythere* in marine intercalations of the Lower Rhaetian. However, detailed ostracod zones were not distinguished [4, 11, 12]. The contorta Zone is not documented paleontologically in Poland, because neither the pelecypod *Rhaetavicula contorta* nor guide ostracods (except for *Bairdia* sp. [4]) have been found so far. The "Upper Rhaetian" deposits [11] were previously assigned by Dadlez and Kopik [4] to the *Rhaetavicula contorta* Zone of the "Middle Rhaetian". However, the microfaunal assemblage of the Polish Lowlands listed by them [4, 7, 11, 12] occurs both in the *Unionites posterus* and *Rhaetavicula contorta* Zones.

Will [32], who carried out studies of the area of NW Germany, makes use of of paleontological-lithological premisses to present a detailed subdivision of the Rhaetian and a floristic boundary between the Rhaetian and the Liassic.

In the Earth history, the time-span of the Upper Triassic is estimated at about 12 million years [3]. The most significant feature of epicontinental Keuper and Rhaetian sediments is the stamp of continuous, enantiodromic diastrophism, particularly intensified during a few successive eo-Kimmeridgian phases.

The shallow epicontinental Upper Triassic basin occupied some parts of the Polish Lowlands (Fig. 1) and German Lowlands and reached as far as Lorraine. Successive ingressions from the Alpine geosynclinal basin are marked. At the same time, paleotectonic modifications of the sedimentary basin, extensive and variable in time, took place. These changes resulted in a differentiation of sedimentary conditions in various parts of the basin, including the formation of local gaps. Moreover, the common scarcity of faunal fossils, particularly of guide fossils, make biological subdivision and correlation with the Alpine region difficult to perform.

On the basis of lithofacial criteria, in the 1920's and in later years, German authors performed a detailed stratigraphic subdivision of clay-carboniferous and gypsum Keuper, still valid and widely acknowledged.

Such sudbivisions for the upper stage of the Upper Triassic were neither so detailed nor so univocally understood (in the whole area of occurrence of epicontinental Rhaetian, both in Poland and Germany). This is due to numerous stratigraphic gaps in the vertical profile of the Rhaetian.

PLATE I

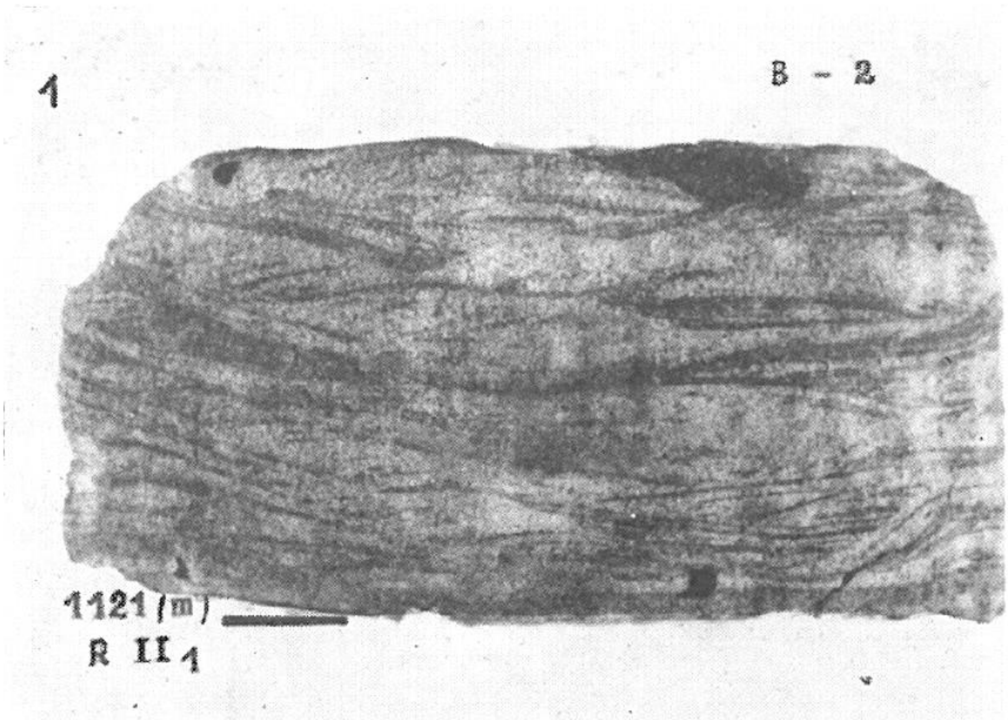


Photo 1. Core from borehole B-2. Depth — 1121 m; bottom part of the cyclothem R II_1. Graded sandstone, from coarse- to fine-grained, cross-bedded. Dip about 5°. (×1.0)

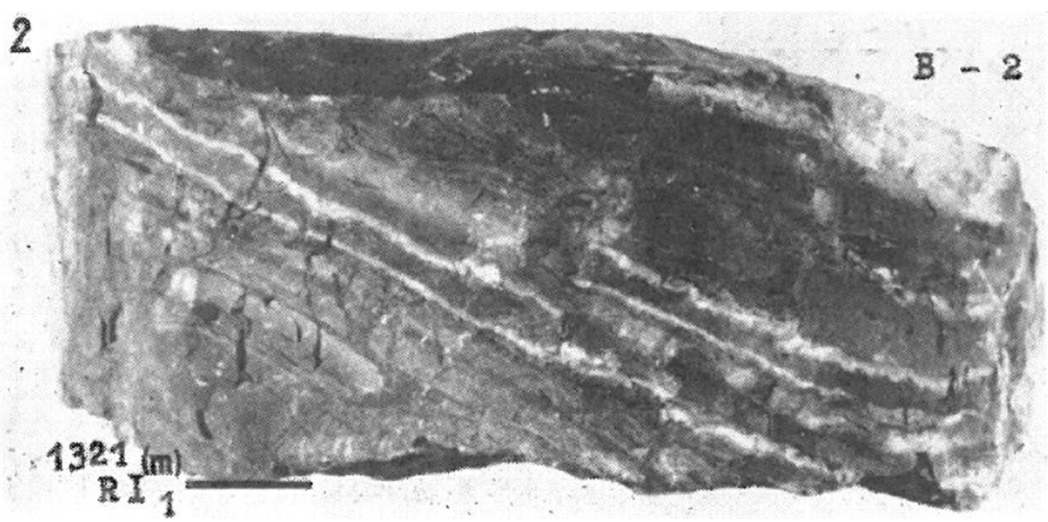


Photo 2. Core from borehole B-2. Depth — 1321 m; bottom part of the cyclothem R I_1. Dolomitic claystone with fine, parallel bedding with pelitic dolomite. Dip angle about 25°. (×1.0)

PLATE II

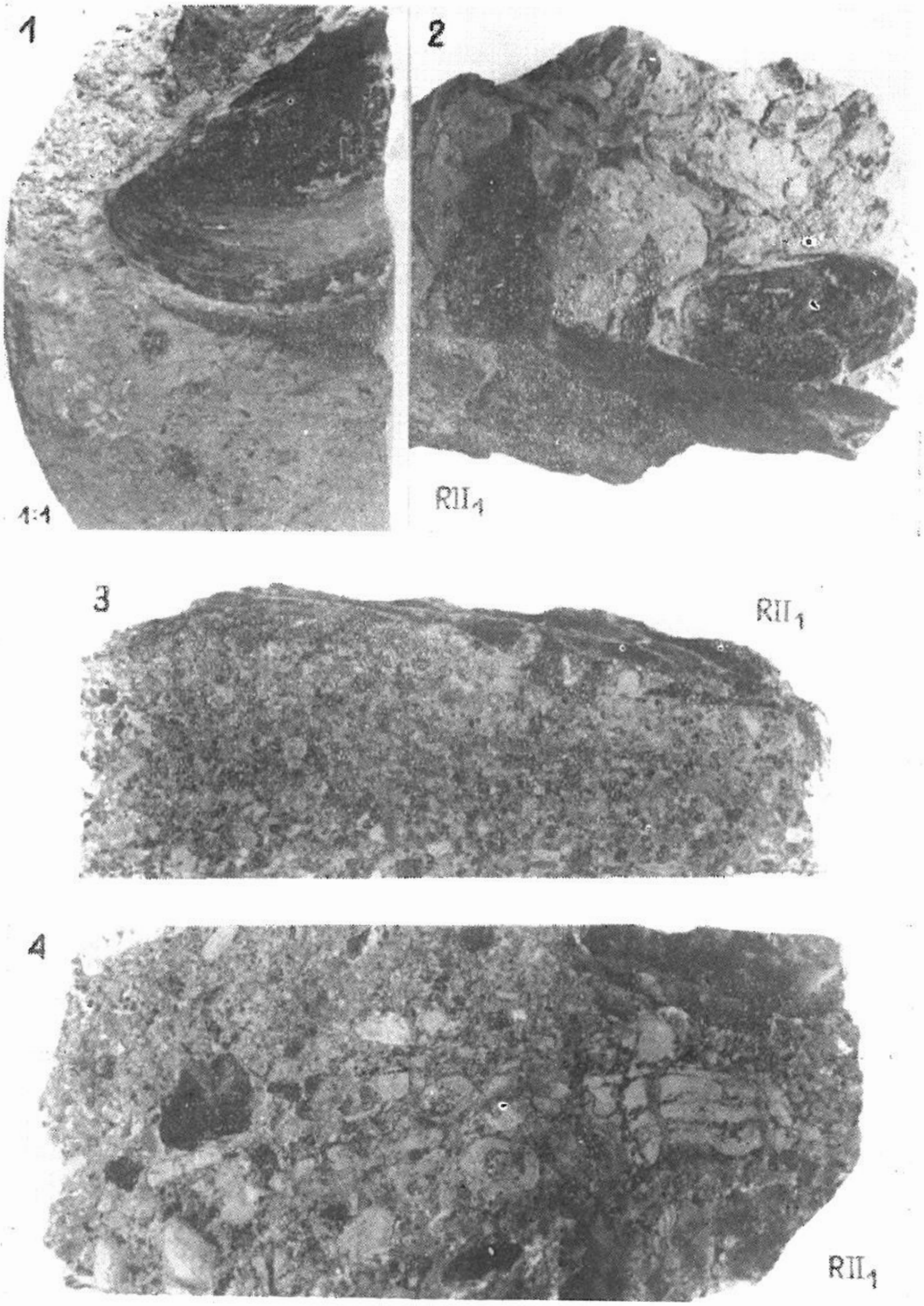


Photo 1, Photo 2. Core from borehole from the vicinity of Zawiercie. *Unionites posterus* in deposits of upper part of the cyclothem R II_1. ($\times$ 1.0)

Photo 3, Photo 4. Basal conglomerates of the cyclothem R II_1 from the region of the upper course of Warta river. ($\times$ 1.0)

PLATE III

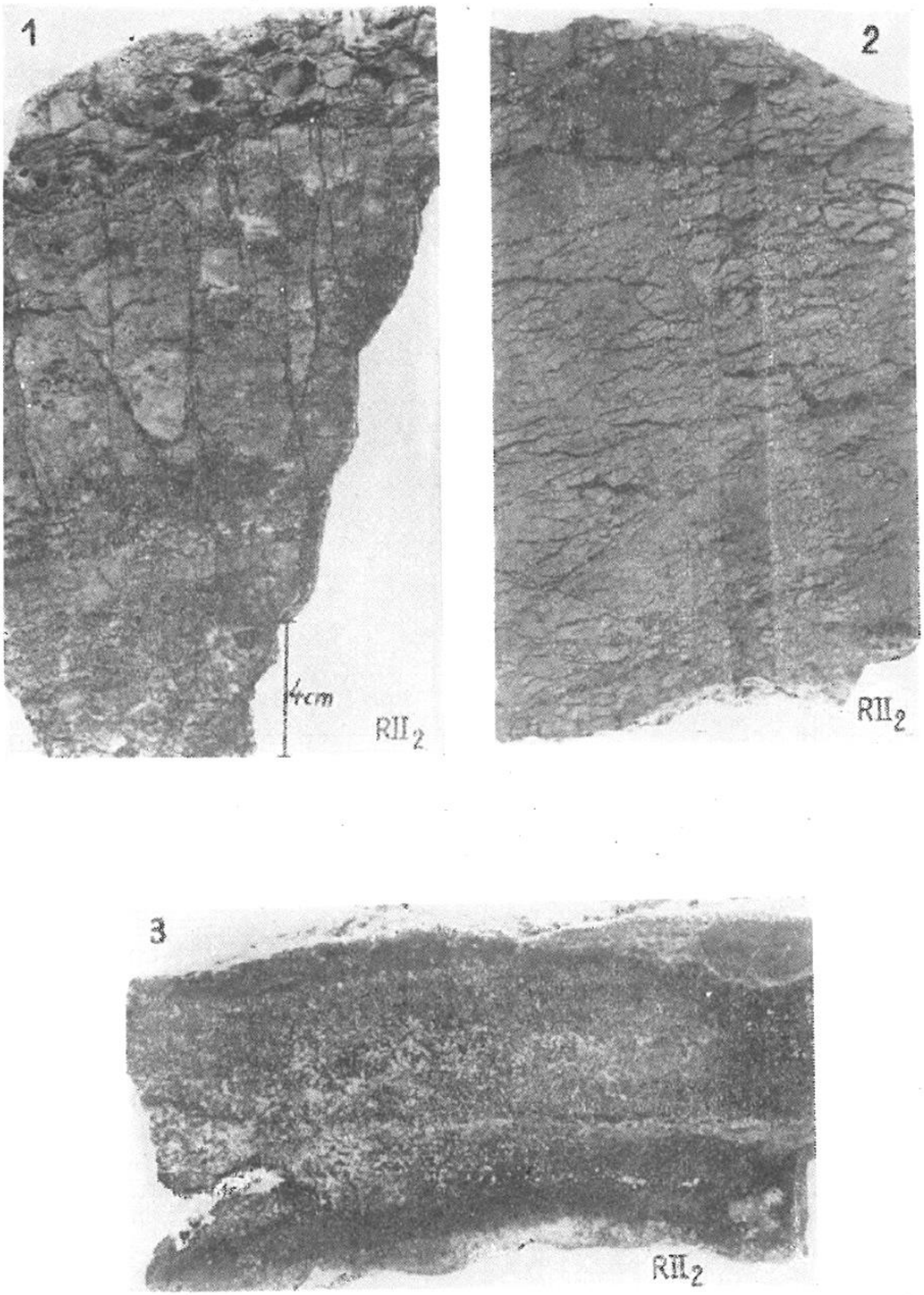


Photo 1. Karst weathering of Woźniki limestones. Vicinity of Zawiercie. (× 0.20)
Photo 2. Woźniki limestone from the vicinity of Zawiercie. Fissures filled with quartz. (×1.0)
Photo 3. Syderitized Woźniki limestones from Poręba near Zawiercie. (× 1.0)

PLATE IV

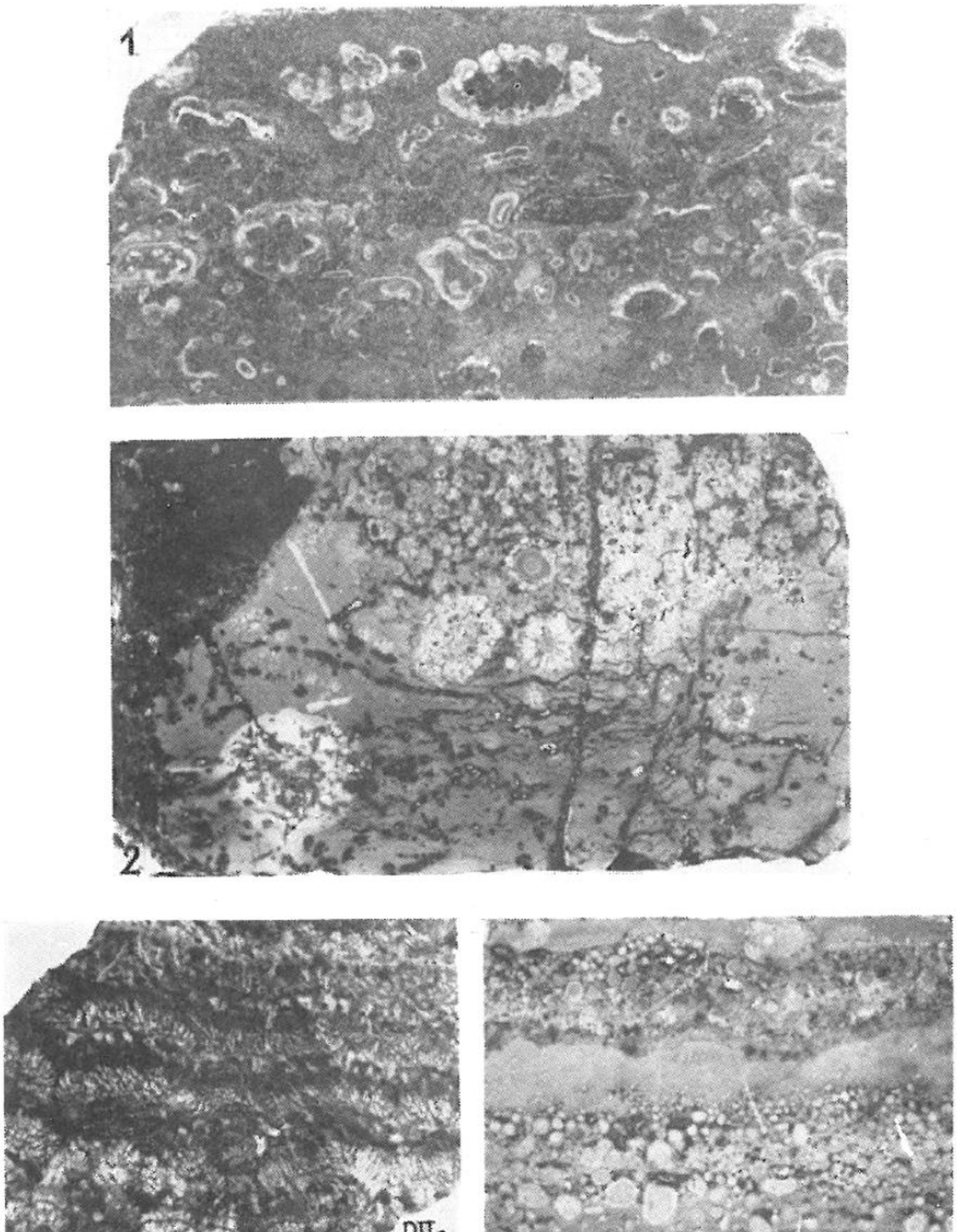


Photo 1. Macroremnants of terrestrial flora occurring in Woźniki limestones. Well core from Poręba near Zawiercie. (× 0.5)

Photo 2. Woźniki limestone with algal remnants and burrowings. Vicinity of Zawiercie.

Photo 3. *Stromatolites* in Woźniki limestones. Vicinity of Zawiercie. (× 1.0)

Photo 4. Thin-bedded Woźniki limestone with ooids. Vicinity of Zawiercie. (× 1.0)

The subdivision of that stage presented in this paper is based (after Różycki [26]) on the criterion of sequence of cyclic changes in sedimentary conditions of the basin.

Moreover, it was assumed that these changes were primarily connected with the cyclic course of diastrophism.

In consequence of a correlation of characteristic sets of beds and of drawings of successive paleogeographical maps it was found that various diastrophic changes were of common character, although not identical in their content, and were marked by changes in the vertical lithological sequence of deposits, showing at the same time a high regularity in their horizontal distribution. In most cases, these changes can be correlated with the area of the German Lowlands.

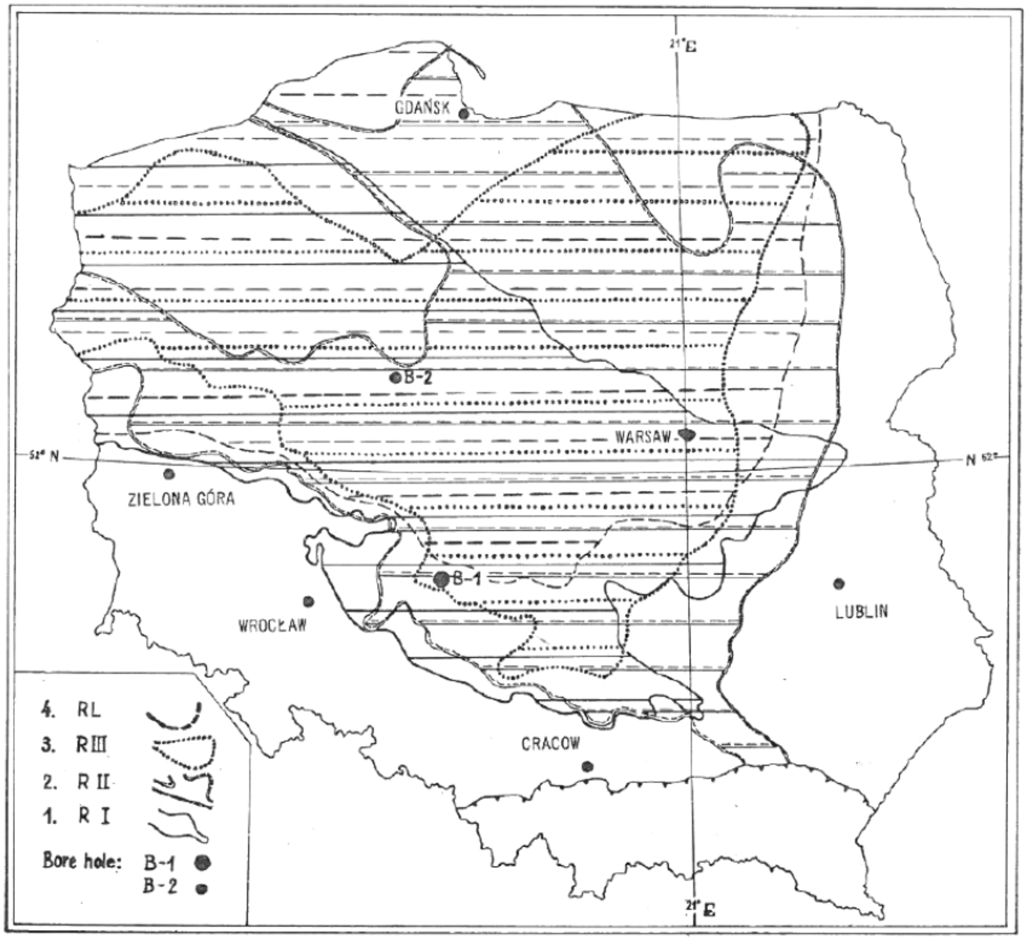
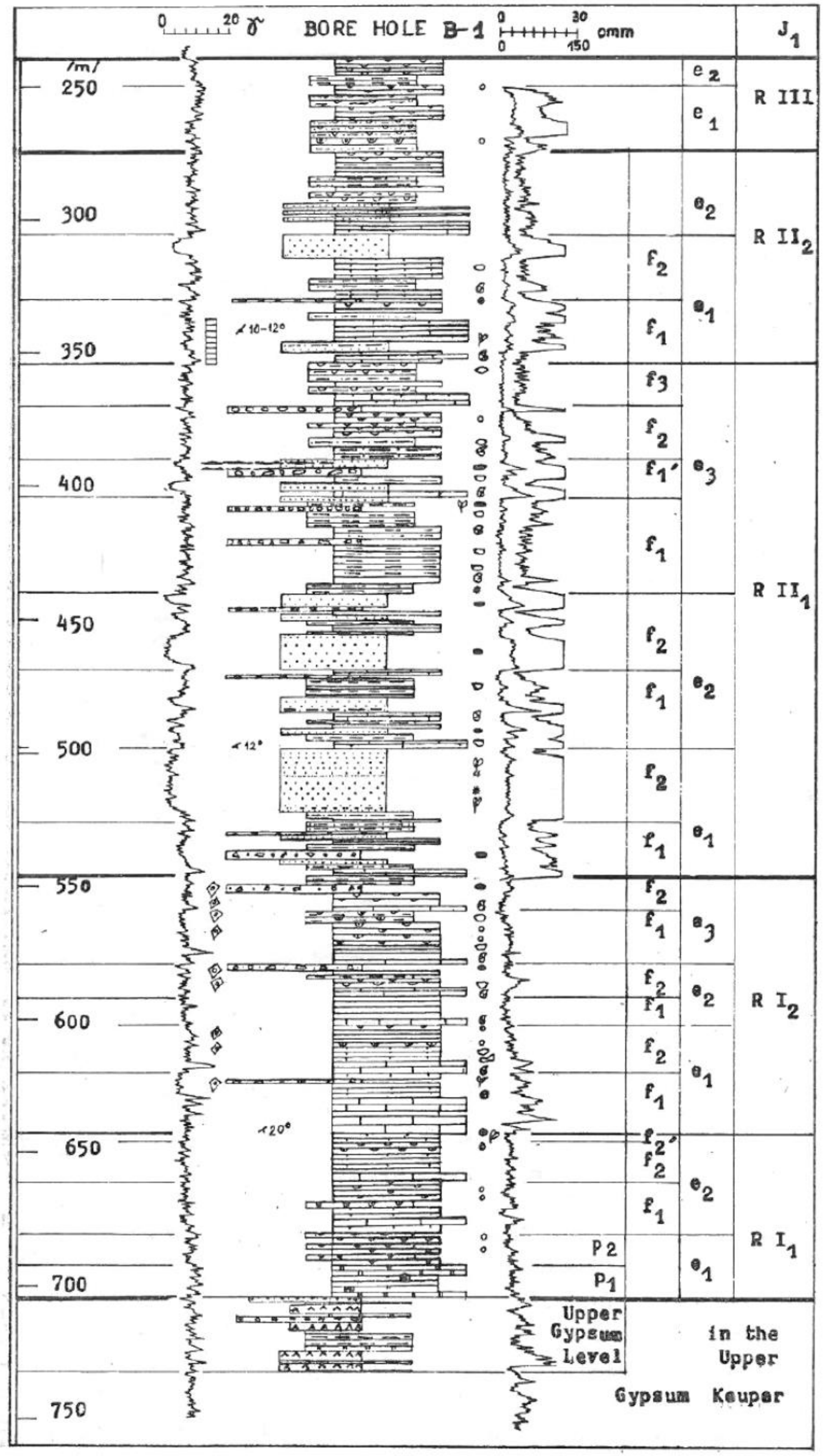


Fig. 1. Contemporary extent

In the subdivision proposed, paleotectonic cycles were applied to the time scale. By "paleotectonic cycle" is meant a complex of diastrophic changes, with up and down limitations in the time scale by the definite course of regional deformation of the basin and by accompanying climatic variations and sea-level changes.

In the scale of changes in lithologic character of the undergoing deposition, the "great cyclothem" corresponds to the time — span of one complete paleotectonic cycle. Here, great cyclothem is the term used to describe a sedimentary unit of the


BORE HOLE B-1
0 20 γ
0 30 omm
0 150
J1
/m/
250
300
350
400
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R III
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R II1
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f1
f2
f1
f2
f1
f2
f1
f2'
f2
f1
P2
P1
10-12°
12°
20°
Upper Gypsum Level
in the Upper
Gypsum Keuper

first order. The assumed criterion of differentiation of a single cyclothem is a sedimentary succession beginning with transgressive deposits and ending with regressive ones. It was noted that cyclothems based on such assumption repeatedly occur in the vertical profile of the Rhaetian (cf. Fig. 2), being differentiated among themselves by the order of magnitude of marine influences and their regional ranges. The term "cyclothem" will be further applied to sedimentary units of the second order, which begin with transgressive sediments, traceable in the whole basin. Also, in the whole basin, the rhytmical sequence of vertical changes is maintained, whereas facial distribution is dependent on basin morphology.

Within the particular cyclothems also phantom links, i.e. such parts in which deposition did not continue or the sediment was thereafter removed, should be considered. Establishment of the size of a missing sedimentary section is only possible if still smaller sedimentary units will be distinguished within every cyclothem. Auxiliary terms applied for the third order of magnitude — span (marked with the letter "e" in Fig. 2), for the fourth — phase ("f" in Fig. 2), for the fifth — level ("p" in Fig. 2), and for the sixth order of magnitude — lithologic section.

It was noted that in the course of the Rhaetian, three paleotectonic cycles took place. During these cycles the epicontinental basin underwent structural modification and three large cyclothems marked with the symbols R I, R II and R III were deposited.

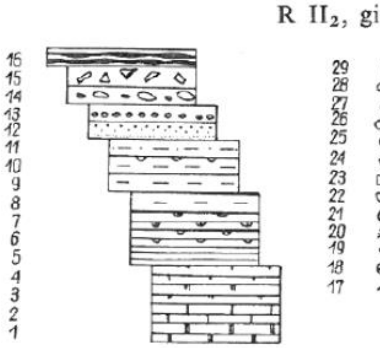
Higher intensifications of diastrophism of the three eo-Kimmeridgian phases took place respectively: before R I, between R I and R II, and between R II and R III.

These phases were marked in the central parts of the basin by successive angular disconformities in the position of sediments (cf. B — 2, Pl. I, Photos 1 and 2), and in other parts of the basin by regional sedimentary gaps of various magnitude.

In the older lake cyclothem, R I, two cyclothems were distinguished — R I_1 and R I_2, (Table I, Fig. 2) similarly as in the middle great cyclothem R II, where cyclothems R II_1 and R II_2 were distinguished.

A generalized profile of a complete sedimentary sequence from the eastern Sudetic forefield (Borehole B — 1*), cf. Figs. 1, 2) is typical for cyclothems R I_1, R I_2, R II_1 and R II_2 of epicontinental Rhaetian.

← Fig. 2. Typical profile of complete sedimentary sequence, for cyclothems R I_1, R I_2, R II_1 and R II_2, given on the example of borehole B-1.



1 — dolomite, *2* — limestone, *3* — dolomitic claystone, *4* — limy calcic claystone, *5* — claystone, *6* — clotty claystone, *7* — claystone with allogenic clots, *8* — sandy claystone, *9* — claystone with sandstone intercalations, *10* — sandy clotty claystone, *11* — clayey sandstone, *12* — fine-, medium and coarse-grained sandstones, *13* — conglomerate, *14* — gravels, *15* — breccia, *16* — coal, *17* — dips of beds, *18* — concentrations of secondary sulphates, *19* — carbonate, marly of siderite allogenic clots, *20* — glauconite, *21* — foraminifers, *22* — ostracods, *23* — "Woźniki limestones", *24* — „Lisów breccia", *25* — microspores, *26* — Bonebed, *27* — feldspar pebbles, *28* — quartz pebbles, *29* — detritus of carbonitized plants

* Rhaetian profile from borehole B — 1, in full name: 1 — KW Wieluń, was previously interpreted by Deczkowski [8], with reference to the stratigraphic subdivision of Dadlez [4] from Western Poland.

TABLE 1

Stratigraphic correlation of the epicontinental Rhaetian

Stratigraphic division / Regional division — Division, Stage	Suggested terminology — Cyclothems — 1st size	2nd size	Name (Epicontinental Rhaetian in Poland, W. Grodzicka-Szymanko 1971)	Southern Kujawy, S. Z. Różycki 1958		West Poland, R. Dadlez and J. Kopik 1963, R. Dadlez 1967			Lowland Poland and Góry Świętokrzyskie, J. Kopik 1967,—70			Nordwestdeutschland, H.—J. Will 1969	
LOWER JURASSIC	RL	RL	Ksawerów Cyclothem	Cycle III	Ksawerów Series	LOWER JURASSIC	Upper Rhaetian	Wielichowo Beds	LOWER JURASSIC	Triletes Beds		OBERER KEUPER, Rhätkeuper	Triletes-Schichten oberer Teil
UPPER TRIASSIC — T 3³, Rhaetian	R III	R III	Kłodawa Cyclothem	Cycle II	Upper Kłodawa Series				UPPER TRIASSIC	Upper Rhaetian	Contorta Horizon		Triletes-Schichten unterer Teil
	R II	R II₂	Woźniki Cyclothem	Cycle I	Lower Kłodawa Series		Lower and Middle Rhaetian	Zbąszynek Beds					Contorta-Schichten: contorta (Teil) -Zone
		R II₁	Warta Cyclothem							Lower Rhaetian	Postera Horizon	Steinmergelkeuper	Postera-Schichten: elegans -Zone
	R I	R I₂	Lisów Cyclothem					Jarkowo Beds					prima-Zone: hechti -Subzone; prä-hechti -Subzone
		R I₁	Zawiercie Cyclothem					Drawno Beds					Saurichthys -Schichten

In order to make everyday use of these terms easier, additional names were given to them, either taken from geographical location of their best known profiles, or from traditional terms known from the literature and referred to typical lithological units, occurring within the cyclothems (Table I).

The division of epicontinental Rhaetian proposed, and a comparison with the actually applied subdivisions of the Rhaetian by various authors are presented in Table I.

The third and youngest upper paleotectonic Rhaetian cycle was marked with the symbol R III. It is a significant, although different from the two older ones, element of the development of the Rhaetian basin on the platform. After completion of cyclothem R II_2 sedimentation, further, pre-Liassic modification of the structural frame took place. This phase of diastrophism in the area of Polish Lowlands was not found to be accompanied by a marine impulse. Within cyclothem R III, correspon-ding to "Lower Beds with *Triletes*" [32], nonmarine facies are dominant and their lithological character still has many "Upper Triassic" features.

The idea of stratigraphic divisions based on the criterion of cyclic rhythm of non-marine sedimentation was elaborated by S.Z. Różycki [26] for establishing a detailed stratigraphy of the Rhaetian and Liassic in the are of southern Kujawy.

The profile of the "Upper Kłodawa series" [26] determined lithofacially, presents a complete and typical development of cyclothem R III. Correlation of a detailed

TABLE II

Correlation of S.Z. Różycki's subdivision with the author's subdivision into cyclothems (Southern Kujawy Region)

S.Z. Różycki 1958		Subdivision into cyclothems 1971		
	Cycle III:			
	E			
Ksawerów	D		RL	Ksawerów Cyclothem
	C			
Series	B			
	A			
	Cycle II:			
Upper	D	e_2		
Kłodawa	C		R III	Kłodawa Cyclothem
Series	B	e_1		
	A			
	Cycle I:			
	F	e_{1-2}	R II_2	Woźniki Cyclothem
	E	e_3		
Lower Kłodawa	D	e_2	R II_1	Warta Cyclothem
Series	C	e_1		
	B			Hiatus
	A		R I_1	R I_2
				Zawiercie Cyclothem

lithostratigraphic subdivision according to S.Z. Różycki, together with the proposed subdivision into cyclothems is given in Table II.

Successive intensification of diastrophism, which took place at the completion of deposition of cyclothem R III definitely ended the existence of the sedimentary basin with Upper Triassic structural frame in the Polish Lowlands.

Deposition of sediments belonging to the limnic cyclothem marked with symbol "RL" and corresponding to the "Upper Beds with *Triletes*" [32], was preceded by a regional erosion.

The most complete known development of cyclothem RL is represented by a detailed lithofacial profile of the "Ksawerów series" from southern Kujawy, given by S. Z. Różycki [26].

Sediments of cyclothem RL already exhibit features typical of the Lower Jurassic. Clay rocks of dark-gray and brown-black colour predominate. The structural pattern of sediments RL is quiet and generally flat, with rare traces of slickenside, and similar in tectonic style to that of the overlying horizons sediments of the Liassic. Thickness of that cyclothem in up to a few scores of meters in Northern Poland and up to 180 m in the Szczecin synclinorium. Sediments RL are rich in floral macrofossils and palynologically documented by assemblages of characteristic megaspores and microspores in some regions.

Biostratigraphical remarks

Changes in the organic assemblages during the Rhaetian took place in a way harmoniously connected with changes in configuration of the basin accompanying climatic fluctuations. The general outline of vertical ranges of animal and plant organisms, depending on ecological laws which are different in water basins and on land surrounding those basins, is given on Fig. 3. Various hemeras are listed on the basis of the data collected from the literature [1, 2, 13—20, 22, 28, 30, 32, 33] for selected most characteristic fossils of the Rhaetian.

Transgressive-marine impulses are marked in sediments by common and abundant occurrence of foraminifers of the genera *Variostoma* and *Diplotremina*, among others.

Gradual transition to brackish and lagunal environment is marked by development of ostracods of the genera *Notocythere* [32] = *Rhombocythere* [1] and *Darwinula*.

Transitional periods, i.e. corresponding to decline of regression and outset of another marine ingression. are characterized by the greatest intensification in the development of terrestrial plant communities. Micro- and megaspores are the best indicators here. Successive climatic fluctuations and changes determine their vertical individual and quantitative development.

The first large group of microspores* (Fig. 3) is represented by numerous genera and species; only the most common are listed. This group existed from the decline of the Gypsum Keuper, through the whole of the Rhaetian, and became almost completely extinct at the beginning of the Lower Jurassic, i.e. during cyclothem RL corresponding to the Upper Beds with *Triletes*.

The second group of microspores ** (Fig. 3) is represented on the diagram by two characteristic species. They appear in the cyclothem R I, and achieve main development in RL, becoming extinct in the *Thaumatopteris schenki* Zone.

Megaspores, a few guide species of which are listed on Fig. 3, appear in R II, thrive during RL and partly pass to the *Thaumatopteris schenki* Zone.

Macroflora is represented by pteridosperm *Lepidopteris ottonis* (Goepert) Schimper (Fig. 3), and occurs in sediments of cyclothems R II $_{1-2}$ and R III, and was not recorded above the top of the Beds with *Triletes*.

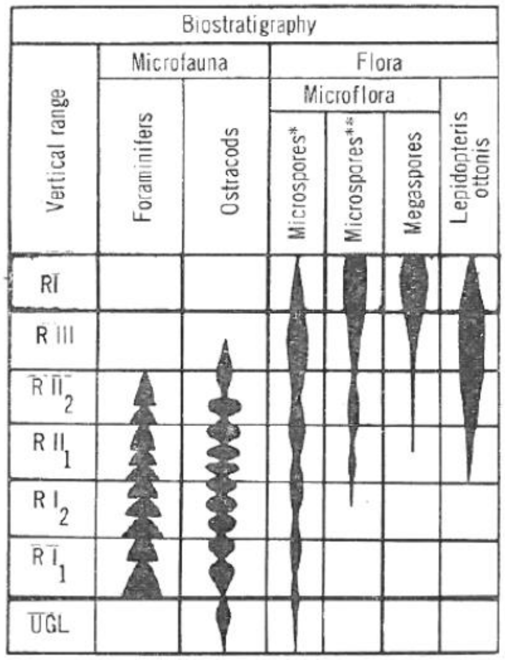


Fig. 3

Microfauna: foraminifers – gen. *Variostoma* and *Diplotremina*; ostracods – gen. *Notocythere* and *Darwinula*
Microflora: microspores – *) (*Granuloperculatipollis rudis* Venk. and Góczân, *Corrolina meyeriana* (Klaus) Venk. and Góczân, *Classopollis classoides* (Pf) Pot. and Jans., gen. *Enzonalasporites*, gen. *Ovalipollis*, group *Cheirolepidaceae*; – **) *Ricciisporites tuberculatus* Lundbl., *Selaginella hallei* Lundbl.; megaspores – *Trileites pinguis* (Harris) Pot., *Bacutriletes tylotus* (Harris) Pot., *Verrutriletes litchi* (Harris) Pot., *Maexisporites misellus* Marc., *Verrutriletes utilis* Marc.
Flora: *Lepidopteris ottonis* (Goepprte) Schimper
UGL – Upper Gypsum Level of the Upper Gypsum Keuper

The growing — from the cyclothem R I_2 — evolutionary transforming floral association, reaches its maximum at cyclothem RL and thereafter rapidly becomes extinct in the Liassic α.

The moment of extinction of this association was recognized by a number of Scandinavian authors as an upper boundary of the Rhaetian [2, 10, 15]. In Poland this view is shared by T. Marcinkiewicz, in results of her studies on megaspores [18].

Observations of plant hemeras in the whole of epicontinental Upper Triassic reveal that the development of flora begins usually below the sedimentary boundary of sediments, main intensification of the development falls to the transition between two lithostratigraphical units, and the occurrence of indicative flora still continues in the lowermost parts of the younger unit, already above sedimentary boundary.

Thus it may be assumed that, by analogy to older subdivisions, also this boundary based on floral indices may be located at the beginning of maximal development of floral association, i.e. between R III and RL and not at the moment of its final extinction, i.e. at the base of the *Thaumatopteris schenki* Zone.

DEPARTMENT OF GEOLOGY OF DEEP LOWLAND STRUCTURES, GEOLOGICAL INSTITUTE, WARSAW, RAKOWIECKA 4
(ZAKŁAD GEOLOGII STRUKTUR WGŁĘBNYCH NIŻU, INSTYTUT GEOLOGICZNY)

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В. Гродзицка-Шиманко, **Циклично-седиментационное подразделение рэта в пределах Польской низменности**

Содержание. В мелком эпиконтинентальном позднетриасовом бассейне, охватывающем значительную часть Польской низменности (фиг. 1), отмечаются очередные ингрессии, поступающие из альпийской геосинклинали. Одновременно происходила существенная и дифференцированная во времени палеотектоническая перестройка седиментационного бассейна. Циклические изменения диастрофизма отличались повсеместностью и хотя по содержанию не тождественные, они отразились в вертикальном изменении литологической последовательности отложений, сохраняя при этом выдержанность горизонтального распространения. Эти изменения привели к образованию локальных перерывов, особенно часто наблюдаемых в верхнем ярусе верхнего триаса, в рэте. Ритмически-циклическая последовательность морских и неморских отложений является основой детального стратиграфического подразделения, предлагаемого в настоящей работе для рэтских циклотем R I_{1-2} и R II_{1-2}. Литологические особенности отложений, их структурная позиция, развитие континентальной растительности (фиг. 3), характерное для переходных моментов в стратиграфии верхнего триаса, обусловливает проведение верхней границы рэта между циклотемами R III и RL.