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# PALAEOGEOGRAPHY AND LITHOLOGY OF THE VENDIAN AND CAMBRIAN OF THE WESTERN EAST-EUROPEAN PLATFORM

PUBLISHING HOUSE WYDAWNICTWA GEOLOGICZNE
WARSAW 1987

# PALAEOGEOGRAPHY AND LITHOLOGY OF THE VENDIAN AND CAMBRIAN OF THE WESTERN EAST-EUROPEAN PLATFORM

## CONTRIBUTION OF THE SOVIET-POLISH WORKING GROUP ON THE PRECAMBRIAN-CAMBRIAN BOUNDARY PROBLEM

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Editors of the English version:
Alexei Yu. ROZANOV (Palaeontological Institute
of the Academy of Sciences of the USSR)
Kazimierz ŁYDKA (University of Warsaw)

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Translated from Russian by Irina M. Bagaeva, K. Łydka, K. Jarmułowicz-Szulc, M. Wichrowska

Authors:
*B.M. Keller, A.Yu. Rozanov, K.A. Mens, N.M. Chumakov, V.Ya. Bessonova, V.A. Velikanov, V.V. Kirsanov, V.V. Kiryanov, A.P. Brangulis, T.V. Yankauskas, L.V. Korenchuk, K. Łydka, M. Juskowiakowa, M. Wichrowska, E.A. Pirrus*

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## FOREWORD

The present volume, the third in a series of monographs, is concerned with the palaeogeography and lithology of the Vendian and Cambrian of the western East-European Platform. The volume is an English version of the monograph published in Russian in 1980, with the only exception of the paper by K. Jaworowski. This edition is the result of co-operation between the Polish Academy of Sciences and the Academy of Sciences of the USSR.

The volume discusses the researches of the Polish-Soviet Working Group immediately involved in IGCP Project 29 "Precambrian – Cambrian Boundary" sponsored by IUGS – UNESCO. The Working Group comprised specialists from Warsaw University, the Estonian and Ukrainian SSR Academies of Sciences, Lit NIGRI, Bel. NIGRI, the Geological Survey of the Council of Ministers of the Latvian SSR, VNIGRI, the Geological Institute of the Polish Central Geological Survey, and the Geological Institute of the USSR Academy of Sciences.

Substantial new material has been accumulated since the appearance of the Russian version. However, this has not led to any significant changes in the basic conclusion or view approved by the Working Group and published in 1980. Thus the English edition is essentially an unaltered translation of the Russian text.

But account must be taken of the fact that today the majority of researches trace the Precambrian – Cambrian boundary above the top of the Rovno horizon (regional stage) due to its being the nearest to the bottom of the Tommotian stage, which marks the beginning of the Cambrian.

<table>
<tr><td rowspan="6">Cambrian</td><td>Middle</td><td>Amgian</td><td>Kibartu</td></tr>
<tr><td rowspan="5">Lower</td><td>Tojonian</td><td rowspan="2">Rausve</td></tr>
<tr><td>Botomian</td></tr>
<tr><td rowspan="2">Atdabanian</td><td>Vergale</td></tr>
<tr><td>Talsy = Dominopol</td></tr>
<tr><td>Tommotian</td><td>Lontova</td></tr>
<tr><td rowspan="3">Vendian</td><td rowspan="3">Upper Vendian</td><td>Nemakit-Daldynian</td><td>Rovno</td></tr>
<tr><td rowspan="2"></td><td>Kotlin</td></tr>
<tr><td>Redkino</td></tr>
</table>

To avoid misunderstanding, it should be made clear that the notion of a horizon most closely approximates the term "stage". Therefore some of the stratigraphic units are named in this volume interchangeably horizons or stages. Here belong the Redkino, Kotlin, Rovno, Lontova, Talsy,Vergale, Rausve, and Kibartu stages (horizons). A. Rozanov, B. Sokolov, M. Fedonkin and others, in describing the Vendian subdivisions, give preference to the term "stage".

In connection with discussing the stratigraphic units, we must apologize for an error on page 44 of Volume One of the series "Upper Precambrian and Cambrian Palaeontology of the East-European Platform". The true relationship between the stages and the horizons (regional stages) of the Lower Precambrian of the East--European Platform is shown in the table above:

The editors of the English edition gratefully acknowledge the co-operation of Dr Robert Riding and thank him for his carecritical review of the text and for many valuable comments.

Alexei Yu. Rozanov
Kazimierz Łydka

# PREFACE

The joint Polish-Soviet investigations of the Upper Precambrian and Cambrian deposits of the East-European Platform resulted in a new stratigraphic scheme for the Vendian and Lower Cambrian based on the vertical range of acritarch and other fossil assemblages which were studied in detail and described monographically. The results have already been published in two parts. One of them deals solely with paleontological problems and the other contains results of stratigraphic studies (Palaeontologia..., 1979; Stratigrafia..., 1979).

The recognition of minute stratigraphic units and their tracing over vast areas of the East-European Platform enabled the authors to compile litho-palaeogeographic maps for relatively small stratigraphic intervals. All in all, four maps were compiled for the Precambrian (Vilchany, Volhyn, Redkino, and Kotlin stages) and another four for the Cambrian (Rovno, Lontova, Talsy, and Vergale – Rausve stages. The available preliminary maps allow reconstruction of the entire evolution of an ancient Vendian – Cambrian basis on the East-European Platform and clarify ideas on the reorganization and changes which took place at the Precambrian/Cambrian boundary.

Models available for certain subregions were used as a basis for litho-palaeogeographic maps compiled by B. Areń, V.Ya. Bessonova, A.P. Brangulis, V.A. Velikanov, V.I. Vlasov, V.V. Kirsanov, V.V. Kirjanov, I.V. Klimovich, K. Lendzion, K.A. Mens, L.T. Pâskevičiene, E.A. Pirrus, L.V. Piskun, A.Yu. Rozanov, V.F. Sakalauskas, N.M. Chumakov, and T.V. Jankauskas.

The maps were edited by V.Ya. Bessonova, A.P. Brangulis, V.A. Velikanov, V.I. Vlasov, V.V. Kirsanov, V.V. Kirjanov, K.A. Mens, A.Yu. Rozanov, N.M. Chumakov, T.V. Jankauskas.

Though those who participated in the joint Polish-Soviet works were not going to thoroughly study the lithology of the Upper Precambrian and Cambrian deposits of the East-European Platform, the editors of this book decided that it would be reasonable to discuss some distinctive features and structures of sedimentary and volcano-sedimentary Vendian and Cambrian strata. Hence, a brief account of problems concerning the lithology of the Vendian and Cambrian deposits of the western East-European Platform is included. This section was written by V.A. Velikanov, M. Wichrowska, L.V. Korenchuk, K. Łydka, E.A. Pirrus, M. Juskowiakowa.

The present volume of the joint Polish-Soviet studies contains two parts: Part I deals with palaeogeographic problems and is supplemented by litho-palaeogeographic maps; Part II discusses the most important problems of the lithology of the sedimentary and volcano-sedimentary rocks.

PART I

# VENDIAN AND CAMBRIAN PALAEOGEOGRAPHY OF THE WESTERN EAST-EUROPEAN PLATFORM

## INTRODUCTION

This part is devoted to the palaeogeography during a certain length of time at the Cambrian/Precambrian boundary in the western East-European Platform.

To choose a length of time the authors started from the stratigraphic scheme of the Vendian and Cambrian deposits of the East-European Platform (Stratigrafia..., 1979), it was compiled by those who participated in joint works (Tables 1, 2).

Despite the fact that stratigraphy and lithology of Vendo-Cambrian deposits in the area discussed were not uniformly and often poorly known the data published in earlier monographs allow recognition in most subregions of the main stratigraphic units and, more or less accurate, outlining of their boundaries. In determining the extent of stratigraphic units used for litho-palaeogeographic maps, the most important is their correlation with the type sections. All of them are situated in the area discussed. The correlation of Late Vendian and Early Cambrian units was based mainly on palaeontological data controlled by lithological criteria which were decisive by the correlation of Early Vendian units.

The authors realize that this correlation may not be accurate enough for some parts of the section, however, a rather logic pattern of litho-palaeogeographic maps on the whole implies the absence of gross errors.

The proposed litho-palaeogeographic maps were developed mainly for the smallest stratigraphic units, i.e. horizons*. This principle applies well to the palaeogeography of the Cambrian and Precambrian boundary beds. As a rule, horizons coincide with natural changes in the geological development of a platform and hence reflect peculiar features and trends in the tectonic evolution of an area and associated sedimentation. Based on these principles, it became possible to single out four stages in the Vendian (in ascending order) viz., the Blon – Vilchany, Volhyn, Redkino, and Kotlin.

The Blon – Vilchany (Lower Drevlyany) Stage marked by continental glaciation terminates the pre-plate development of the East-European Platform, at least its western parts. The Volhyn (Upper Drevlyany) Stage is transitory in nature. It begins with the deposition of thick volcano-sedimentary strata in a number of depressions and terminates with the extension of sedimentary areas onto adjacent shields. It is associated with the beginning of a transgression which during the Late Vendian led to the appearance of extensive water basins and drastic decrease of shield area. This transgression gave rise to the formation of the Russian and Volhyn – Podolian plates of the East-European Platform. Using palaeontological data two stages were recognized in the Upper Vendian. Each stage is composed of typical

* Here horizon = regional stage.

Table 1

Stratigraphic chart for the Upper Precambrian of the Western East-European Platform

<table>
<tr><th rowspan="2">Horizon (after B. Areń, and B.M. Keller, cf. Stratigrafia, 1979)</th><th rowspan="2">Series</th><th colspan="3">Western slope of the Ukrainian crystalline shield</th><th colspan="2">Podlasie-Brest depression</th><th colspan="2" rowspan="2">Orsha depression and the Baltic shield and south-western Moscow Basin</th><th rowspan="2">Southern slope of the Baltic shield</th><th rowspan="2">Moscow Basin</th></tr>
<tr><th>Podolia</th><th>Volhynia</th><th>South-eastern Poland*</th><th>East-Poland*</th><th>South-western Byelorussia</th></tr>
<tr><td>Kotlin (Kanilovka)</td><td rowspan="4">Valdai</td><td>Kanilovka Formation</td><td>Kanilovka Formation</td><td>Białopole Formation</td><td>Siemiatycze Formation</td><td>Gdov Formation</td><td>Povorovo sub-Series</td><td></td><td>Kotlin Stage Gdov Formation</td><td>Voronka Fm<br>Reshma Fm<br>Kotlin (Lyubim) Fm</td></tr>
<tr><td rowspan="3">Redkino</td><td>Nagoryany Formation</td><td>Kolka Formation</td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3">Girsk Formation</td><td rowspan="3">Redkino sub-Series</td><td rowspan="3">Mezha Formation<br>Smolensk (Liozno) Formation</td><td rowspan="3"></td><td rowspan="3">Ust' Pinega Fm<br>Pletenevka Fm</td></tr>
<tr><td>Yaryshev Formation</td><td>Roznichi Formation</td></tr>
<tr><td>Mogilev Formation</td><td>Chartoryisk Formation</td></tr>
<tr><td rowspan="4">Drevlyany</td><td rowspan="2">Volhynia</td><td>Grushka Formation</td><td>Berestovtsy Formation</td><td rowspan="4">Sławatycze Formation</td><td rowspan="2">Sławatycze Formation</td><td rowspan="2">Rotai Formation</td><td colspan="2">Svisloch Formation</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td></td><td>Gorbashev Formation</td><td colspan="2"></td></tr>
<tr><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2">Brody Formation</td><td rowspan="2"></td><td rowspan="2">Gorbashev Formation</td><td rowspan="3">Charcta Series</td><td>Vilchany Stage</td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td>Blon Stage</td></tr>
<tr><td>Kudash</td><td></td><td></td><td></td><td></td><td></td><td></td><td>Lapichi (Osipovichi) Formation</td></tr>
</table>

* Edit.-note. Some Polish authors actually use a different scheme of correlation.

Table 2

Correlation of Lower Cambrian sections of the East European Platform as accepted by the Polish-Soviet Working Group in Tallin (1974) and modified in Minsk (1975) and Moscow (1976)

| Holy Cross Mts* | | East Poland* | | Ukraine | Brest Depression | vil. Łeba North Poland* | Stage | Baltic Basin: North Poland* | Baltic Basin: Lithuania | Baltic Basin: Latvia | Baltic Basin: Estonia | East Estonia | Leningrad Region | Moscow (central) Basin | East Lithuania Byelorussia | East Latvia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $E_2$ | | $E_2$ | | $E_2$-$E_3$ | $E_2$-$E_3$ | $E_2$ | $E_2$ Kibartai | $E_2$ | Kibartai Formation 1 | | | | | $E_2$-$E_3$ | | |
| Proto-lenus | Kamieniec | Protolenus | Radzyn ■ | Switjas ■ | Equivalents of Switjas | Holmia | $E_1$ Rausve | Protolenus ■ | Virbalis Formation ■ | Tebra Formation ■ | Kurzeme | | | | | Cirma ■ |
| Holmia *B* Ⓣ | Klimontów | Holmia | Radzyn Ⓣ ▲ | ▲ Ⓣ Lyuboml | Equivalents of Switjas | Holmia | $E_1$ Vergale | Holmia *B* ▲ | Gёge Formation | Tebra Formation ▲ Ⓣ | Kurzeme | | Izhora ▲ | "Izhora" ? | Lakajai ▲ | ▲ |
| Holmia *A* △ | Gieraszowice | Holmia | Kaplonosy △ | Domino-pol △ | Equivalents of Domino-pol | Holmia | Talsy (Lůkati) $E_1$ | Holmia *A* | | 2 Venta Fm △ | Tiskre Lůkati | △ △ | | | | |
| Sub-Holmia | Gieraszowice | Mobergella | Zawi-szyn | | | Mobergella Beds | Talsy (Lůkati) $E_1$ | Holmia *A* | | 3 Ovishi Formation △ | Syru Formation | | | Glebovo Beds ⊕ | | |
| Sub-Holmia | Bazów | Platysole-nites | Mazowsze Beds ⊕ | Stokhod Zbruch ⊕ | Equivalents of Stokhod ⊕ | Żarno-wiec | $E_1$ Lontova | Holmia *A* | | | | Lontova Stage ⊕ | ⊕ Lontova Stage | Lezha Formation ⊕ | Alunta Formation ⊕ | Lontova Stage ⊕• |
| Sub-Holmia | Jasień | Sabellidites | Mazowsze Beds ○ | Rovno, Khmelni-tski ○ | Equivalents of Rovno | Żarno-wiec | Rovno | Holmia *A* | | | | | Lontova Stage | Rusonovo Beds ○, Danilov Beds ○ | Rudamina Formation ○ | Equivalents of Rovno Stage ○ |
| | Kotuszów | Lublin | | Kanilovka | | | Kotlin | | | | | Voronka Kotlin | | Seliger | Vilkiskiai | Voronka Kotlin |

*Edit.-note. Some Polish authors actually use a different scheme of correlation.

○ - acritarch of the Rovno Stage; ⊕ - acritarch of the Lontova Stage; △ - acritarch of the Talsy (Lůkati) Stage; ▲ - acritarch of the Vergale Stage; ■ - acritarch of the Rausve Stage; Ⓣ - trilobites Strinuaeva primaeva; 1 - Kibartai unit; 2 - Saka unit; 3 - Durben unit.

formations reflecting a sedimentary pattern, respectively, in the Redkino and Kotlin basins.

In the Early Cambrian – when normal marine sedimentary environment dominated the entire area – four stratigraphic intervals (in ascending order) were recognized as well, namely, the Rovno, Lontova, Talsy, and Vergale – Rausve, all of them but the latter correspond to stages of the same name. It is difficult to propose a litho-stratigraphic standart for the Vergale and Rausve Stage, because their deposits being poorly known biostratigraphically, do not allow tracing of the boundary of the stages over the entire area disscussed. In particular it concerns uniform sand-silty deposits in the near-shore facies.

The litho-palaeogeographic maps presented here follow in general the technique used in the "Atlas of litho-palaeogeographic maps" (Palaeogeografia SSSR, t. 1, 1974), however, types of deposits are given in a more general way because our work was aimed at the recognition of common features in development of the area in question with special reference to sedimentary basins in the Late Precambrian and the Early Cambrian. The palaeontological and mineralogical data are presented to characterize fossil assemblages and lithogenic environments of each facies zone in general.

## DREVLYANY SERIES

It should be remembered that the Drevlyany Series (Drevlyany Series of I.E. Postnikova) or Lower Vendian of some authors includes the Blon – Vilchany, and Volhyn deposits in the western East-European Platform. On ths basis of the decisions accepted at the meeting in Ufa in 1977 these deposits were placed into the Vendian though many scientists including some participated in the Polish-Soviet works consider that the Vendian should be restricted to the Valdai Series. As to the Drevlyany Series represented by rather diverse rocks two litho-palaeogeographic maps were compiled, viz., one for Blon and Vilchany and the other for Volhyn Stages.

### BLON AND VILCHANY STAGES

The Blon and Vilchany Stages starting the Vendian in the western East-European Platform are represented by very diverse terrigenous rocks dominated by different continental glacial deposits. At present they occur mainly within the ancient Riphean Volhyn-Orsha Basin (Fig. 1). Their distribution pattern suggest that at the time of their deposition and some time after the deposition of the formation discussed, the Volhyn-Orsha Basin continued to subside, though tectonically it was not such an active structure as in the Riphean.

The Blon Stage occupies a limited area within the southern Orsha Basin and shows a great variability in thickness (0 to 200 m), partly due to continental sedimentary conditions but mainly due to intense denudation in pre-Vilchany and Vilchany time. Evidence of erosion is found at the top of the Blon Formation in the form of dissected buried relief (Kozhemyakina and Chumakov, 1969).

The Vilchany Stage covering almost the entire area of the Orsha and partly Volhyn Basins shows a much wider distribution than that of the Blon Stage. Such a difference in the area of distribution is typical of continental deposits of early and late stages of a glacial period. The Vilchany Stage attains the greatest thickness (about 300 m) in the southern Orsha depression in about the same district where the Blon Stage occurs (see Fig. 1). Like the Blon Stage the thickness of the Vilchany Stage changes over a short distance. Therefore isopachs shown on the

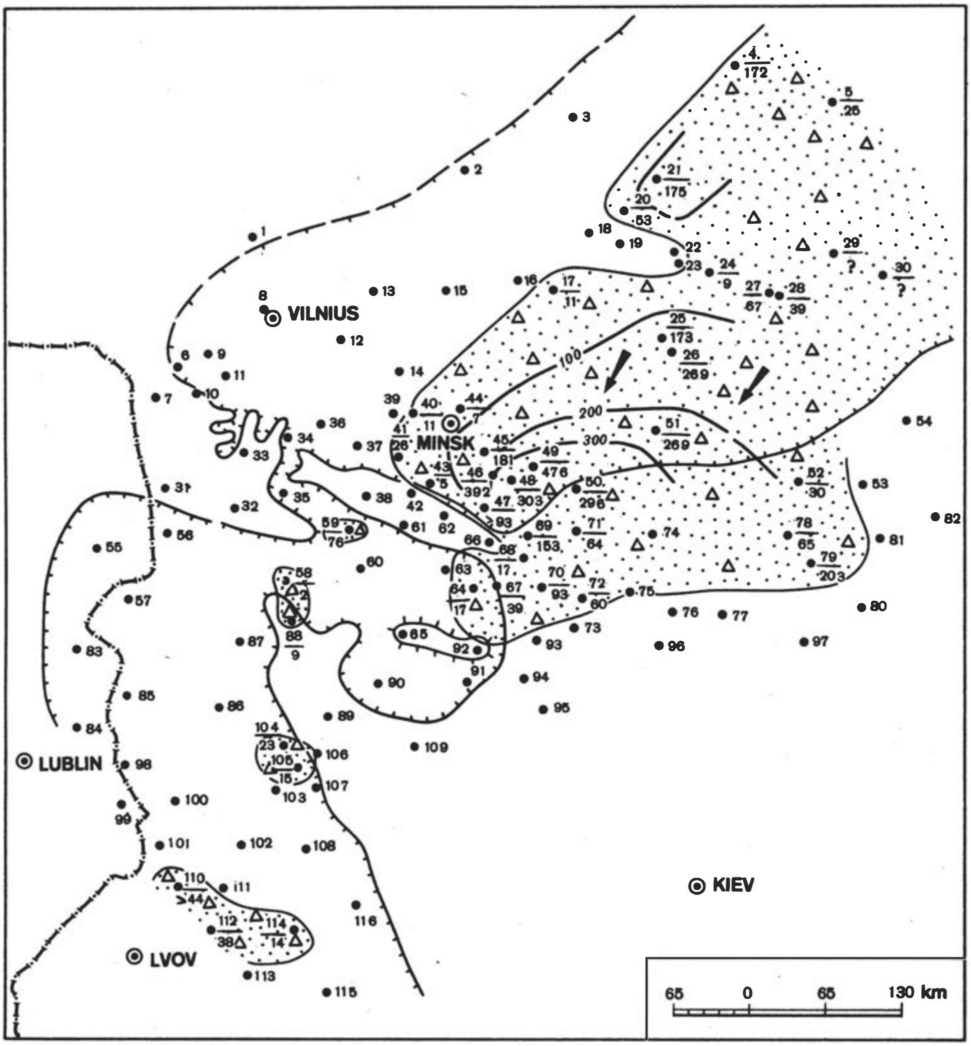



Fig. 1. Litho-palaeogeographic map. Blon and Vilchany Stage Compiled by N.M. Chumakov from data of B. Areń, N.V. Veretennikov, A.S. Makhnach, V.I. Shkuratov

For legend see Fig. 3. Boreholes: *1* – Ukmyarge, *2* – Drissa, *3* – Nevel, *4* – Toropets, *5* – Nelidovo, *6* – Ilgai, *7* – Druskininkai, *8* – Vilnius, *9* – hole 49, *10* – hole 62, *11* – Pavyarsyakis, *12* – Smorogon, *13* – Kupa, *14* – Krasnoe, *15* – Dokshitsy, *16* – Lepel, *17* – Chashniki, *18* – Shumilino, *19* – Letsy, *20* – Gorodok, *21* – Mezha, *22* – Bogushevsk, *23* – Bogushevsk (Liozno), *24* – Rudnya, *25* – Orsha-1, *26* – Orsha-2, *27* – Smolensk-1, *28* – Smolensk-2, *29* – Yartsevo, *30* – Dorogobuzh, *31* – hole 28, *32* – hole 15 of Sloninsk field party, *33* – hole 44 of Lida field party, *34* – hole 18 of Lida field party, *35* – hole 39 of Lida field party, *36* – hole 7 of Stolbtsy field party, *37* – hole 8 of Stolbtsy field party, *38* – hole 9 of Baranovichi field party, *39* – Aksakovshchina, *40* – Zaslavl, *41* – Noreika, *42* – hole 31 of Minsk field party, *43* – Khotlyany, *44* – Gorodishche, *45* – Sitniki, *46* – Blon, *47* – Zhilin Brod, *48* – Osipovichi-4, *49* – Osipovichi-14, *50* – Klichev, *51* – Vilnitsy, *52* – Kostyukovichi, *53* – Shirkovka, *54* – Rognedino, *55* – Rajsk, *56* – Svisloch, *57* – hole 27 of Brest field party, *58* – hole 14 of Slonimsk field party, *59* – hole 3 of Kirov expedition, *60* – hole 13 of Kirov expedition, *61* – hole 19 of Baranovichi field party, *62* – Gresk, *63* – Starobin, *64* – Novaya Dubrovka, *65* – hole 42, *66* – Solon, *67* – Lyuban, *68* – Glussk (371 k), *69* – Simonovichi, *70* – Borisovskaya 5p, *71* – Bobruisk, *72* – Visha, *73* – Domanovichi, *74* – Rogachev, *75* – Berezinskaya, *76* – Khotetskaya, *77* – Gomel, *78* – Strugova Buda, *79* – Klintsy, *80* – Ponurovka, *81* – Pochep, *82* – Vygonitsi, *83* – Biała Podlaska, *84* – Krowie Bagno, *85* – hole 9 of Brest field party, *86* – hole 5, *87* – Dragochin, *88* – Motol, *89* – hole 21, *90* – Stolin, *91* – Turov Op, *92* – Zhidkovichi, *93* – Kopotkevichi, *94* – Skolodin, *95* – Zaozernaya, *96* – Regitskaya, *97* – Chelkov, *98* – Berezhtsy, *99* – Białopole, *100* – Ovadno, *101* – Litovezh, *102* – Lutsk, *103* – Kolki, *104* – hole 231, *105* – hole 4p, *106* – hole 200, *107* – hole 110, *108* – hole 350, *109* – hole 3239, *110* – Novo-Vitkov 3p, *111* – Berestechko, *112* – Brody, *113* – Zalozhtsy, *114* – Kremenets, *115* – Kurilovka 16945, *116* – hole 197 map reflect only a general trend in distribution of thicknesses of deposits discussed. On the flanks of the Orsha Basin the Vilchany Stage rapidly thins out and its thickness along margins of the Byelorussia-Baltic and Sarmatian shields does not exceed several meters or wedges out at all. However the thickness changes gradually along the axis of the Orsha Basin. It implies that a thickness and structure, as shown elsewhere (Bessonova and Chumakov, 1969), of the Vilchany Stage to a greater degree were determined by the tectonic regime of the area. Such a situation is rather paradoxical when continental glacial deposits are considered. However, it was repeatedly mentioned in the case of Pleistocene glacial deposits (Moskvitin, 1938; Tsapenko and Makhnach, 1959 and others).

The present limits of the Vilchany Stage cannot be considered as original being mainly erosional contacts. The south-eastern boundary within the Orsha Basin has undoubtedly resulted from a pre-Devonian erosion. This is evidenced from the Devonian deposits onlapping older Vendian and Riphean horizons in a south--eastern direction. Apparently at that time erosie contact of the Vilchany Stage came into being on the flanks of the Morin-Bobovyany uplift. There are some reasons to suggest that other contacts of the Vilchany Stage are also erosional and were caused by the removal of initially continuous cover of the Vilchany deposits during continental non-deposition which preceded the Svisloch Formation (Stratigrafia..., 1979). This is suggested by isolated patches of glacial deposits preserved under the deposits of the Svisloch Formation on the continuation of the main Vilchany terrane in the Polesie depression and Volhyn basin (Veretennikov *et al.*, 1972; Makhnach *et al.*, 1976). The fact that the Vilchany Stage contains continental glacial (Chumakov, 1971; Makhnach *et al.*, 1976) also suggests that initially they formed a continuous cover over extensive areas.

The data on distribution of the Vilchany and Blon Stages and their thicknesses allow the conclusion that their preservation is in places of the greatest original thickness and least subsequent erosion.

The formations are dominated by till and tillite as well as sandstone and sand, end minor clay-silty rocks and pebbles. The lithology of these deposits was described in detail elsewhere (Bessonova and Chumakov, 1968, 1969; Verstennikov, 1968; Makhnach *et al.*, 1976; Chumakov, 1978). Massive red-brown, grey or mottled till and tillite whose individual beds in the Vilchany Formation are 150 m thick account for 10% to 90% of the succession discussed.

They consist mainly of clay-silt-sandy rocks with scattered clasts (2% to 15%) of crystalline basement and Riphean sedimentary rocks ranging in size from gravel to boulders 40–70 cm in diameter. The rocks are poorly sorted (Trask sorting coefficient is 3.3 to 18 and in 75% of cases exceeds 6) and characterized by multi-mode grain-size distribution histograms (Bessonova and Chumakov, 1969; Chumakov, 1978). Apart from oligo- and mesomictic fine sand and silt fractions, clay matter forms an important part of till and tillite (in the Vilchany Stage especially). It amounts to 6–40% and is represented mainly by randomly oriented trioctahedral hydromica and admixture of other clay minerals implying a slight reworking in the course of transport and sedimentation.

No indications of some regular differentiation in till and tillite structure within the Orsha depression were found except for a slight increase in clay content of the Vilchany till in the south-western part of the depression. However, feldspar clasts become more abundant among silt-till. These changes go along with an increase in clay and feldspar content in rocks of the bed and suggest that glaciers had accumulated rocks over which they moved (Bessonova and Chumakov, 1969). It is evident also from the high content of medium- and well rounded quartz grains in till of the Blon and lower Vilchany Stages. The presence of grains with rounded regeneration rims points directly to transport from the Riphean Orsha Formation underlying glacial deposits over most of the Orsha Basin. Such processes as assimilation and mechanical transport of inhomogeneous sedimentary material of the bed operating by glacial movement may well explain the polymodal pattern of histograms of till and tillite grain size distribution. Their original red coloration inherited from the Riphean deposits is also largely due to assimilation (Chumakov, 1978). Grey colour of till and tillite is mainly a secondary phenomenon, this is well exemplified by mottled varieties of these rocks. Grey spots occur in till and tillite in the form of veins along joints and sandy bands, and rims around pebbles. Small grey spherical scattered spots are attributed to reductive effect of bacteria colonies while veins, bands and large mottles are due to ground water.

Most boulders in till and tillite are poorly rounded (roundness value of 1–2 on the A.V. Khabakov scale). There are some well- rounded pebbles broken with traces of a eolian weathering. On flattened and slightly polished faces of schist clasts one can see fine longitudinal striations, which are subparaller or cross at a low angle, rather similar to glacial scoring (Bessonova and Chumakov, 1968). Clasts of crystalline rocks in the Vilchany and Blon Stages in most of the Orsha Basin are erratic because at the time of their deposition the basement within the Orsha, Krestsy, and Klintsy Basins had a sedimentary cover. Erratics are mainly fragments of Riphean orange-coloured quartzite sandstone forming most of boulders in till and tillite. These specific rocks are known from north-eastern Byelorussia and they crop out on the pre-glacial surface outside the area. This allows us to establish, first, that quartzite fragments were transported for some 100–200 km within the southern and central part of the Orsha Basin, and, second, that glaciers moved from north-east to south-west.

The glacial deposits discussed are very impersistent along strike. Often it is difficult to compare two borehole sections spaced at several kilometres. Thickness of beds and units changes over short distance; some of them wedge out and often new ones appear.

Sands and subordinate sandstones and pebble gravel account for 5% to 85% and 70% to 90% of the Vilchany and Blon sections, respectively. Fluvio-glacial, limnoglacial, deltaic, and a eolian varieties could be present as well (Bessonova and Chumakov, 1969). Clay-silty rocks are minor in the deposits discussed. The most common are thinly and rhythmically bedded formations of the Pleistocene glacial varva type. They often contain coarser material such as fallen boulders accompanied by typical deformations and bedding joints in underlying and envelopping structures in overlying beds.

The absence of any indications of mechanical sorting in till and tillite both in sections and over the area; slight mechanical and chemical transformation of their constituent matter; the presence of large striated erratic and fallen boulders; association with varves and structures very similar to those of cryoturbation (Chumakov, 1978) – all this, if wide distribution and almost horizontal bedding of the deposits are allowed for points to a glacial origin of the Blon and Vilchany Stages. The latter two features as well as unconformities and locally buried relief at the base and top of the Blon and Vilchany Stages, obvious evidence of assimilation of sea-floor rocks, strong variability of deposits along the strike, association of till and tillite with periglacial deposits and local dislocations at the base of tillite (Bessonova and Chumakov, 1969) suggest that glaciations corresponding to the Blon and Vilchany Stages were continental in nature.

The presence of glacial deposits in two uncomfortable formations and numerous individual till and tillite units and beds as well as differences in composition imply multiple glaciations with complex history and hence two steps can be recognized, viz., Blon and Vilchany, the latter being younger.

Glaciations in western areas of the European Platform form a part of a major glacial event which at the beginning of Vendian time covered Europe and regions adjacent to the North Atlantic, as well as Africa, Australia, and Asia. This event known as the Lapland glacial period (Chumakov, 1971, 1974, 1978) took place 630 – 650 Ma ago (based on old constans K decay is 650 – 670 m.y.). This glaciation covered much of the ancient Fenno-Sarmatian continent which occupied most of the European Platform. In the centre of the continent (western regions of the European Platform, Ladoga Lake depression, Pachelma trough, interior parts of Scandinavia) glaciations were continental, while around the periphery (outer regions of Scandinavia, Polyud Range) they acquired a shelf pattern. A reconstruction of the Lapland ice sheet shows the motion of glaciers from the centres of glaciation somewhere in the north-eastern Fenno-Sarmatian continent in different directions and south-eastward towards the Orsha and Volhyn Basins (Chumakov, 1971, 1978).

## VOLHYN STAGE

Volcanic, sedimentary-volcanic, and sedimentary deposits of the Volhyn Stage are more common than glacial deposits of the Blon and even Vilchany Formations (Fig. 2, inset). Present limits of the Volhyn Stage* are very complex in outline due to subsequent uplift and erosion which is mainly pre-Devonian within the Pripyat Basin and Polesie saddle. The existing parts of the series allow as to conclude that once it filled-in the Volhyn-Orsha Basin where it had greatest thickness (50 – 500 m) and in places thin sediments (< 50 m) covered also margins of the bordering Byelorussian-Baltic and Sarmatian shields. This implies that in Volhyn time the Volhyn-Orsha Basin continued to develop intensely especially in the southern, Volhyn, part- the area of strongest downwarping with centres of intense volcanic activity. It widened considerably north-westward at the expense of the Podlasie-Brest depression. A displacement during this time of the centre of the greatest downwarping south-westward follows a trend in the development of the Volhyn-Orsha Basin started at the close of the Riphean and beginning of the Vendian. An original south-eastern boundary of the Volhyn sedimentary basin was eroded and if exists at all (See Fig. 2). Only to the north-east, in the Smolensk Region (Roslavl borehole) and in the extreme south-east, in Podolian and Moldavia, particularly along the Dniester River, there are coarse clastic facies of the Volhyn deposits marking the north-eastern and south-eastern margins of the basin. They are also common in the north-western part of the Volhyn deposits distribution in Smolensk, Kalinin, Pskov Regions, in North West Byelorussia and East Lithuania outlining partly the north-eastern boundary of the sedimentary area. Farther south deposits of marginal parts of the Volhyn Basin are eroded.

Sedimentary environments and palaeogeography of Volhyn time were very complex and diverse in the area discussed. As a first approximation we can recognize three areas of sedimentation and three corresponding types of palaeogeographic environments, i.e. a) volcanic area; b) area where sedimentation involved pyro-

* In the present work the Volhyn Stage includes the Gorbashev, Berestovtsy (= Rotaichitsy), Sławatycze, Svisloch, Grushka, and the base of the Chartoryisk Formations (Stratigrafia..., 1979).

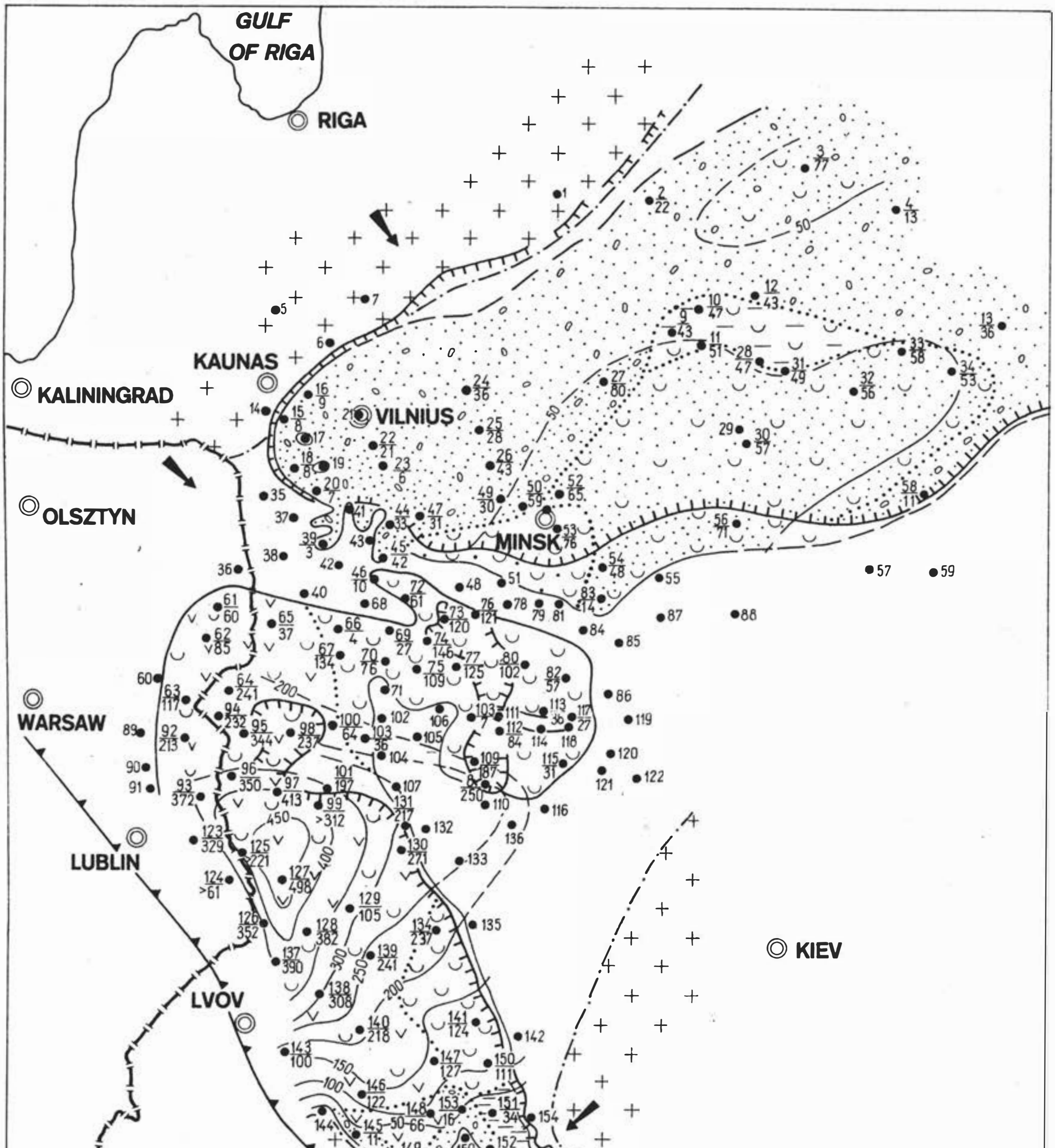
clastic material supplied from volcanic area; and c) area where supply of pyroclastic material was unimportant or absent.

A type locality of the Volhyn Series, as well as south-western Byelorussia and East Poland was a typical area of trappean volcanism. Cross-bedded sands and red siltstones of the Gorbashev Formation representing apparently fluvial and proluvial deposits accumulated first on the hilly moraine plain. Then (judging from the appearance of ash in the section as early as Gorbashev time) volcanoes began to form. At the beginning of Berestovtsy time they erupted a great amount of basic pyroclastics which accumulated over the entire territory discussed. Explosive eruption alternated with basalt extrusion. The amount and extent of the latter increased with time and locally (western and north-western parts of the region) plateau-basalts were formed. An extensive distribution of plateau-basalts implies that volcanism of the central type was replaced mainly by fissure-volcanism. At the same time the volcanic area expanded and eruption of basalt lava began on the Podolia-Moldavian margin of the basin where earlier only eluvial-colluvial-proluvial deposits of the lower Grushka Formation accumulated (Velikanov, 1976). The composition of the volcanics also changed. South--western Byelorussia in the Brest depression, during middle Berestovtsy (Rotaichitsy) time, witnessed the eruption of andesite-dacite and trachyrhyolite tuffs and lavas. These are suggested to "result from differentiation of basalt magma and its contamination by upper lithosphere rocks"... (Makhnach *et al.* 1976, p. 305).

The volcanic area had a very complex palaeogeography. Apart from plateau--basalt and volcanic mountains there could be numerous valleys and depressions occupied by shallow reservoirs. Some of them were rather large and formed marine basins with volcanic islands developed from the east and north-east into the volcanic area. Basalt flows coming into the basin or erupted on the floor acquired a spilitic pattern. The presence of palagonite basalts rich in zeolites might imply that show and ice caps covered the summits of volcanic mountains (Makhnach *et al.*, 1976). The emplacement of volcanic rocks was accompanied by their intense erosion and redeposition of the sedimentary products in lows at the foot of volcanic mountains. Partly volcanomictic material was discharged by rivers and marine currents outside the volcanic area and deposited in adjacent basins.

The increasing role of volcanomictic rocks in the upper Berestovtsy Formation and especially at the base of the Chartoryisk Formation suggests the decline in volcanic activity at that time and increase of erosion.

Tuff, tuffite, and tufogenic terrain adjoins the volcanic area to the east and north-east. It embraces south-eastern Volhyn and southern, central, and eastern Byelorussia (Polesie depression, southern and central slopes of the Byelorussian uplift, part of the Orsha Basin). The thickness of the Volhyn Series in this area is less than in the volcanic area. Besides, it markedly decreases away from the volcanic centres south-eastward and north-westward (from 200–150 to 100–50 m) which is typical of pyroclastic rocks. Sedimentary conditions in this area are discussed in more detail. Within Byelorussia the deposition of the Volhyn Series seems to have begun later than in the volcanic area because andesite--dacite fragments occur, starting from the base of the Svisloch Formation. The latter consists of variegated tuffites and tuffs (mainly psamitic) interbedded with polymictic and rare arkose sandstones, mudstones, and micaceous clays. These rocks are often tufogenic. Rather persistent sections of the formation, fine horizontal bedding in clays, mudstones and fine crose bedding in sandstones suggest a deposition in an extensive water basin, apparently marine basin.


GULF OF RIGA
RIGA
KAUNAS
KALININGRAD
VILNIUS
OLSZTYN
MINSK
WARSAW
LUBLIN
KIEV
LVOV
CHERNOVTSY
KISHINEV
50 0 50 100 km

Pyroclastic and volcanomictic material supplied into the basin was spread by currents and wave action across much of its area. Besides, destruction products of shield crystalline rocks, locally coarse-grained, were brought from land surrounding the Volhyn Basin. The well preserved original angular shape of the pyroclastic material suggests that it was mainly supplied to the basin through the atmosphere in the form of volcanic ash. An asymmetric pattern of the tuff, tuffite, and tufogenic rock zone, developed only to the east and north-east of volcanic centres, suggests the predominance here in Volhyn time of south-western and western winds which transported ash northward and eastward.

The proportion of pyroclastic material and its grain size in rocks of the Svisloch Formation gradually decreases north-eastward along the axis of the Orsha Basin. In the central Orsha Basin there are tufogenic bands while farther north-east pyroclastics occur only as admixture. The proportion of pyroclastics drastically decreases towards the flank of the Volhyn Basin. This can be attributed to the obscuring effect of a relatively intense supply of terrigenous material within

Fig. 2. Litho-palaeogeographic map. Volyn Stage Compiled by N.M. Chumakov, V.Ya., Velikanov, B.I. Vlasov from data of B. Areń, V.Ya. Bessonova, N.V. Veretennikov, I.V. Klimovich, K. Lendzion, A.S. Maknach, V.F. Sakalauskas, V.I. Shkuratov

For legend see Fig. 3. Boreholes: *1* – Ludza, *2* – Pustoshka, *3* – Toropets, *4* – Nelidovo, *5* – Central Lithuania (Tsentralnaya Litva), *6* – East Lithuania (Vostochnaya Litva), *7* – North-eastern Lithuania (Severo-Vostochnaya Litva), *8* – Stolino, *9* – Shumilino, *10* – Gorodok, *11* – Letsy, *12* – Mezha, *13* – Vyazma, *14* – Prenai, *15* – hole 46, *16* – Paukshchei, *17* – hole 49, *18* – hole 60, *19* – hole 59, *20* – hole 63, *21* – Vilnius, *22* – Vilkishkyai, *23* – hole 75, *24* – Kupa, *25* – Kurinets, *26* – Krasnoe, *27* – Lepel, *28* – Bogushevsk, *29* – Orsha-1, *30* – Orsha-2, *31* – Rudnya, *32* – Smolensk, *33* – Yartsevo, *34* – Dorogobuzh, *35* – Druskininkai, *36* – Sokółka, *37* – hole 15 of Shuchin field party, *38* – hole 25 of Shuchin field party, *39* – hole 18 of Shuchin field party, *40* – Gritski, *41* – hole 9 of Lida field party, *42* – hole 46 of Lida field party, *43* – hole 19 of Lida field party, *44* – hole 13 of Lida field party, *45* – hole 29 of Lida field party, *46* – hole 39 of Lida field party, *47* – hole 7 of Stolbovo field party, *48* – hole 9 of Baranovichi field party, *49* – Zaslavl, *50* – Minsk, *51* – hole 33 of Minsk field party, *52* – Smolevichi, *53* – Smilovichi, *54* – Lapichi, *55* – Klichev, *56* – Vilchitsy, *57* – Kostyukovichi, *58* – Roslavl, *59* – Shirkovka, *60* – Stadniki, *61* – Tatarowce, *62* – Rajsk, *63* – Mielnik, *64* – hole 27 of Brest field party, *65* – Svisloch, *66* – hole 35 of Slonimsk field party, *67* – hole 28 of Slonimsk field party, *68* – hole 44 of Slonimsk field party, *69* – hole 33 of Slonimsk field party, *70* – hole 14 of Slonimsk field party, *71* – Kaziki, *72* – hole 1 of Slonimsk field party, *73* – hole 2 of Kirov expedition, *74* – hole 12 of Kirov expedition, *75* – hole 10 of Baranovichi field party, *76* – hole 195 of Baranovichi field party, *77* – hole 13 of Kirov expedition, *78* – hole 336, *79* – Gresk, *80* – Starobin, *81* – Zhlobin, *82* – Nizhnyaya Dubrovka, *83* – Daraganovo, *84* – Solon, *85* – Glussk, *86* – Chervonnaya Sloboda, *87* – Bobruisk, *88* – Rogachev, *89* – Zambrów, *90* – Radzyń, *91* – Parczew, *92* – Biała Podlaska, *93* – Kaplonosy, *94* – Kustinsk, *95* – hole 11 of Brest field party, *96* – hole 9 of Brest field party, *97* – hole 1 of Brest field party, *98* – hole 6 of Brest field party, *99* – hole 4cn of Lvov expedition, *100* – Dragonin, *101* – hole 37 of Lvov expedition, *102* – Dostoevo, *103* – Ivanovo, *104* – Makhro, *105* – Pinsk, *106* – Bogdanovka, *107* – hole 67 of Lvov expedition, *108* – Luchinets, *109* – Stolin, *110* – hole 1507, *111* – hole 42 of Geological Survey of the BSSR, *112* – hole 31 of Geological Survey of the BSSR, *113* – hole 08 of Geological Survey of the BSSR, *114* – hole 204, *115* – Turov, key hole, *116* – hole 119, *117* – hole 384 of Geological Survey of the BSSR, *118* – hole 380 of Geological Survey of the BSSR, *119* – Kopotkevichi, *120* – Sklodin, *121* – Buinovichi, *122* – Zaozernaya 5p, *123* – Busówno, *124* – Białopole, *125* – Berezhtsy, *126* – Litovezh, *127* – Ovadno, *128* – Gorokhov, *129* – Lutsk, *130* – hole 270 of Lvov expedition, *131* – hole 206 of Lvov expedition, *132* – hole 160 of Lvov expedition, *133* – hole 135 of Lvov expedition, *134* – hole 2G of Lvov expedition, 135 – hole 147 of Lvov expedition, *136* – hole 3239 of Hydrogeological party, *137* – Novo-Vitkov, *138* – Brody, *139* – Pelga, *140* – Zalozhtsy, *141* – hole 126612 of the Bug River area expedition, *142* – hole 18220 of the Bug River area expedition, *143* – Peremyshlyany, *144* – Zavadovka, *145* – Bugach, *146* – Khmelevka, *147* – hole 16944 of the Bug River area expedition, *148* – hole 16901 of the Bug River area expedition, *149* – hole 16905 of the Bug River area expedition, *150* – hole 12606 of the Bug River expedition, *151* – hole 11659 of the Bug River area expedition, *152* – hole 14794 of the Bug River area expedition, *153* – hole 16922 of the Bug River area expedition, *154* – hole 3351 of the Bug River area expedition, *155* – Chernovtsy, *156* – hole 17643 of the Bug River area expedition, *157* – Vysshee Olchedaevo village, *158* – hole 14769 of Geological Survey of Moldavian SSR, *159* – hole 16933 of the Bug River area expedition, *160* – hole 101 of Soroksk field party, *161* – Grushka village, *162* – hole 213 of Geological Survey of Moldavian SSR, *163* – hole 536 of Geological Survey of Moldavian SSR, *164* – hole 542 of Geological Survey of Moldavian SSR, *165* – hole 12 of Prichernomorie (Black Sea) expedition, *166* – hole 160 of Soroksk field party, *167* – hole 4 of Geological Survey of Moldavian SSR, *168* – hole 1 of Prichernomorie (Black Sea) field party these zones. This allows the recognition a sedimentary terrane of the Volhyn Series around the periphery of the tuff terrane. The former is dominated by relativaly coarse-grained red-beds. The accumulation of these deposits apparently took place in subaerial environments and, locally, in the near-shore parts of the marine basin. Along the north-western boundary of the Volhyn deposits in East Lithuania the Myarkis Formation, assigne to the Volhyn Stage, forms a thin discontinuous cover on the crystalline basement, mainly infilling erosional depressions. The formation is made up of poorly sorted coarse-grained so-called "fanglomerates" (Sakalauskas, 1968a). The composition and mode of occurrence of the Myarkis Formation suggest that it, like the above mentioned lower Grushka Formation of Podolia and Moldavia, is built up of continental eluvial, colluvial, proluvial, and partly hydrogenic deposits.

Volhyn time witnessed the termination of the early period in Vendian history of the East-European Platform marked, like its Riphean Stages, by the development of linear depressions and extensive shields. A general high elevation of the platform during the stage considered here gave rise to the wide development of landforms and continental deposits which were replaced by marine environments and sediments only at the end of the stage. In this respect the Late Volhyn Stage can be considered as the transition to a subsequent Late Vendian (Valdai) change in the history of the platform, marked by a quite different tectonic regime and palaeogeographic conditions, i.e. emplacement of syneclizes and predominance of marine basins.

## VALDAI SERIES

The Valdai Series marks the beginning of an important new step in the development of the East-European Platform. Its principal characteristic feature is an extensive marine transgression which resulted in a considerable extension of the sedimentary area. A rearrangement of the structural framework of the platform, which led to the formation of the extensive Moscow Basin of north--eastern and sublatitudinal strike, is related to the Baikalian tectonic movements at the beginning of the Valdai. There are published data (Bruns, 1963, 1964; Keller, 1968; Yakobson, 1966) showing that in the western East-European Platform the rearrangement gave rise to a crucial change in structural strike. The maps compiled by the authors suggest that mainly they are inherited in nature.

Comparison of litho-palaeogeographic environments of Blon – Vilchany, Volhyn and Redkino Stage reveals a successive pattern and one can see certain phases in their change which gradually led to the formation of an extensive epicontinental basin. The basin was bounded by low-lying emergences of Baltic, Sarmatian and Byelorussia – Mazury islands situated in place of uplifted parts of the East-European Platform basement.

Within the present structural framework the Valdai deposits form two isolated terranes. The northern terrance embraces the Moscow Basin and is superimposed on slopes of ancient shields; the southern terrane coincides with the Kishinev – Lvov trough and the Podlasie-Brest depression, Between the two main terranes of the Valdai Series there are isolated outcrops near the Kletsk – Stolin trough. The absence of the Valdai rocks from the Polesie depression implies their subsequent erosion (Aizenberg *et al.*, 1975).

Thus, the Valdai structural rearrangements resulted in the formation of an extensive epicontinental marine basin (Keller, 1968, 1973; Keller *et al.*, 1974;

Bruns, 1963, 1964) with mainly terrigenous sedimentation. It graded into limited shallow areas and formed alluvial plains. Such a structural-facies zone was situated west and south-west of the Chashniki buried fault zone where near-shore plain and continental red coarse-grained and sild-sandy facies formed throughout the Valdai step. Only during the periods of maximum transgression were they covered by waters of the marine basin.

The accumulation during the Valdai step of terrigenous rhytmic successions of widely similar structure and facies suggests a single morphological environment over vast areas of the East-European Platform. Its main features are discussed in the following sections.

## REDKINO STAGE

At the very beginning of the Redkino Stage, during the deposition of the Pletenevka and Smolensk Formations, sedimentation took place in low parts of the palaeorelief; only later, when the Redkino transgression reached its maximum, did sedimentation greatly extend over the East-European Platform. It covered the entire Moscow Basin whose strike changed to easterly and north-easterly. The least subsidence in this structure occurred in the north-eastern part of the area discussed, and the most complete and thickest sections of the Redkino deposits are known from the Ivanovo depression and Kotlas trough. The thickness of the Redkino deposits considerably decreases towards the Nelidovo – Torzhok arch and Pestovo, Rybinsk, and Moscow uplifts.

In Moldavia and in the Ukraine the area of greatest subsidence, where the Redkino deposits are above 150 m thick, stretches along the north-eastern part of the basin: hence the trough in which the Redkino deposits accumulated was strongly asymmetrical.

The present limit of the Redkino deposits is almost everywhere erosional. Judging from the distribution of facies and thicknesses of the Redkino and Kotlin deposits along the western and south-western margins of the centriclinal closure of the Moscow Basin, a margin of the Redkino sedimentary basin was situated not far from the outcrops of the Redkino deposits. However, the distribution pattern shown on Fig. 3, inset (Redkino Stage), is somewhat idealized. A drastic decrease in thickness towards the syneclise margins and the Byelorussia – Mazury massif could be attributed to subsequent erosion rather than to thinning in a near-shore area. In the southern and eastern Moscow Basin the boundaries of the Redkino sedimentary basin are established quite tentatively, one can assume a more extensive area of sedimentation here.

For some parts of south-western Podolia a coastline of the Redkino Basin is reliably stablished from the boreholes mapped, and thus near-shore facies of the Yaryshev and Nagoryany Formations have been determined. A boundary of the Redkino Basin can be traced as far as Volhynia and Moldavia. The eastern boundary of the south-western Redkino Basin could hardly extend for more than 10 – 20 km with respect to the present outcrops of the Redkino deposits within the pre-Cretaceous erosion surface.

The Redkino Basin of the Lvov – Kishinev trough during periods of maximum transgression seems to have been connected with the Moscow trough via a passage within the Kletsk – Stolin trough.

The absence of the Redkino deposits in the Łuków – Ratno uplift and small local uplifts in the basin is due to post-sedimentary erosion. More persistent connections with basins of the Galician geosyncline only remain within its Black

Sea part. The Carpathian segment of the geosyncline was separated from a platform basin by a belt of crystalline basement uplifts.

The Redkino marine transgression was discontinuous, with intermittent regressions. This is obvious from a rhytmic development of strata. Each new transgression started with a basal coarse-clastic sandy unit and graded into a clayey unit corresponding to a transgression maximum.

Transgression within the Moscow Basin reached its maximum by the end of the Middle Redkino (Nelidovo) Stage. This is confirmed by the fact that the Nelidovo deposits rest unconformably on the older Vendian rocks and, in places, directly on the crystalline basement. In the northern zone they locally overlie Riphean deposits.

The south-western margin of the platform witnessed a different trend in the development of the basin during the Redkino Stage. The most common rocks are of the Mogilev Formation, and its equivalents in Volhynia (Chartoryisk Formation) and in the south-western Podlasie – Brest depression (Girsk Formation), suggesting a transgression maximum. A gradual decrease in the size of the basin, and regression south-westward, took place from Yaryshev and probably Yampol Formation Deposits of the Yaryshev and Nagoryany Formations seem to wedge-out towards the Buchany – Lutsk arch.

Rock composition, changes in grain size of clastic material, as well as structural features of deposits found across the entire study area, suggest a great diversity in topography-from gentle to dissected – of the landmass bordering the Redkino Basin.

Uplifts of the Baltic and Byelorussia – Mazury shields constituted the most elevated parts, while the south-western Sarmatian shield in Podolia had the most subdued relief.

The uplifts of the Byelorussia – Mazury shield were the main source areas for clastic material of the Redkino Basin, this is confirmed by the distribution of the most coarse-grained deposits (conglomerate, gritstone, sandstone and the like) in the territory adjoining them to the north and south, abundance of large fragments (up to boulder-size) of different rocks in the lower Girsk Formation and coarsening of terrigenous rocks as the uplifts are approached.

In the Early Redkino Stage much of the coarse clastics were supplied from the western parts of the Podlasie-Brest depression and Volhynia-Podolia where cones of Volhynian volcanoes were intensely eroded.

Local basement protrusions were other source areas affecting the composition and thickness of deposits within the sedimentary basin. Here sedimentation took place occasionally or was altogether absent. Among the latter are the Assamalla, Uljaste, Mynyste, Lokno and other uplifts.

On land both chemical and physical weathering took place. The latter predominated during the early stage of transgressions, as shown by composition of the rock-forming authigenic clay components (Bessonova *et al.*, 1972) and inferred from the geochemical pattern of minor element distributions (Makhnach *et al.*, 1976; Makhnach, 1977).

The Redkino Basin was dominated by terrigenous rocks with a strongly subordinate hemogenic sedimentation (presence of siderite and phosphate in a carbonate matrix).

The Smolensk, Pletenevka, Girsk and Olchedaev – Lomozov Formations composed of conglomerates, gritstones to thin silts and clay, as well as their rapid replacement in the section and across the area suggest that during the early stages of the Redkino Basin sedimentation took place under conditions of dissected topography and intense planation of source areas. The data available allow recognition of facies of eluvial-deluvial fans of deltaic currents, rivers, and shallow water for the Redkino Stage.

Judging from the presence of sulphide, glauconite grains, bands rich in organic matter and phosphates, abundant acritarchs, as well as structural features, the clay-silty facies of the Smolensk Formation can undoubtedly be referred to as basinal facies. The basin was shallow and marked by a quiet and locally stagnant hydrodynamic regime which was preserved oving to the presence of numerous islands.

Widespread structures of deltaic and current types point to the importance of rivers in the accumulation of the Redkino gravel-sand sediments. One of the rivers could well have flowed in the Early Redkino Stage along the central Russian aulacogene from Rybinak to Kotlas where an area of deltaic formations can be delineated.

There are numerous indications of high seismic activity in the area supported by localization of slumped beds and their occurrence in various rocks of the same stratigraphic levels over extensive areas. In steeper parts of the sea floor, seismicity gawe rise to various subaqueous slump deformations. Volcanic activity could strongly affect water salinity of the Redkino Basin and lead to organic explosion at that time over the entire platform. Marker units of mudstone rich in organic matter were deposited during the Middle Redkino (Nelidovo) age following the manifestation of volcanic activity.

This time was marked by the most favourable sedimentary environment and reducing geochemical conditions necessary for accumulation, burial and transformation of organic matter into hydrocarbons. The considerable differentiation of the basin floor has affected the thickness, facies composition of sediments, and their enrichment in organic matter. Geological studies show that the Redkino Stage is marked by a high content of organic matter (Kirsanov and Shibalin, 1970; Rodionova *et al.*, 1972; Kirsanov, 1970; Larskaya, 1974). The organic carbon content varies from a hundredth fraction of a per cent to 1.65% and in some mudstone bands amounts to 6% (Larskaya and Zagulova, 1974; Rodionova *et al.* 1972).

Geochemical conditions of organic matter accumulation in sediments were different as well. The content of sulphate sulphur amounts to 0.01 – 2.9%, that of leptochlorite iron – 0.42 – 4.57%, pyrite iron – 0 – 2.53% and ferrous iron – 1.15 – 7.31%. This implies that reducing processes were operative in some areas. Marked variations in the parameters listed suggest the change from reducing to oxidizing conditions. The predominance of ferric and sulphide iron reflects mainly reducing geochemical environments during diagenetic transformation of the clay sediments of the middle Redkino Stage for most of the Orsha Basin, as well as for the Pachelma and Soligalich troughs. Organic matter in marker units of darkgrey mudstone, rich in organic matter, accumulated under the conditions most favourable for bitumen formation. In the remaining part of the Moscow Basin the accumulation of clay rocks in the middle Redkino Stage took place mainly in low reducing geochemical environment and in anoxic and oxidizing environments along the flanks.

Marine sedimentary environment of the Redkino deposits are indicated by their salinity. Chlorine values are as follows: in sandstone – 0.07 – 0.69%; in clay – 0.09 – 1.4%; in clay-carbonate rocks – 0.31 – 0.76%; and correspondingly, sulphate sulphur values are: 0.01 – 0.16%; 0.01 – 0.55%; 0.04 – 0.64%. A persistent increase in the above components up the section implies a gradual salinization of the sedimentary basins. Low gallium content also supporst marine genesis of the Redkino deposits. The association of the above listed syngenetic authigenic minerals is also consistent with such a conclusion.

Organism which populated the Redkino Basin were quite diverse and abundant. A peculiar Vendotaenian flora with well preserved plant tissue is widespread there. In places these plant remains form mass accumulations (Gnilovskaya, 1971; Sokolov, 1971, 1972). In the Redkino Stage plankton was represented by acritarchs which were very common and are now abundant in the sediments. Peculiar planktonic forms called by V.V. Menner *Beltanelliformis brunsae* are considered by some authors to be gigantic acritarchs and by others as small hydromedusae. The occurrence of non-skeletal fossils in the Redkino deposits of the East-European Platform is of great importance. This fauna was reported in the mid-1970's on Onega Peninsula, along the Syuzma River (Keller *et al.*, 1974). Later, M.A. Fedonkin (1978) found the same fossils on the Zimnii (winter) Shore of the White Sea, north of Arhangelsk. The more than 30 species belonging to 17 genera are at currenthy referred to as the White Sea Vendian biota. Among them there are Coelenterata (scyphon and hydromeduza), arthropods (*Vendomia*), many--segmented forms (*Dickinsonia, Spriggina*), ichinodermata (*Tribrachidium*), as well as forms of uncertain systematics (*Pteridinium, Rangea, Ynkrylovia*). Not so rich an association of species of the Redkino level is known in the Ukraine from the Yampol – Yaryshev deposits of the Dniester River area where Coelenterata represented by sessile forms (according to V.M. Palij, 1976) and rare hydromedusae were found. As to the habitat of the Redkino fauna, opinions differ. Some authors believe that this fauna inhabited shoals of an extensive marine basin of normal salinity and gas regime (Palij, 1976). The others suggest that the White Sea fauna livet in an extensive shallow basin with poorly aerated sea floor and reducing environment and that it was in this basin that a peculiar community of species, represented by soft-bodiet forms, originated.

## KOTLIN STAGE

In the marginal parts of the Moscow Basin a hiatus between the Redkino and Kotlin Stages is easily discernible. As a result the Kotlin deposits rest erosively on the underlying formations. In the Valdai area a kaolinite weathering crust was formed on the argillaceous Middle Redkino (Nelidovo beds), it was drilled by the Valdai borehole. This shorterm regression was followed by an extensive Kotlin transgression.

Most of the central, southern, and north-eastern parts of the Moscov Basin (from Vyazma to Kotlas), as well as the Pachelma trough was occupied by a shallow terrigenous sedimentary basin at the close of the Redkino Stage and at the beginning of the Kotlin Stage. There, deposits of the Kotlin Stage rest directly on the Redkino deposits.

The structural framework and palaeogeographical environment of the Kotlin Stage are mainly inherited from the preceding Redkino Stage (Fig. 4, inset). All the specific structural elements, including the Moscow Basin and Kishinev – Lvov trough continued to exist. They were major subsidence zones filled by waters of an extensive marine basin with freshened marginal parts. The Baltic and Sarmatian shields, as well as the Byelorussia – Mazury uplift contain no Kotlin deposits. As before, there are two extensive sedimentary areas.

In the northern subregion the Kotlin basin had considerably enlarged, extending westward. Here from southern Lithuania to northern Estonia a transgressing sea covered marginal low shield areas made up of crystalline basement rocks which during the preceding Upper Precambrian were zones of denudation and crust generation.

The universal distribution of arkose and polymineral coarse-grained sediments with poorly sorted and rounded clastic material along the western, south-western, and north-eastern segments of the Moscow Basin implies short-distance transport of the material and proximity to the coastline. Not only uplifted parts of the Baltic shield and Byelorussia – Mazury uplift, but also local uplifts within the Moscow Basin, at the Estonia Latvia frontier and in south-eastern Lithuania, were removed at the beginning of the Kotlin Stage.

We cannot reconstruct the southern boundary of the Moscow Basin so precisely because most of the area underlain by the Kotlin Stage was removed during pre-Devonian non-deposition and erosion. Nevertheless, comparison of facies and thickness of these deposits on the southern side of the Moscow Basin allows us to conclude that the southern boundary of the Kotlin basin was far from the present sedimentary area. The presently isolated northern and south-western subregions of the Kotlin deposits might belong to a single sedimentary basin. The rocks from discrete parts of the sedimentary basin show a similarity in mineral composition and structural features, common fossil assemblages and authigenic components.

During the Kotlin Stage the Byelorussia – Mazury uplift was a large peninsula with a dissected topography which continued to supply a large amount of coarse clastics to adjacent zones of sedimentation.

In the period discussed the sedimentary area entirely covered Volhynia-Podolia, occupying part of the territory of the present Carpathians and the Podlasie-Brest depression.

Over most of the Moscow Basin deposits belonging to the early stages of the Kotlin transgression are composed ad the base by gravel-sandy or sandy rocks grading up into clayey or clay-silty or silt-sandy units. Even higher they are replaced by clayey "laminarite" beds which are very persistent across the area and very thick. They were formed when the transgression reached its maximum and during a general decrease in differential movements of all the platform elements. The Kotlin section is crowned to the west by grey, and to the east by variegated and red, clay-silty or silt-sandy deposits of the Reshma Formation; they represent the regressive phase in the development of the Kotlin basin.

In fact, there were no manifestations of volcanic activity when the accumulation of the Kotlin deposits took place. Single clay interbeds rich in pyroclastics are known only from the lower (Makarevo) sedimentary cycle of the Kotlin Stage in the Pachelma trough (Morsovo) and in the Balakhna area (Kirsanov, 1970). Clay rocks of the lower sedimentary cycle (of the Kotlin Stage) are also rich in organic matter which can explain the dark-grey or black colour of the mudstones (Soligalich and Galich troughs).

The extension of the transgression, both in the Moscow Basin and in the Kishinev – Lvov trough, after pre-Kotlin nondeposition led to a subsequent change from continental and near-shore platform (basal beds) to near-shore marine and marine sedimentation.

In the marginal south-western part of the Moscow Basin (western Byelorussia, south-eastern Lithuania) the accumulation of red continental, mainly coarse clastic and sandy deposits (proluvial, deluvial, lacustrine) assigned here to the Gdov Formation continued. Up the section and eastward they grade into sandy and silt- clayey facies of a coastal plain which from time to time was covered by sea.

In the western Moscow Basin and Podlasie-Brest depression coastal plain environments existed for a rather long time. Arkose, polymictic and rare oligomictic composition; high content of mica, kaolinite and iron hydroxides; different types of oblique and wavy bedding; poor sorting and irregularly rounded clastics; original red and variegated colour of the rocks; the absence of trends showing a change in rocks of different grain size; numerous traces of rolling, deformation and erosion – all this is evidence for the coastal plain genesis of terrigenous deposits of the areas (Bessonova and Gorelik, 1974; Mens and Pirrus, 1974). The above facts imply a fresh-water sedimentary environment. This is also indicated by the absence of such authigenic minerals as glauconite, siderite, pyrite, as well as trace fossils. On the contrary, there are all the features characteristic of shallow marginal formations of large sedimentary basins. Along with sandstone and coarse-clastic rocks the number and extent of siltstone and clay interbeds increase towards the interior parts of the Moscow Basin. In the eastern Moscow Basin the lower part of the section in dominated by green-grey rocks. Interbeds with pyrite phenocrysts, siderite micronodules, and glauconite globules are rather rare. Clastic material is not rich in feldspar, and large-grained sand and gravel is well sorted and rounded. Basal clay and rare poikilitic carbonate cement is common. Bedding is mainly horizontal, lenticular, lenticular-wavy, and gentle wavy.

Sedimentation took place in near-shore marine and shallow-water marine, rather dynamic environments. Poor reducing and partly reducing sedimentary conditions of the Kotlin deposits later were replaced by oxidizing conditions.

Geochemical studies of the Kotlin deposits from the Orsha and Podlasie-Brest depressions revealed a relatively low content of organic matter. An average content of organic matter in the sandstones does not exceed 0.1%, and in clays and clayey siltstones it reaches 0.2%, rarely, 0.4 – 0.5%. The amount of organic matter increases to 2% only in some dark-grey or almost black clay interbeds in the axial zone of the Moscow Basin (Kirsanov and Shibalin, 1970).

The sedimentary basin was shallow and had unstable hydrodynamic and gas regimes. Such features on bedding planes as ripple, current and wave marks, low rain channels, irregular contacts of adjacent beds imply a small depth of the marine basin.

Water salinity of the Kotlin basin was not constant. At times it was freshened (mainly in marginal parts due to influx of river water from adjacent landmass), and at times the salinity became normal or even high. This is shown by the alternation of carbonate-free kaolinite beds with deposits rich in dolomite, siderite, pyrite, locally with celestite and barite, or galena and sphalerite.

Judging from the salt component ration, the salinity in the Kotlin basin was mainly normal. The chlorine content does not exceed 0.1 – 0.2%. Clay sediments contain 120 – 250 g per t of boron suggesting normal marine environments.

The water gas regime also was not constant and changed from oxidizing to weakly reducing and reducing. This is proved by the composition of authigenic minerals in different parts of the Kotlin basin and by recent geochemical studies (Larskaya, 1974; Larskaya and Zagulova, 1974; Larskaya *et al.*, [illegible]; Kirsanov and Shibalin, 1970, 1972). The combination of oxidizing and reducing sedimentary environments during the Kotlin Stage suggests the presence of submarine depressions filled by stagnant water. Deposits of such areas contain peculiar black films of organic matter, accumulations of siderite (or ankerite) and pyrite (up to 2%). Ferrous iron dominated over ferric iron, resulting in a $Fe^{2+}/Fe^{3+}$ ratio of 5.4.

In the central parts of the Moscow Basin sedimentary environments often changed from oxidizing and suboxidizing to reducing. As a result the Kotlin Formation often shows alternation of rocks rich in iron hydroxides and ferrous iron with rocks whose authigenic minerals are dominated by mobile ferric iron. During those short periods of time when the sedimentary basin floor was subsiding, the oxidizing/reducing boundary was above sediments. This favoured the accumulation of organic matter and establishment of oxidizing conditions. The rocks formed at that time are grey and green in colour. However, only dark-grey and almost black clay sediments show high organic matter content.

An almost complete absence of persistent interbeds of sandy and coarse clastic rocks over most of the Kotlin basin as well as predominance of massive and horizontal layered structures point to a quieter hydrodynamic regime as compared to the Redkino Stage. Relatively quiet dynamic environments are also indicated by rhythmically bedded rocks such as clay and siltstone interbeds typical of Recent large lake basins. However, the presence of such features as rolling, mud-streams, subaqueous slumping, microfolds, lenticular, lenticular--wavy, oblique, and trough-like bedding suggest a quite unstable hydrodynamic regime for the shallow Kotlin basin.

Not only structural features and hieroglyphs, but the presence of such peculiar rocks as micalites containing more than 50% of mica (biotite and muscovite) point to currents and wave action. Their occurrence in the parts away from the coastline suggests the transport of suspended mica plates for a long distance and their sedimentation in quieter zones of the basin. The deposition of clay-silty sediments of the upper Kanilovka Formation and their equivalents in Poland and south-western Byelorussia took place in a vast open marine basin with normal salinity and rather high wave activity (Velikanov, 1975; Larskaya *et al.*, 1975). V.N. Vernikovsky and V.A. Khizhnyakov (1975) believe that the Kanilovka basin was shallow and marked by low wave activity and mainly reducing sedimentary conditions. The presence of siderite, absence of glauconite, as well as clay mineral composition show that it was a fresh water basin. However, the appearance of sandstone in basal carbonate matrix in the upper part of the section shows that with time the basin became more complex and sedimentation approached the normal marine regime.

Vegetation became most abundant in the Kotlin Stage. Remains of algal plankton (Acritarchs) occur throughout the Kotlin deposits, and clay rocks are overcrowded with Vendotainides, the most abundant among them being the representatives of the genera *Vendotaenia* and *Tyrasotaenia*.

Metazoa have not been found in the Kotlin deposits as yet. There are some trace fossils, small epifauna (ichnites), and rare "worm tracks" which cut bedding planes (Meisa borehole), 621 – 627.

At the close of the Kotlin Stage the western margin of the Moscow Basin and Pestovo, uplift underwent considerable emergence. Deposits of the Kotlin Stage (Seliger Formation) were uplifted above sea level, and locally they were deeply eroded, so over a relatively large area conditions became favourable for the formation of a subaerial weathering crust (Mens and Pirrus, 1969). The weathering has resulted in ferrugination of clay rocks. The absence of kaolinizated products of weathering, the small thickness of the weathering crust and its confinement to the marginal zone of the sedimentary basin, and the short time of its formation suggest that this crust is intraformational (Kirsanov, 1970).

In the northern Baltic area, the short-term subaerial development was followed by the formation of an essentially fresh-water shallow basin where variegated red beds of the Voronka Formation were deposited.

The mineral composition of the rocks formed in the Voronka basin, high

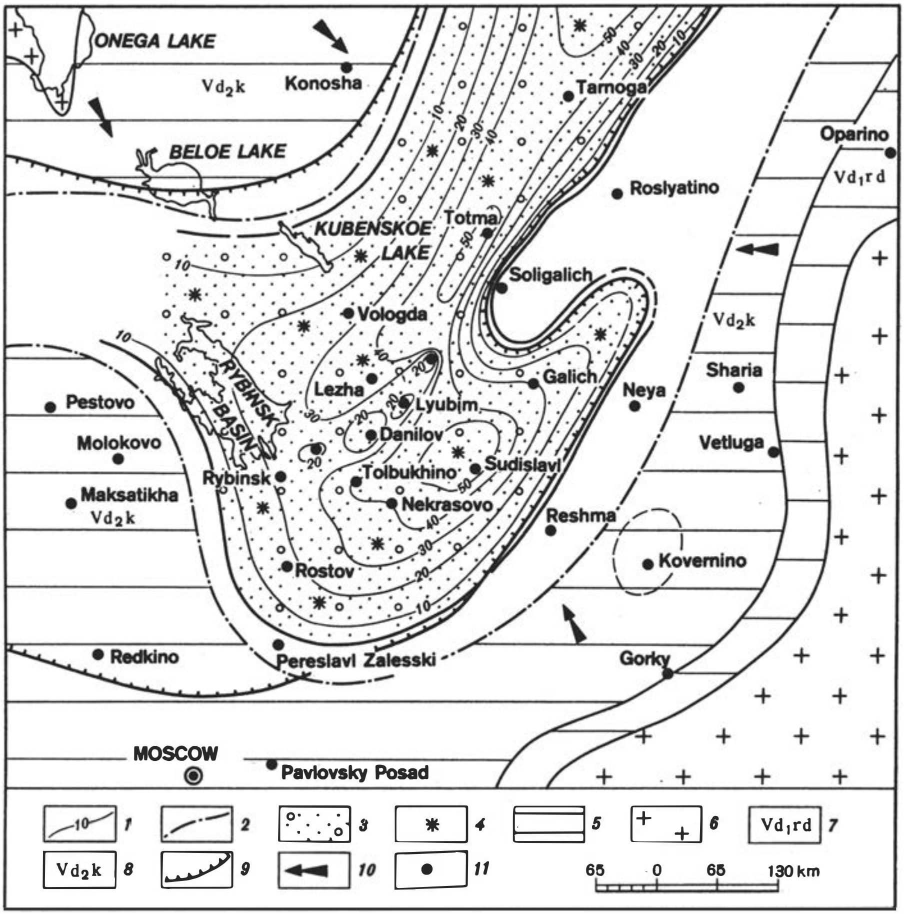



Fig. 5. Litho-palaeogeographic sketch map of the central East-European Platform. Radishchev Stage (regressive relict sedimentary basin at the close of the Valdai epoch). Compiled by V.V. Kirsanov

K e y: *1* – isopachin meter, *2* – inferred original limit of the Radishchev Formation, *3* – sandstone and subordinate gravelstone with gravel and pebble admixture, *4* – primary red color, *5* – source areas built up of Valdai deposits, *6* – source areas built up of crystalline rocks, *7* – Redkino deposits, *8* – Kotlin deposits, *9* – limit of the overlying Lower Cambrian Rovno deposits, *10* – direction of transport, *11* – boreholes

kaolinite content of clay fractions (80–90%), monomineral-quartz composition of sands, distribution of authigenic chamosite (Pirrus, 1973) – all this is evidence for a peculiar pattern of the basin. All the above rocks began to form after a long period of non-deposition. Lithology of the Veronka Formation, viz. variegated siltstones and clays grading into sands up the section, implies regression. The Voronka basin seems to have been connected with a regressive basin of the eastern Moscow syneclise.

During the regression, at the end of the Vendian, sedimentation areas within the Moscow Basin drastically decreased. Variegated and red gritstones and sand-clayey deposits of the Reshma Formation were formed in the remaining basin. The upper part, representing a small separate sedimentary cycle, was recognized by V.V. Kirsanov (1974) as the Radishchevo Formation. Palaeogeography for the time of its deposition is shown on Fig. 5. The types of deposits, structural and textural features of rocks, the presence of glauconite, kaolinite, gravel, and pebble suggest sedimentation under shallow-water conditions. The red colour of the deposits points to high aeration of the water and predominantly oxidizing conditions. The Radishchevo Formation can be equated in the time of its accumulation with sands of the Voronka Formation of the Baltic area.

The present limits of the Radishchevo Formation are erosional in nature and cannot be considered as true boundaries of a sedimentary basin. An elevated zone, complicated by local uplifts near Bukalov, Danilov, Lyubim, and Diyakonovo was situated along the central Russian aulacogen at the end and the beginning of the Radishchevo Stage. The Soligalich and Roslyatino uplifts seem to be located on the north-eastern extention of the area, the Radishchevo deposits being absent there at present. The Bukalov – Diyakonovo uplifted area separates the Radishchewo basin into the Galich and Lezha Kotlas areas of maximum downwarping. Here the Radishchevo deposits rest on different beds of the Reshma (Seliger) Formation and their thickness decreases to 1 m.

The elevated parts of the landmass are recognized by the absence of the Radishchevo deposits. Their distribution was west and south of the town of Pereslavl – Zalessky and south-east of Makarevo, Reshma, and Nelidovo. On land both the Kotlin and Redkino terrigenous deposits and basement rocks (Volga – Kama landmass) were subjected to erosion. The uplift of the entire Moscow Basin area at the end of the Redkino Stage led to slight erosion of the Radishchevo deposits in the north-eastern part of the Moscow Basin. Near the Pestovo uplift and Maksatikha the upper sedimentary cycles of the Kotlin Stage were completely eroded at that time.

## EARLY CAMBRIAN

### ROVNO STAGE

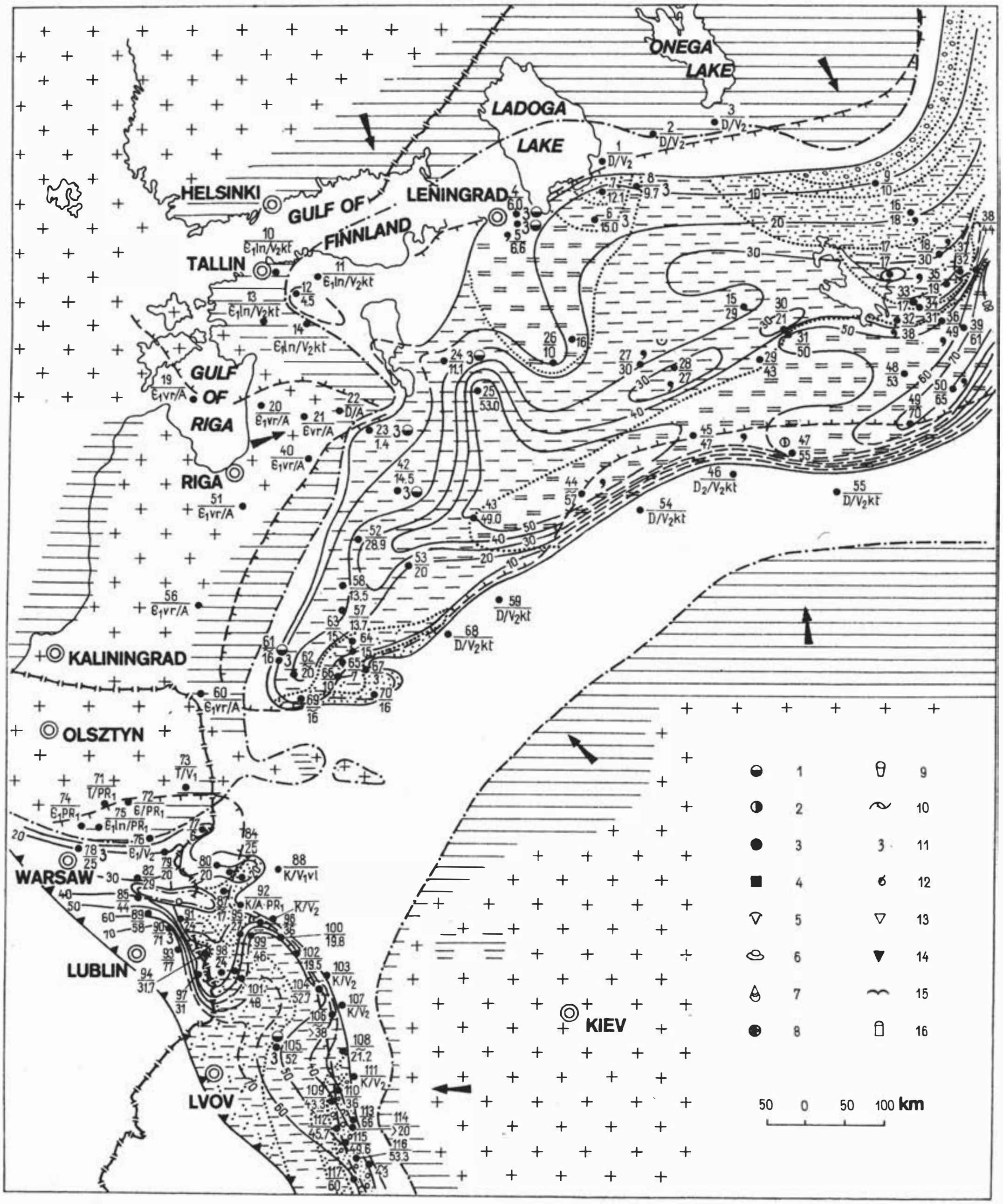
On the East-European Platform the Rovno deposits are known from two vast areas separated by the Byelorussia – Mazury anteclise (Fig. 6, inset).

However, the type of succesion of the "southern" and "northern" terranes and a complete similarity in flora and fauna suggest that the two parts of the basin once were closely connected.

Nevertheless in the Byelorussian – Mazury anteclise are and east of it there may have existed islands where both crystalline rocks and Vendian sedimentary strata were subjected to erosion. This is shown by coarse-clastic facies of the Rovno deposits developed in the south of the "northern" terrane (north of Minsk) and in the north of the "southern" terrane (Brest area).

The reconstruction of the Rovno palaeobasin presents substantial difficulties because deposits of this age were later eroded. Coastal facies (or, more accurately, the deposits interpreted as coastal facies) have only been found in some areas. One of them is Podolia where coastal facies have been studied in considerable detail. It is difficult to infer the existence of a larger basin here which once might have occupied part of the Ukrainian shield. However, north of the town of Khmelnitsky, near the present eastern limit of the Rovno deposits there are more deeper-water facies suggesting extension of the basin farther east. This limit may have been farther south, as compared to the present areal extent of the Rovno strata, as neither the thickness nor facies of their final locations (Toropets, Redkino, Pereslaval boreholes) suggest proximity of the coastline.

The connections of the basin to the east are equivocal at present. However, attention should be drawn to the occurrence of sabelliditida to the south of the eastern slope of the Urals; they are also very common on the eastern Siberian platform (Irkutsk amphitheater, Igarka and Anabar areas) where V.A. Luchinina, V.V. Kiryanov, and M.B. Gnilovskaya (1978) point to the presence of the Rovno



strata yielding typical East-European faunal assemblages. An inherited pattern of the development of the Valdai and Rovno basins suggests that in Rovno time a wide sea passage may have followed the Pachelma trough.

The north-eastern limit of the basin is even more uncertain. North of the towns of Cherepovets and Vologda the Rovno Stage includes terrigenous rocks which might be considered as coastal facies. Though such an interpretation is accepted here as well, it should be remembered that the Rovno age of these deposits has not been substantiated.

West of the above areas, along the present depositional limits of the Rovno deposits, the areas of possible coastal sedimentation grade into increasingly deep-water parts of the basin, and the Leningrad region was already characterized by the accumulation of argillaceous rocks associated with the deepest parts of the basin. This suggests that the Rovno basin probably stretched farther north of Leningrad and opened to the north, towards the White Sea.

The north-western rim of the basin was situated much farther west than the present limit of the Rovno deposits as shown by outliers beneath the Lontova beds in central Estonia.

The western boundary of the "northern" terraine can be interpreted in different ways. Some workers believe that the Baltic basin may have continued far to the west, covering the Kurzeme Peninsula, western Lithuania, and the entire Brest – Mazury uplift. However, this is more feasible, though non reliably substantiated, for the Lontova Stage, even though during Rovno Stage the basin may have been more extensive as compared to the present extent of the Rovno deposits. Small thicknesses of the Rovno sequences, their mainly silty and sandy composition and a probable presence of the upper sedimentary cycle argue for this.

The above consideration is confirmed by the typical Ludza-15 section which has been studied thoroughly (Birkis *et al.*, 1972; Rozanov, 1973); an acritarch assemblage supporting the age occur in the Rovno deposits together with sabelliditids and platysolenitids.

Fig. 6. Litho-palaeogeographic map of the western East-European Platform. Lower Cambrian. Rovno Stage. Compiled by A.Yu. Rozanov and V.V. Kirsanov from data of B. Aren, A.P. Brangulis, V.Ya. Bessonova, K.A. Mens, V.V. Kirsanov, V.V. Kiryanov, K. Lendzion, E.A. Pirrus, A.Yu. Rozanov, T.V. Jankauskas

For legend see Fig. 3. Fauna: *1* – acritarch of the Rovno assemblage, *2* – acritarch of the Lontova assemblage, *3* – acritarch of the Talsy assemblage, *4* – acritarch of the Vergale and Rausve assemblage, *5* – trilobites, *6* – Lukathiella, *7* – brachiopods, *8* – Mobergella, *9* – Volborthella, *10* – ostracods, *11* – Sabelliditids, *12* – pyritized tracks, *13* – hyolithids, *14* – Hyolithelminthids, *15* – crawlingtraces, *16* – Platysolenitids. Boreholes: *1* – Pasha, *2* – Karginichi, *3* – Koshtugi, *4* – Leningrad, *5* – Kostovo, *6* – Zarechie, *7* – Usadishche, *8* – Kunevichi, *9* – Kubenskoe, *10* – Arukyula, *11* – Tappa, *12* – Ardu, *13* – Kynnts, *14* – Etamma, *15* – Pestovo, *16* – Vologda, *17* – Poshekhonie, *18* – Lezha, *19* – Rukhnu, *20* – Staitsele, *21* – Strenche, *22* – Myniste, *23* – Aluksne, *24* – Sosedovo, *25* – Porkhov, *26* – Staraya Russa, *27* – Valdai, *28* – Bologoe, *29* – Maksatikha, *30* – Molokovo-1, *31* – Molokovo-2, *32* – Rybnisk, *33* – Bukalovo-1, *34* – Bukalovo-2, *35* – Danilovo, *36* – Tolbukhino, *37* – Lyubim, *38* – Lyubim-7, *39* – Nekrasovo, *40* – Taurupe, *42* – Ludza, *43* – Nevel, *44* – Toropets, *45* – Kuvshinovo, *46* – Staritsa, *47* – Redkino, *48* – Rostov, *49* – Pereslavl – Zalesski, *50* – Ilyino – Khovanskoe, *51* – Bauska, *52* – Vishki, *53* – Verkhniy Dvinsk (Drissa), *54* – Nelidovo, *55* – Povorovo, *56* – Kryakliava, *57* – Tverečius, *58* – Druksiai, *59* – Shumilino, *60* – Druskininkai, *61* – Vilnius, *62* – Vilkishkyai, *63* – Kupa, *64* – Borodino, *65* – Kononovichi, *66* – Smorogon, *67* – Kurenets, *68* – Lepel, *69* – Poshkos, *70* – Krasnoe, *71* – Ostrów Mazowiecka, *72* – Zambrów, *73* – Tatarowce, *74* – Wyszków, *75* – Tłuszcz, *76* – Stadniki, *77* – Krzyże, *78* – Okuniew, *79* – Mielnik, *80* – Zhabinka, *82* – Zembry, *84* – Girsk, *85* – Radzyń, *86* – Wisznice, *87* – Shcherbik, *88* – Drogichin, *89* – Parczew-10, *90* – Krowie Bagno, *91* – Kaplonosy, *92* – 310 Ratno, *93* – Busówno, *94* – Berezhtsy, *95* – Vyzhevsk, *96* – Nuino, *97* – Białopole, *98* – Stenzharichi, *99* – Serekhovichi, *100* – Berezhintsa, *101* – Vladimir Volynski (structural well), *102* – Gradie, *103* – Derazhnoe, *104* – Kreven, *105* – Brody, *106* – Kunin, *107* – Taikury, *108* – Belogorie, *109* – Ivanovka, *110* – Ivanovtsy, *111* – M. Zozuli, *112* – Gusyatin, *113* – Gorodok, *114* – Lesovitsy, *115* – Zarechanka, *116* – Kamenets Podolski, *117* – Darabany. For locations see Fig. 2

The western boundary of the Rovno basin in the "southern" terraine is quite unknown. Data obtained for eastern Poland suggest that the basin opened to the south-west; this is consistent with the presence of a rather thick succession of siltstones and shales of the sub-Holmia horizon (and, possibly, Kotuszów beds of the Holy Cross Mountains, which beds are usually assigned to the Vendian), part of which probably corresponds to the Rovno Stage.

The available data show that an extensive regression of the Kotlin sea during the Reshma Stage was followed by a new stage associated with the Rovno transgression. As a whole, the sedimentation pattern remains similar to that of the Kotlin Stage, though sedimentation was not continuous at this boundary. At present, it is impossible to find a section where the Rovno deposits conformably onlap the Kotlin beds. The Rovno Stage starts, as a rule, with gravelstones and sandstones, and the upper Kotlin Stage mainly consists of highly kaolinized rocks. The short-term accumulation of gravelstones and sandstones was followed by the deposition of clays (locally with siltstones) characteristic both of old and young Kotlin and Lontova basins.

At the end of the Rovno Stage the basin may have drastically decreased in size. As a result the Lontova deposits almost ubiquitously onlap the Rovno beds unconformably; the former commonly start with a gravelstone and sandstone unit as well.

In some regions the Rovno Stage shows a distinct bipartite structure. The sections in the exial part of the Moscow Basin provide a good example. However, in the western areas of their occurrence, in the eastern Soviet Baltic area, and in Ukraine, the Rovno deposits, as a rule, are represented by one sedimentary cycle. In the Baltic area, the common occurrence of sabelliditids and platysolenitids points to the upper parts of the Rowno Stage (East Latvia and Lithuania). however, in Ukraine we have the lower part of the Rovno Stage, while the upper part was eroded or not deposited at all.

The above data suggest that the outline of the Rovno basin must have greatly changed. In the west part of the northern region and in the southern region transgression reached its maximum in the Late and Early Rovno Stage, respectively.

The composition of the Rovno deposits and, particularly, an assemblage of trace fossils typical of all the known shallow basins of the world imply that this basin remained very shallow even during the maximum transgression. Fossils collected in the area suggest that fauna and flora which populated the basin were not very diverse. Sabelliditids and platysolenitids are in fact the only fossils known from the Rovno Stage. It should be noted, however, that buried faunas, especially sabelliditids, are universally abundant. This implies that in Rovno time the sea was rich in this fauna.

The abundance of phytoplankton is suggested by its presence in almost all the samples collected from these deposits.

The abundance of phytoplankton, silicate tubes of platysolenitids but the absence of carbonate deposition seem to suggest temperate latitudes. However, all the reconstructions (see Rozanov, 1976) based on palaeomagnetic and tectonic data, show that the East-European Platform must have been situated in the tropical or subtropical belt.

## LONTOVA STAGE

Sedimentation of the Lontova Stage belongs to the Baltic stage when what is known as an "eastern" basin was most extensive on the East-European Platform, projecting much farther west as compared to the Upper Vendian stage of marine transgression. The Baltic stage in the development of the platform is characterized by a tectonic setting inherited from the Late Precambrian; such negative structures as the Moscow Basin and Podlasie-Brest depression, and the others emplaced as early as the Late Vendian flooded with waters of the basin, continue to develop.

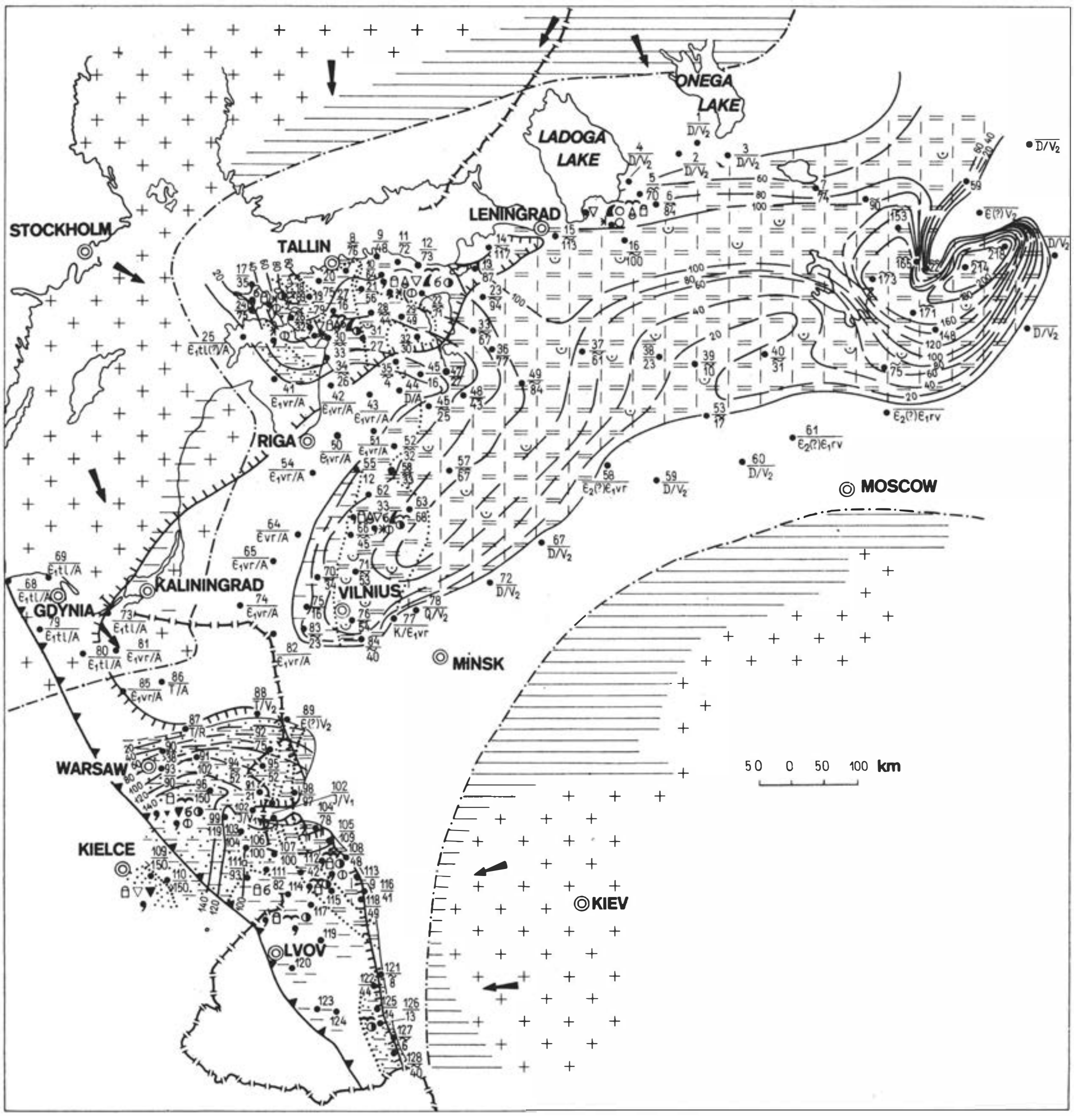
A partial but, in places, probably vigorous Rovno regression inferred from the presence of the spotty Rovno deposits far from their main terraine was followed by a new – Lontova – marine transgression on the western East--European Platform (Fig. 7, inset). In general, the transgression was controlled by a structural framework inherited from the Rovno Stage; the sea widely inundated the study area without obvious traces of ingression even during its early phases. A relatively small proportion of coarseclastic rocks in the Lontova deposits over most of the area, even in the basal beds, points to a fairly gradual marine transgression together with smooth topography of both the basin floor and surrounding source area. However, the Lontova transgression was not continuous over the entire area under consideration. It proceeded more or less steadilly only in the north and north-west where basal beds of the horizon represented by the intercalations of sandstone, siltstone and clay grade into clayey-silt, and then purely clayey sediments up the section, as the sea advanced. In the remainder of the area transgression proceeded stepwise slowing down and even stopping in places. Evidence of multistage transgression is most obvious on either side of Byelorussian-Mazury anteclise where the sections contain as many as three sedimentary rhythms (Korkutis, 1975) separated by erosional features and conglomerate and gravelstone interbeds at the base of rhythms. Such a pattern of the Lontova Stage at sites not far from the present major tectonic structure can be attributed to the fact that as far back as the Early Palaeozoic this segment of the Earth's crust was more active than adjacent regions.

The character of the Rovno/Lontova boundary indicates that near this level non-deposition seems to have taken place over most of the area, as evidenced by the presence of coarse-clastic rocks at the base of the horizon, that locally form a conglomerate interbed, as well as by traits of subaerial weathering in some sections of the upper Rovno Stage (Kirjanov, 1968; Grigyalis *et al.*, 1971; Kirsanov, 1974). This conclusion is consistent with palaeontological data, particularly for Volhynia, where the upper Rovno Stage has no beds containing both platysolenitids and sabelliditids, while in the sections of the Moscow Basin, along its western flank (Latvia, Lithuania), beds yielding both sabelliditids and platysolenitids often occur in the upper Rovno Stage. However, there is no distinct lithological contact between the Rovno and Lontova Stages (Birkis *et al.*, 1972; Kirsanov, 1974; Jankauskas, 1975 and others). In the north, at least in the northern part of the Leningrad Region, the picture is quite different – there is no discernible break in sedimentation there, and a distinct change in biotic character at the boundary discussed is provided by means of acritarch; there the Rovno deposits can be considered as the basal beds of a single major Baltic sedimentary embracing mainly the Lontova Stage (Stratigrafia..., 1979).

Areal distribution of the Lontova deposits differs slightly from that of the Rovno deposits. So, in the north and south-east the areal extent of the Lontova deposits is less than that of the underlying Rovno deposits; this is probably due to pre-Devonian erosion of the Lontova deposits along the southern, eastern, and northern limits of deposition of the Baltic phase of the Cambrian. On the contrary, the Lontova deposits are commoner in the north-west and west where thay overlap rocks of different age, including crystalline Archean to Proterozoic rocks.

In the study are the Lontova deposits occur in two isolated – northern and southern – terraines separated by Precambrian rocks, including, basement rocks in the Byelorussia-Mazury anteclise area. However, the same type of faunal assemblages both in the northern and southern terrains suggests that a single sedimentary basin occupied the entire East-European Platform during the Lontova Stage. This is also confirmed by a single distribution pattern of lithofacies zones of the Lontova Stage.

The present areal extent of the Lontova deposits allows reconstruction of the boundaries of the basin. In the north and east the present limits of the Lontova



deposits cross the high clay content facies zone of the sedimentary basin which implies denudation. Condensed thicknesses or a complete absence of the Lontova deposits observed within small positive tectonic structures (Myniste–Lokno uplift at the frontier of Estonia, Latvia and Pskov region, and Łuków–Wisznice uplift at the boundary of Podlasie and Lublin structures) are also related to some post-Lontova erosion as suggested by the lithofacies distribution. Only in Estonia and Podolia, where we find coastal facies, did the coastline of the Lontova basin run far from the present limit of the Lontova deposits. In Latvia and Lithuania, the western coast of the Lontova basin, as shown by the distribution of lithofacies, was also situated not very far from the limit of the underoded deposits of this age.

In Lontova Stage the basin which then certainly existed in the south-west, i.e. in the area of the Podlasie-Brest depression and Lublin uplift, was connected via these regions directly to a sedimentary basin of the eastern Holy Cross Mountains, where *Platysolenites antiquissimus* Eichw. was found in the Jasień Beds of the sub-Holmia horizon composed of greenish-grey silty shales (Michniak and Rozanov, 1969).

The Lontova basin appears not to have been closed in the north either. Thus, Early Cambrian clay-silt deposits are known to occur beyond the East-European Platform, viz. in North Finland, North Sweden, and in northern Norway (Finnmark and Tromsö) where shales and sandstones assigned to the Hyolithus zone occur. In the northern part of the platform a passage may have existed which linked the Lontova basin and a geosynclinal sea in northern and north-western Scandinavia. Such a passage is suggested by a similarity in lithology and fossils of the Lontova deposits of the East-European Platform and those of the Hyolithes zone in Finmark. Platysolenit species are common in both units, and their range exhibits the same ranges in the succession. For example, *Platysolenites antiquissimus antiquissimus* Eichw. occurs throughout the section in both stratigraphic units, while *Platysolenites antiquissimus spiralis* Posti was discovered only in the upper parts of the units (Hamar, 1967; Posti, 1978).

The Lontova platform marine basin washed extensive coasts. A landmass was certainly situated north-west of the area underlain by the Lontova deposits.

Fig. 7. Litho-palaeogeographic map of the western East-European Platform. Lower Cambrian, Lontova Stage. Compiled by K.A. Mens and E.A. Pirrus from data of B. Areń, A.P. Brangulis, V.A. Bessonova, V.V. Kirsanov, V.V. Kiryanov, K. Lendzion, T.V. Jankauskas

For legend see Fig. 3. Key to fauna see in Fig. 6. Boreholes: *1* – Tumazy, *2* – Karginichi, *3* – Koshtugi, *4* – Pasha, *5* – Malashaty, *6* – Kunevichi, *7* – Desyatovskaya, *8* – Arukyula, *9* – Koryuze, *10* – Tapa, *11* – Essu, *12* – Aa, *13* – Porkhovo, *14* – Koporie, *15* – Kost[illegible], *16* – Zarechie, *17* – Takhkuna, *18* – Khaapsalu, *19* – Koluvere, *20* – Laitse, *21* – Ardu, *22* – Rannapungerya, *23* – Stolbovo, *24* – Emmaste, *25* – Eikla, *26* – Virtsu, *27* – Kynnu, *28* – Eiamaa, *29* – Palamuze, *30* – Pärnu, *31* – Viliyandii, *32* – Kaagvere, *33* – Korytno, *34* – Khyaedemeste, *35* – Otepää, *36* – Sosedno, *37* – Staraya Russa, *38* – Valdai, *39* – Bologoe, *40* – Maksatikha, *41* – Rukhnu, *42* – Staitsele, *43* – Strenchi, *44* – Myniste, *45* – Vyaimela, *46* – Ponkuli, *47* – Petseri, *48* – Krasnodudovo, *49* – Porkhov, *50* – Nitaure, *51* – Taurupe, *52* – Madona, *53* – Kushinovo, *54* – Bauska, *55* – Plyavians, *56* – Atăsiene, *57* – Ludza, *58* – Toropets, *59* – Nelidovo, *60* – Staritsa, *61* – Redkino, *62* – Akniste, *63* – Vishki, *64* – Kryakyanava, *65* – Lyadai, *66* – Svedasai, *67* – Gorodok, *68* – Smołdzino, *69* – Żarnowiec, *70* – Ukmyarge, *71* – Leliai, *72* – Lepel, *73* – Krynica Morska, *74* – Kibartai, *75* – Tauchenis, *76* – Vilkishkyai, *77* – Muleikova, *78* – Konorovichi, *79* – Kościerzyna, *80* – Prabuty, *81* – Olsztyn, *82* – Druskiniskai, *83* – Ilgai, *84* – Poshkos, *85* – Nidzica, *86* – Olsztyn, *87* – Ostrów Mazowiecka, *88* – Tatarowce, *89* – Svisloch, *90* – Wyszków, *91* – Wrotnów, *92* – Krzyże, *93* – Okuniew, *94* – Mielnik, *95* – Lesevchitsy, *96* – Zambrów, *97* – Terespol, *98* – Kobrin, *99* – Radzyń, *100* – Wisznice, *102* – Domachevo, *103* – Krowie Bagno, *104* – Nuino, *105* – Bolshoi Obzyr, *106* – Busówno, *107* – Berezhtsy, *108* – Godomichi, *109* – Kotuszów, *110* – Bazów, *111* – Białopole, *111a* – Łopiennik, *112* – Vladimir Volynski, *113* – Klevan, *114* – Litovizh, *115* – Lutsk, *116* – Klevan, *117* – Gorokhov, *118* – Radov, *119* – Brody, *120* – Peremyshlyany, *121* – Ivanovtsy, *122* – Ivanovka, *123* – Zavadovka, *124* – Budach, *125* – Gusyatine, *126* – Zarechanka, *127* – Kamenets Podolski, *128* – Barabany. For locations see Fig. 2

Hence, a sublongitudinal uplift (or a chain of uplifts) was situated on the site of present Finland and Sweden; it stretched southward to North Poland. This landmass had separated the platform basin from a geosynclinal sea located north and north-west of Scandinavia. Another landmass was to the south-east and east. However, it is difficult to postulate the existence of a single Sarmatian shield for the Lontova Stage, as many authors believe (Bruns, 1964; Sokolov, 1964, and others). The Ukrainian shield may have been separated from the Voronezh uplift by the Dnieper-Donets depression, and the Voronezh uplift may have been separated from the Volga-Kama upland by the Pachelma trough; the paucity of data restricts the possibilities for reconstruction of the outlines of the areas, since the equivalents of the Lontova Stage in the Urals have not been palaeontologically substantiated as yet.

Clastic material was supplied to the north-western part of the basin from the west: in this direction the size and number of fragments markedly increase in the deposits discussed. A sublongitudinal uplift along the western coast of the Lontova basin is likely to have been a sediment source-area provenance for this part of the basin which then was situated within the Podlaska-Brest depression. In the south clastic material for the Lontova sedimentary basin was derived mainly from the Ukrainian shield.

Material derived from the source area was predominantly oligomictic in composition (scarcity of rock fragments; predominance of quartz over feldspar represented mainly by varities of the potassium series; predominance of green mica over brown mica; and high content of heavy fraction of stable heavy minerals) thus implying strong weathering of source rocks. Only in the Volhynia part of the western slope of the Ukrainian shield is pebbly material of the basal bed of the horizon made up of fragments of brownish-grey phosphorites and greenish--grey siltstones; amphiboles and pyroxenes are common accessory minerals.

Minor coarse clastic material in the Lontova horizon and relatively mature composition of the clastic component of the deposits over most of the area underlain by sediments of this age, point to poorly dissected topography of the landmass which surrounded the Lontova basin. The only exception was the Podolian slope of the Ukrainian shield with a relatively dissected topography reflected by widespread coarse clastic material in the basal part of the horizon. Grain size distribution, grain-roundness, and mineralogy of the Lontova deposits, there of suggest that to a certain extent the landmass was also composed of sedimentary rocks including argillaceous Upper Vendian and, in places, Rovno deposits which, when eroded, contributed much pelitic material in suspension to the sedimentary basin. Thus, comparison of clay components of the Kotlin and Lontova formations in North Estonia in mineralogy revealed not only a close similarity, not only quantitatively but also in the types of minerals present (Pirrus, 1970).

In the study area the Lontova horizon is made up solely of terrigenous rocks dominated by clays. The thick accumulation of clay strata is typical of the Lontova Stage of the East-European Platform. These clayey rocks are poorly, if at all, bedded, if ever. The Lontova argillaceous strata are characterized by intensive accumulation of hydromica varieties with admixture of chlorite, while marked amounts of kaolinite are observed only in the coarser deposits (basal beds, near-shore deposits). A substantial amount of kaolinite in the lower beds of the horizon which rest directly on the kaolinite-bearing Valdai deposits or on weathered basement rocks indicates that this mineral was derived from the underlying formations. Substantial amounts of kaolinite in the upper Lontova horizon generally consisting of finely dispersed rocks are attributed to subaerial weathering of these rocks in post-Lontova time. In places clays are interbedded with thin siltstones and fine-grained quartzose and glauconite-quartzose sandstones having horizontal or cross or, locally, wavy bedding. The only exceptions are western Volhynia, western Podolia and the north-western Baltic area where sandstones, siltstones and, less commonly, gravelstones and conglomerates, dominate the Lontova section suggesting that these areas were situated not far from the coast of the basin.

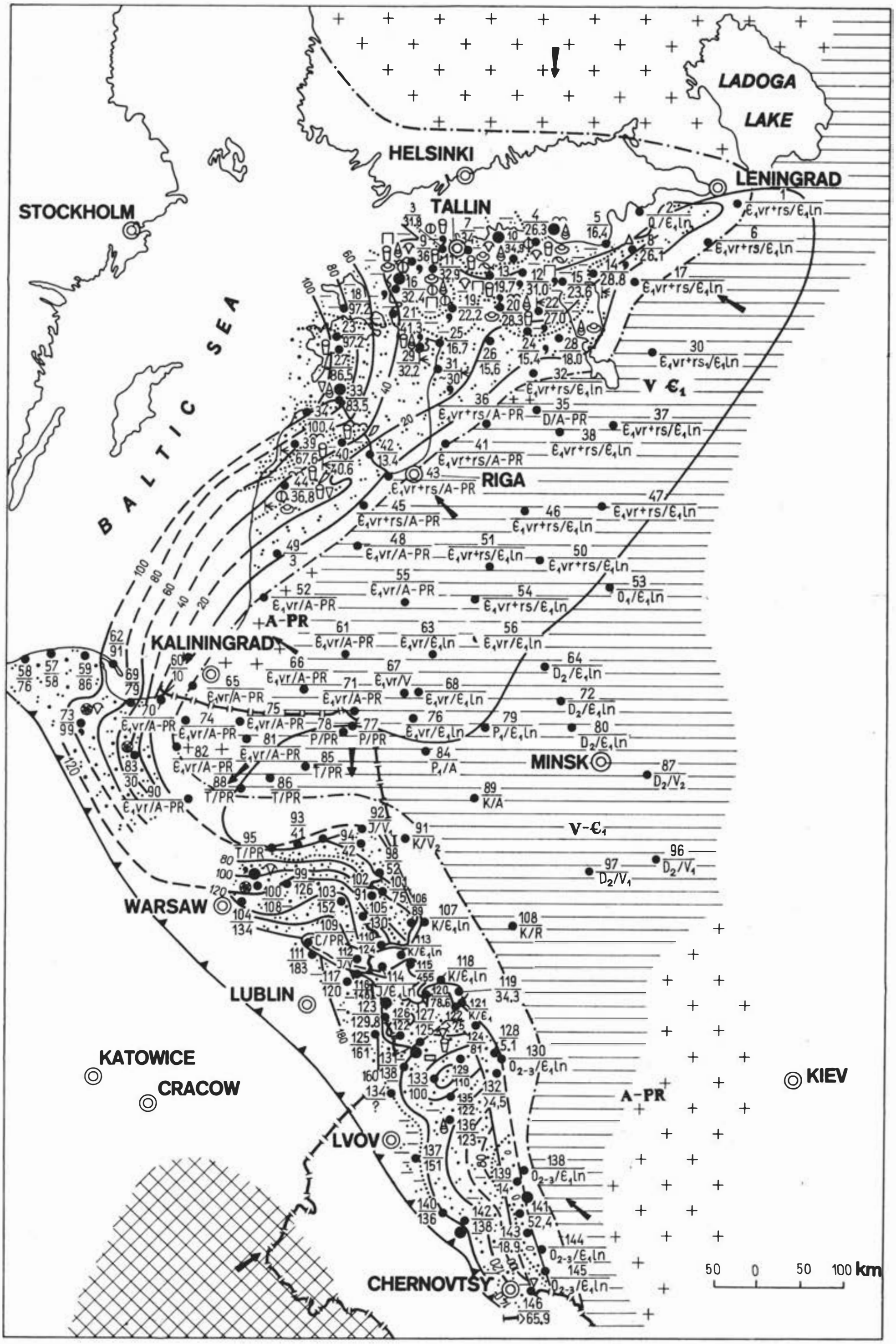
The Lontova Stage of sedimentation is characterized by relatively smooth changes in facies environments as reflected in a gradual eastward decrease in sand and increase in clay content. Exceptions to this are Lontova deposits on the western slope of the Ukrainian shield where clay content increases westward.

The presence of glauconite and phosphatized siltstone pebbles on the surfaces of local intraformational breaks in the Lontova deposits indicate sedimentary environments close to normal marine ones. The abundance of trace fossils, and wide distribution of authigenic glauconite, point to sufficient aeration of the bottom. The above features of the Lontova deposits, along with data on composition of the benthic fauna, as well as the types of ichnocoenoses, suggest that the basin was rather shallow. Even the sites of accumulation of clay rocks showing primary red-coloured bands and spots (eastern Estonia, western Leningrad and Pskov regions) were not very deep, as shown by the presence of gastropods and hyolithids. The accumulation of a thick uniform Lontova clay succession showing no distinct bedding over a vast area may be associated with retarded water flow in the interior part of the basin. This view is also supported by abundant occurrences of branching and less common meandering forms of ichnites in finely dispersed clays. Only in the north-west and south-east sand-siltstones dominate the sections. The presence of pebbles or conglomerate interbeds, along with rare fossils and wide distribution of vertical ichnites in these rocks, points to rather rapid water flow.

The end of the Lontova Stage in the development of the East-European Platform is characterized by the rise of the entire area above sea level. It is very difficult to reconstruct the events of the ascending crustal movements for this region since the regressive cycle deposits have not been found, except for the westernmost margin of the platform, and even deep-water formations are usually eroded. This is the result of a considerable reorganization in the structural framework of the East-European Platform which preceded the sedimentation of the next – Talsy – Stage, hence the accumulation of the Talsy deposits took place only to the north-west and south-west, while in the rest of the area the Lontova horizons is overlain by Early Cambrian or still younger rocks.

## TALSY STAGE

The Lontova marine regression affected the entire East-European Platform. There are no examples of Lower Cambrian deposits overlying the true Lontova beds in continuous succession. On the contrary, even the best successions at the boundary between the Talsy and underlying formations have distinct evidence of non-deposition. Only in the western parts of the Baltic syneclise, in North Poland, do the Holmia Cambrian and underlying deposits grade into each other in the view of Polish geologists (Żarnowiec Formation, and probable equivalents of the Mazowsze Formation, Zawiszyn Formation and overlying beds). However, the assumption that the Żarnowiec Formation, and the deposits tentatively correlated with the Mazowsze Formation of the Lublin slope of the plat-


LADOGA
LAKE
HELSINKI
LENINGRAD
STOCKHOLM
TALLIN
BALTIC SEA
RIGA
KALININGRAD
MINSK
WARSAW
LUBLIN
KATOWICE
CRACOW
KIEV
LVOV
CHERNOVTSY
A-PR
V-Є1
50 0 50 100 km

form, could be older than the Holmia beds has not been supported by paleontological evidence. It is conceivable that these beds which are basal formations of the transgressive complex, are not coeval in different regions of North Poland. As for the Zawiszyn Formation (= Mobergella "zone") – its sub-Holmia (pre-Talsy) age and stratigraphic position in the Cambrian section in western areas of the Baltic Basin and in the Podlasie depression, where it was first recognized, are still debatable. Moreover, when the volume on stratigraphy had been prepared for publication, an acritarch assemblage, very similar to that of the Talsy horizon, was found by T.V. Jankauskas in the type section of the formation (Tłuszcz-1 borehole). These data allow us to consider the Zawiszyn Formation as Talsy in age*.

As we cannot assign the break in sedimentation between the Lontova and Talsy Stages on the East-European Platform to a particular stratigraphic interval in the Cambrian, consequently, we do not also know the relative duration of post-Lontova Stage, during which the platform was above sea level. The time span may have been lengthy enough because we find at the top of the Lontova deposits rather thick (up to 15 m) weathering crusts represented by variegated ferruginate rocks with a high kaolinite content and subaerially weathered minerals. Thus, by the onset of the Talsy transgression, the East-European Platform may have been a peneplaned landmass with slightly dissected topography.

The new – Talsy – transgression was associated with a considerable reorganization in the structural framework of the East-European Platform.

At the Talsy Stage, as compared to the Lontova Stage, processes of downwarping were operative essentially in other regions of the platform (Fig. 8, inset). Thus, at the Early Talsy Stage the emplacement of the Baltic Basin took place.

* This involves certain difficulties in compilation of the map chiefly due to some inconsistency between the extent of the Zawiszyn Formation and that of the Talsy Stage in some Polish sections; this can affect the details of the Polish part of the map.

Fig. 8. Litho-palaeogeographic map of the western East-European Platform. Lower Cambrian. Talsy Stage. Compiled by V.V. Kiryanov from data of B. Areń, A.P. Brangulis, V.Ya. Bessonova, V.V. Kiryanov, K. Lendzion, T.V. Jankauskas

For legend see Fig. 3. Key to fauna see in Fig. 6. Boreholes: *1* – Kostovo, *2* – Siesta–Palkino, *3* – Muraste, *4* – Essu, *5* – Utria, *6* – Silverskaya, *7* – Arkukyula, *8* – Porkhovo, *9* – Vikhterpalu, *10* – Tapa, *11* – Laitse, *12* – Ellavere, *13* – Ardu, *14* – Yaama, *15* – Rannapungerya, *16* – Khaapsalu, *17* – Stolbovo, *18* – Emmaste, *19* – Kynnu, *20* – Eiammaa, *21* – Virtsu, *22* – Palamuze, *23* – Eikla, *24* – Laeva, *25* – Pärnu, *26* – Viliyandi, *27* – Kingisepp, *28* – Kaagvere, *29* – Seliste, *30* – Sosedno, *31* – Zyaedemeeste, *32* – Otepää, *33* – Kolka, *34* – Ovishi, *35* – Myniste, *36* – Valmiera, *37* – Krasnodudovo, *38* – Aluksne, *39* – Piltene, *40* – Talsy, *41* – Birini, *42* – Engure, *43* – Kemeri, *44* – Vergale, *45* – Dobele, *46* – Atasiene, *47* – Ludze, *48* – Shakina, *49* – Salantai, *50* – Vishki, *51* – Butkunai, *52* – Traubai, *53* – Verkhenedvinsk, *54* – Svedasai, *55* – Kryakyanava, *56* – Leliai, *57* – Łeba, *58* – Smołdzino, *59* – Żarnowiec, *60* – Yagodnaya, *61* – Shakyai, *62* – Hel, *63* – Paukshchyai, *64* – Kupa, *65* – Ladushkine, *66* – Gusevskaya, *67* – Prenai, *68* – Kubilyai, *69* – Gdańsk, *70* – Krynica Morska, *71* – Kalwaria, *72* – Kurenets, *73* – Kościerzyna, *74* – Henrykowo, *75* – Kętrzyn, *76* – Ilgai, *77* – Suwałki, *78* – Jeleniewo, *79* – Poshkos, *80* – Krasnoe, *81* – Kętrzyn, *82* – Olsztyn, *83* – Prabuty, *84* – Gudo Shalis, *85* – Ełk, *86* – Pisz, *87* – Cherven, *88* – Olszyny, *89* – Koptsy, *90* – Nidzica, *91* – Tatarowce, *92* – Svisloch, *93* – Zambrów, *94* – Iwanki–Rogozy, *95* – Ostrów Mazowiecka, *96* – Glussk, *97* – Starobin, *98* – Krzyże, *99* – Wrotnów, *100* – Tłuszcz, *101* – Doshevichi, *102* – Lesevchitsy, *103* – Mielnik, *104* – Okuniew, *105* – Orlya, *106* – Kobrin, *107* – Girsk, *108* – Pinsk, *109* – Łuków, *110* – Stradech, *111* – Radzyń, *112* – Wisznice, *113* – Lyakhovtsy, *114* – Mutvitsa, *115* – Zhirichi, *116* – Kaplonosy, *117* – Krowie Bagno, *118* – Nuino, *119* – Bolshoi Obzyr, *120* – Serekhovichi, *121* – Chernyavka, *122* – Zayachevka, *123* – Berezhtsy, *124* – Godomichi, *125* – Białopole, *126* – Stenzharichi, *127* – Vladimir Volynski, *128* – Kleven-19, *129* – Lutsk, *130* – Kleven-4, *131* – Litovizh, *132* – Radov-Selo, *133* – Gorokhov, *134* – Glinyany, *135* – Berestechko, *136* – Brody, *137* – Peremyshlyany, *138* – Ivanovtsy, *139* – Ivanovka, *140* – Zavadovka, *141* – Gusyatin, *142* – Buchach-1, *143* – Zarechanka, *144* – Kamenets Podolski, *145* – Darabany, *146* – Kotylevo. For locations see Fig. 2

An axial, most deeply subsided part of the Lvov – Lublin marginal system (including the Podlasie depression), widened and was displaced south-westward. On the contrary, continental conditions dominated the regions previously flooded by the Lontova sea, namely, the Moscow Basin, Orsha – Krestsy depression, Podlasie and Latvia saddles, along with the central parts of the Baltic and Ukrainian shields.

After the pre-Talsy break, the new marine transgression occupied only affected the area of the western slope of the Ukrainian shield and the Brest depression, while in the second half of Talsy time it advanced onto the south-eastern slope of the Baltic Shield. The marine transgression spread over the western and southern slopes of the Mazowsze-Byelorussian anteclise as well. It should be noted that in the Early Cambrian the former structures represented a single element of the platform. The deposits found by A.E. Biryulev (which are not yet adequately studied but are certainly Cambrian in age) in the graben-like structure of the eastern part of the Ratno Uplift which separates them at present, suggest that the age of the uplift and that of the Łuków – Wisznice continuation into East Poland is younger than was previously thought. In Talsy time the uplift may have been below sea level. This is also illustrated by an isopach map of the Talsy deposits in the regions studied. The younger Svadnen uplift in Volhynia seems not to have retarded the Talsy sedimentation.

The most conspicuous transgressive pattern of the Talsy rocks is observed in the north-western Soviet Baltic area. Deposits of the horizon there exhibit a pronounced cyclic structure, viz. basal formations, sediments of maximum marine transgression and regression can be recognized.

The oldest basal deposits of the horizon consist of sandy and silty rocks up to 60 m thick; they are placed in the coeval Ovishi and Syru Formations in the western parts of Latvia and Estonia. The predominance of sandy rocks over clayey and silty material in the Ovishi Formation as compared to the Syru Formation suggests the accumulation of the former during more vigourous subsidence which was compensated by the deposition of coarse terrigenous material. These deposits are obviously related to the axial part of the Baltic Basin and rest on the basement rocks; they seem to be most widespread beneath the present Baltic Sea. Crystalline rocks constituting the southern slope of the Baltic Shield and the north-western slope of the Mazowsze-Byelorussian anteclise may have served as the most prolific source area for the axial part of the basin during the deposition of the Ovishi Formation.

A large amount of clay and silty material in the Syru Formation can be attributed to the sedimentary environments within the north-eastern centriclinal termination of the axial part of the Baltic Basin where, in Talsy Stage, the descending movements were slow and uneven and governed an unstable hydrodynamic regime in this part of the basin. The material could be derived not only from the basement rocks, but also from the Lower Cambrian clay beds which made up the floor of this part of the basin and low land areas of the south-eastern slope of the Baltic Shield; the low land extended eastward from the Syru Formation.

No distinct basal deposits of the Talsy Stage, similar to those underlying other areas, have been reliably recognized in the Zawiszyn Formation in the western part of the Baltic Basin, despite of the predominance of sand and silty rocks there. They may be equivalent to the lower part of the formation in the westernmost sections of the study area. However, it is not improbable that, as noted above, a sandy sequence tentatively assigned in northern Poland to the equivalents of the Mazowsze Formation, and, in some sections, the Żarnowiec Formation, may also be a basal formation of the Talsy deposits. In this case the map of the Talsy deposits of the western Baltic Basin would differ slightly from the one presented here.

A further subsidence of the platform basement in the Baltic area resulted in the formation of a sublatitudinal ambayment within the south-eastern slope of the shield in the second half of the Talsy time. The embayment covered the entire area of continental Estonia, the northern part of the Leningrad region and probably stretched east of the longitude of Leningrad. Thus, the Talsy marine transgression reached its maximum at that time in the north-western East-European Platform.

The Late Talsy deposits are chiefly represented there by clays interbedded with siltstones; only the upper part of the succession in North Estonia is composed of homogeneous coarse-grained oligomictic siltstones. The most widespread lower clay-silt part of the succession is recognized as the Lükati Formation (up to 18 m thick) in Estonia and the Leningrad region and the coeval lower (sub-Saka) unit of the Ventava Formation (up to 24 m thick) in West Latvia. The time of their deposition probably corresponds to a stage of very low subsidence of the Baltic area associated with a marked decrease in the number of source areas for the marine basin discussed. Shallow water and irregularity of its floor are reflected in a complex system of submarine "barriers" and shoals which were responsible for a sluggish hydrodynamic regime of the basin upon the slope of the shield. A slow and progressive reworking of the bottom topography, made up of the Lontova clays, as well as deposition of coarse terrigenous material derived from the source areas adjacent to the coastline, led to the abundance of pelitic particles in the Lükati Formation on the south-eastern slope of the Baltic Shield. This is consistent with a high clay content chiefly in the lower part of the formation and with a similarity in mineralogy with the underlying Lontova Formation. This is also confirmed by some regularities in the distribution of lithofacies zones within the present extent of the Lükati Formation on the shield slope. A zone extremely rich in pelitic material is known from the north-western part. This zone probably corresponds to the central, most distant part of the marine basin. A zone with a minimum (less than 10%) content of pelitic material is situated in the south-eastern part of the belt. The zone follows the south-eastern limit of the Lükati deposits and suggests proximity to the coastline during the deposition of the formation.

A shallow quiet and well-warmed basin at the time of maximum marine transgression in the eastern parts of the Baltic syneclise was quite favourable for the existence of different organisms, such as *Schmidtiellus mickwitzi* (Schm.), *Volborthella tenuis* Schm., *Luckatiella argillosa* Mens, hyolithids, hyolithelminthes, platysolenitids, various deposit-feeders and abundant species of acritarchs.

The final stage in the deposition of the Lükati Formation was probably controlled by the basin floor at the time having a level profile and, hence, more active hydrodynamic regime. This is indicated by a more homogeneous silty composition of the upper part of the formation throughout its areal extent. Environmental conditions during the terminal stage in the development of the Talsy marine basin of the eastern parts of the Baltic syneclise favoured the appearance of as abundant but low-diversity fauna of inarticulate brachiopods, such as *Mickwitzia monilifera* (Linn.) and others.

The predominance of slity, mixed with sandy, material in the lower unit of the Venta Formation in East Latvia suggests a somewhat different environment in the Baltic Basin. The older sandy and silty Ovishi beds, but not the clayey Lontova deposits seem to have been subjected to some reworking on the sea floor. At the same time the marine basin in this area was also characterized by very slow subsidence, shallow waters, sluggish hydrodynamic regime, and shortage of source areas. This is confirmed by similar structural features of the lower unit of the Venta and the Lükati Formations, numerous trace fossils and similar abundances of fauna and acritarchs.

Late Talsy Stage, i.e. the stage of maximum marine transgression, seems also to be associated with the deposition of the Zawiszyn Formation in the western parts of the Baltic Basin. This is shown by the fact that in North Poland the formation overlaps the Żarnowiec Formation, and the basement complex in the western and eastern sections respectively. Hence, this suggests that the present limit of the Zawiszyn Formation in north-eastern Poland lies not far from the former coastline of the Talsy marine basin in the area. The mainly sandy composition and poor roundness of mineral grains in sandstones of this formation in the western parts of the Baltic Basin reflect short transport and supply of material mainly from basement rocks. Poor sorting of the material, alternations of sandstones and minor siltstones, difference in content of pelitic particles, absence of sharp contacts between sandstone and siltsone interbeds, imply an active hydrodynamic regime in this part of the basin and relatively rapid deposition (Lendzion, 1976). In Late Talsy time the floor of this part of the basin underwent intense, but uneven subsidence. This led to the formation of peculiar habitats for organisms populating the Late Talsy marine basin and the western parts of the Baltic Basin. Such an environment seems to have been favourable for a wide distribution of mobergellas and primitive trilobitelike fossils but unfavourable for faunas inhabiting the eastern parts of the basin at that time.

Like the eastern Baltic Basin deposits of the Talsy horizon have a distinct cyclic structure within the Lvov – Lublin marginal system and slong the slope of the Ukrainian Shield. However, overlap in not observed there because the Talsy deposits are completely removed in the eastern parts of the area. Overlapping of the Talsy horizon in the subregion discussed can be inferred mainly on the basis of lithofacies zoning in different regions.

The lower part of the basal sequence of the Talsy horizon is represented by the Lower Dominopol Member in Volhynia and its equivalents in Podolia, the lower Spanovo Formation of the Brest Depression the lower Kaplonosy Formation of the eastern Podlasie Depression (Mielnik-1 borehole) and of the Lublin slope of the platform. These deposits are equivalent to a sandy rock succession recognized as the upper Mazowsze Formation in the western Podlasie Depression (Okuniew-1 and Tłuszcz-1 boreholes). The thickness of the basal formations of the Talsy horizon varies from 40 m to 100 m.

A very wide areal distribution of the Early Talsy deposits in the western part of the platform, poor sorting of terrigenous material and mainly sandy composition of the rocks suggest their accumulation in an extensive shallow marine basin with an active hydrodynamic regime. The great thickness and rather persistent lithology of the deposits point to a fast and even subsidence of the Early Talsy sea floor compensated by intense sedimentation. The Riphean and Vendian terrigenous rocks may be considered as a source area for the basin. A part from these Precambrian rocks, material seems to have been derived from weathering crusts of the Lontova horizon, indicated by a kaolinite hydromicaceous composition of the clay fraction in the basal deposits of the Talsy horizon, as well as the presence of brown silt interbeds dominated by altered hydrogoethitized micas in the lower part. A relatively low content of altered feldspars (4 to 6%) in these deposits suggests that products of basement rock breakdown had not strongly affected the Early Talsy sedimentation and had been transported for long distances. The only exception may have been the western Podlasie Depression where the amount of feldspars ingreases, according to K. Lendzion, to 7–9%, and in the lower part (Tłuszcz-1 borehole) even to 20–22%. On the sea floor of the Early Talsy basin there may have been an ancient basement high (whose location is still unknown), not covered by younger sediments, which may have been eroded not far from the above mentioned regions. This is supported also by a small thickness (about 11 m) of the underlying Lontova deposits in the Tłuszcz-1 borehole where they rest directly on the basement rocks.

In the Podolian part of the western slope of the Ukrainian Shield the Early Talsy sediments only completely survived post-Cambrian erosion in isolated sections. However, over the whole area they are represented by homogeneous quartzose and rare feldspar-quartzose sandstones with conglomerates and gravelstones at the base. Gravel and pebble are composed of angular quartz fragments from the underlying variegated Lontova siltstones (Zbruch Formation) and, locally, of unaltered feldspar fragments. In some sections gravel material can be also encountered as rare well rounded grains 15–16 m above the base of the sandy sequences. Unaltered feldspars, large rolls of underlying rocks in the lower part, and admixture of coarse clastic quartzose material allow this succession to be considered as near-shore marine facies of the Early Talsy basin. A source area for this part of the basin was probably situated in the immediate proximity of the succession, and, apart from the Early Cambrian and Vendian sedimentary strata, was composed of crystalline rocks. The Early Talsy sandy strata, similar in facies but far removed from the coastline, appear to have been formed on the southern slope of the Mazowsze–Byelorussian anteclise as well.

On the western East-European Platform no fossils have been found as yet in the basal deposits of the Talsy horizon.

In the area discussed, as well as in the north-western part of the platform, Late Talsy time witnessed the maximum marine transgression. This period was marked by a gradual decrease in the rate of subsidence of the region and by reduction of irregularities on the sea floor. However, the subsidence had not slowed down concurrently in different regions of the western East-European Platform, and hence a varying thickness ratio occurs between the lower – basal – and the upper – silty – sequences of the Talsy horizon in different sections. Moreover, the rate of subsidence in Late Talsy time was not constant, viz., phases of relatively stable regime gave way to abrupt subsidence; the character of the hydrodynamic regime of the basin was variable as well. This is reflected in a frequent alternation of sandstone and siltstone units, particularly at the beginning of Late Lükati time. A slight, but regular rise in feldspar content (up to 9%) in the Upper Dominopol Member in Volhynia, with its mineral composition being similar to that of underlying deposits, probably implies a certain widening of provenance areas for the Late Talsy basin in the study area on account of basement rocks. One may expect a similar increase in feldspar content in the course of thorough mineralogical studies of age equivalents of the Upper Dominopol Member in Volhynia in other regions of the western part of the platform, such as the upper Spanovo Formation in the Brest Depression, upper silty strata of the Kaplonosy Formation of the Lublin slope of the platform and eastern Podlasie Depression, as well as the Zawiszyn Formation in the western Podlasie Depression.

As a whole, is a similar bipartite structure of the Talsy sections across the territory of the western East-European Platform not obvious only in two areas. One of them is near the town of Peremyshlyany in the Lvov Region. Here, the south-western most Cambrian section exposed in Volhynia – Podolia, contains the Talsy deposits represented by rather thick monotonous siltstones interbedded with claystones. The region may have been the most distant from the Talsy basin coastline in Volhynia – Podolia and formed at that time part of the axial, most deeply subsided zone of the Lvov – Lublin marginal system of the platform.

The second area is situated in the Vladimir-Volynski deep fault zone. Basal formations of the Talsy horizon (Vladimir-Volynski-1 structural well) are very thin (about 12 m) here. The rest of the Dominopol section (over 100 m) consists of siltstones interbedded with subordinate sandstones. North and south of the borehole, i.e. beyond the fault zone, the structure of Talsy strata (borehole 992 at the town of Vladimir-Volynski and Vladimir-Volynski-1 borehole) is typical of the western part of the platform. Such a drastic facies change at a distance of a few kilometres suggests that during Talsy time the Vladimir-Volynski fault was a synsedimentary local structure. It may have been a narrow, trough several kilometres wide, on the sea-floor marked by a relatively quiet and stable hydrodynamic regime. Some peculiar fossils have been recorded in the Talsy deposits of the region discussed. An acritarch assemblage from the siltstones of the Dominopol Formation in the Vladimir-Volynski fault zone is entirely identical to that of the Late Talsy deposits in Latvia and Estonia, however, it differs slightly from that of the upper part of the formation in adjacent (to the north and south) sections of Volhynia. Trilobites and abundant Volborthella, common in the Late Lükati deposits of the Soviet Baltic area, were also found in the Dominopol Formation of the fault zone.

In the westernmost parts of the Podlasie Depression Mobergella and primitive trilobite-like fossils were found in the Late Talsy deposits (Zawiszyn Formation) represented by sandstones irregularly interbedded with siltstones. Uneven subsidence of the sea floor and resultant peculiar depositional environment probably caused the emergence of specific habitats favourable for the distribution of the above fossils. At a certain stage of basin development similar environments could exist not only in the western parts of the Baltic Basin and Podlasie Depression, but also over most of the western East-European Platform. Therefore some new occurrences of Mobergella are likely to be reported from the eastern sections of the Talsy horizon of the Lvov – Lublin marginal system of the platform where they have not been found as yet.

Talsy Stage terminated with a marine regression on the East-European Platform. This is suggested by the appearance in some sections of variegated rocks rich in altered hydrogoethitized mica at the top of the horizon, as well as sandstones containing very angular and angular-rounded grains of terrigenous minerals in a kaolinite-hydromicaceous matrix. Regressive marine conditions in the western part of the platform at the end of Talsy time are also suggested by single occurrences of inarticulate brachiopods (Mickwitzia) in the upper Dominopol Formation of Volhynia. These brachiopods, as mentioned above, are characteristic of coeval regressive deposits of the Talsy basin in the north-western Soviet Baltic area.

The data currently available do not permit us to reliably estimate the extent of the Talsy marine regression across the platform. Evidence obtained in the territory of Poland about the continuous sections at the boundary of the Zawiszyn Formation and the overlying deposits in the westernmost Baltic Basin and in the Podlasie Depression suggests an incomplete regression on the East-European Platform at the close of Talsy time, when the sea covered only its westernmost part. Marine conditions appear to have persisted also in the more westerly parts of the Lvov – Lublin marginal system within the present Ukrainian SSR.

## VERGALE – RAUSVE STAGE

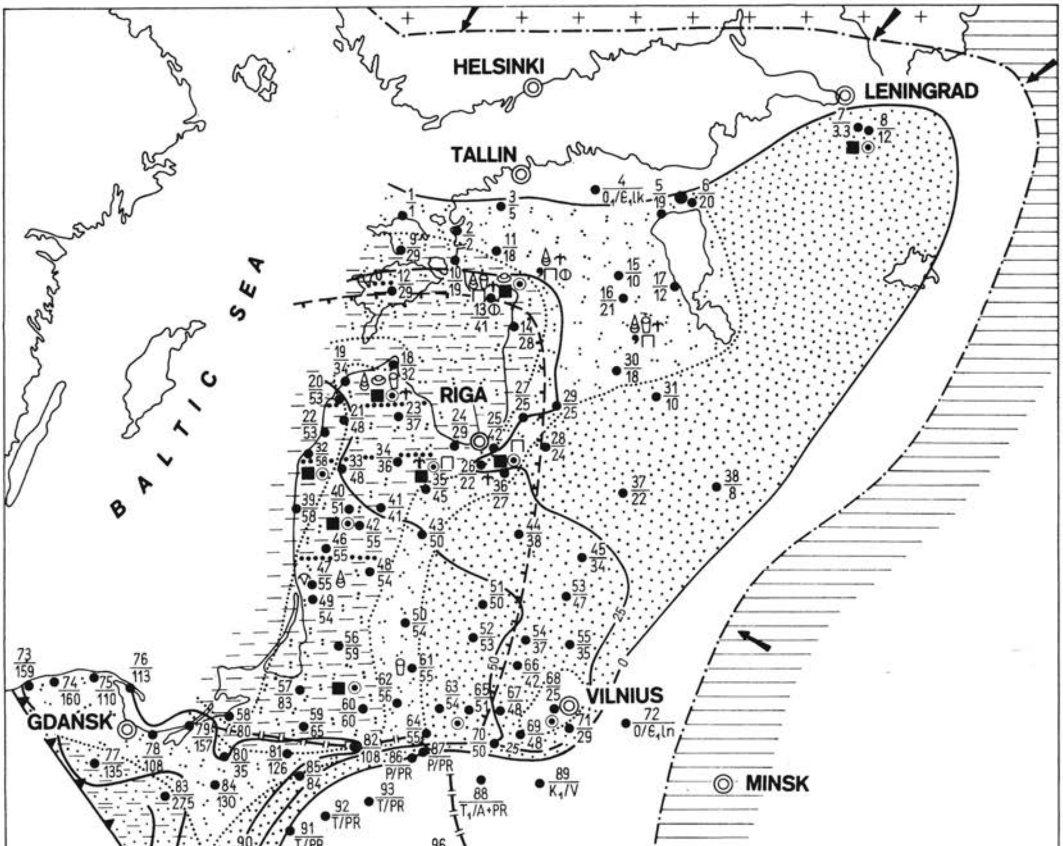
Unlike the early maps for the Early Cambrian, the lithopalaeontological map for the Vergale – Rausve Stage (Fig. 9, inset) shows a longer time span in the geological history of the East-European Platform. Thus, this time span tentatively encompasses, in addition to deposits of the Vergale and Rausve horizons proper, and underlying sand-silt sequence recognized as the Soela Formation, in the northern Baltic Basin, and as the Lyuboml Formation on the Volhynian slope of the Ukrainian Shield in the Kishinev-Lvov Depression. The position of the sand-silt sequence is one of the unsolved problems in the Early Cambrian stratigraphy of the East-European Platform. So far, acritarchs have been found only at two localities (Varbla borehole in the Baltic Basin, and Korytnitsa-B-26 borehole on the Volhynian slope of the Ukrainian Shield). The acritarch assemblage has a peculiar species composition; leiospherids dominate the section, acanthomorphic forms are scarce, but the presence of *Baltisphaeridium ciliosum* Volk. and *B. varium* Volk. suggests affinity with the Vergale, rather than Talsy assemblages. With due regard for this, as well as for the position in the section and mineralogy of the rocks, the sand-silt sequence is considered to be the basal deposits of the Vergale-Rausve Stage of sedimentation. This conclusion is quite tentative, since this sand-silt sequence exhibits stratigraphic independence; in future it may be proposed as a separate unit at the rank of horizon in the regional stratigraphic scheme.

The compilation of an "index" litho-palaeogeographical map for the last stage of the Early Cambrian is hampered by the paucity of palaeontological data necessary for subdivision of the post-Talsy deposits into horizons over the entire western margin of the platform. Moreover, inadequate biostratigraphic information for the Vergale and Rausve deposits proper, in the near-shore facies of uniform sand-silt deposits, does not allow us to trace the boundary between these horizons across the territory under consideration.

The Vergale – Rausve deposits overlap deposits of different age down to the basement rocks. The lower boundary of the complex discussed is distinct owing to the effects of subaerial weathering in the upper part of the underlying rocks. In places this boundary is additionally marked by pebbles of silty and clayey rocks at the base of the rock unit. It is only difficult to draw this boundary in the areas composed of deposits of the regressive phase of the Talsy Stage of sedimentation; these deposits superficially resemble the Vergale – Rausve basal deposits.

At many localities, particularly in the eastern regions, the upper boundary is erosional. Only in places where deposits of the Kibartu horizon are developed, i.e. where stratigraphic succession are observed, is the upper boundary less distinct. Structural characters and rock-type ratios, apart from palaeontological data, serve as controlling factors there.

The litho-palaeogeographical map for Vergale – Rausve Stage is uneverly substantiated. The most reliable data are available for the north-western subregion of the platform, in particular for the Baltic Basin. Very limited information has been obtained to decipher palaeogeographical environments in the south-west. Hence, sedimentary facies have been reconstructed only for the north-west,


HELSINKI
LENINGRAD
TALLIN
BALTIC SEA
RIGA
VILNIUS
MINSK
GDAŃSK
WARSAW
LUBLIN
CRACOW
LVOV
50 0 50 100 km

and only for the present limits of the Vergale – Rausve deposits whose thickness and general distribution were shown for the south-western subregion.

The Talsy marine regression covered almost the entire western margin of the East-European Platform. The available data do not enable reliable determination of the extent of the regression. The sea is believed to have remained along the westernmost rim of the platform (see Fig. 9).

The Vergale – Rausve Stage of development of the area under study has a tectonic framework similar to that of the Talsy Stage: such major structures as the Baltic Basin, Podlasie-Brest Depression, depressions on the Volhynian and Lublin slopes of the Ukrainian Shield, and the like, emplaced at the previous stage, continued to develop. In the Vergale – Rausve Stage all these geostructures were subsided and water-filled areas. In the Talsy Stage, however, unlike a small area of sedimentation, negative structures and some adjacent area were completely inundated.

A strongly eroded easterly section does not allow us to outline the marine basin of that time. The present limit of the Vergale – Rausve deposits in the north lies slightly south of the Gulf of Finland, reaches the Leningrad Region in the north-east, then turns south-west passes via the Ilment Lake to Vilnius where it trends latitudinally and, rounding the Byelorussia-Mazury anteclise, runs farther south (see Fig. 9). The northern and north-eastern limits of the Vergale – Rausve marine basin may have been far beyond those of the present deposits. The northern extent of the boundary is supported by the presence of palaeontologically substantiated age equivalents of the Vergale and Rausve horizons in fractures of the crystalline in Öland and in the Turku Region, Finland (Simonen, 1956). The reconstruction of the north-eastern boundary of the basin (Leningrad and Pskov regions) presents difficulties because of an uncertain stratigraphic position of the Izhora sequence in the western and central parts of the Moscow Basin. In the south-east of the study area (eastern Podlasie-Brest Depression and Volhynian slope of the Ukrainian Shield) the boundary of the basin also lay farther east of the present limit of the deposits, as suggested by rock thickness, clay composition and lack of evidence for near-shore facies. It is difficult to

Fig. 9. Litho-palaeogeographic map of the western East-European Platform. Vergale and Rausve Stage. Compiled by A.P. Brangulis and T.V. Jankauskas from data of B. Areń, A.Ya. Bessonova, K.A. Mens, V.V. Kiryanov, K. Lendzion, E.A. Pirrus

For legend see Fig. 3. Key to fauna see in Fig. 6. B o r e h o l e s: *1* – Takhkuna, *2* – Khaapsalu, *3* – Laitee, *4* – Tapa, *5* – Rannapungerya, *6* – Yaana, *7* – Izhora, *8* – Tosna, *9* – Yammaste, *10* – Virteu, *11* – Rumba, *12* – Eikla, *13* – Seliste, *14* – Khyaedemeste, *15* – Laeva, *16* – Elva, *17* – Mekhikoorma, *18* – Kolka, *19* – Ovishi, *20* – Ventspile, *21* – Piltene, *22* – Yurkalne, *23* – Talsy, *24* – Kecheri, *25* – Riga, *26* – Olaine, *27* – Birini, *28* – Nitaure, *29* – Tsirulishi, *30* – Laanemetsa, *31* – Aluksne, *32* – Pavilosta, *33* – Skrunda, *34* – Kandava, *35* – Dobele, *36* – Baldone, *37* – Atasiene, *38* – Ludza, *39* – Pape, *40* – Vainede, *41* – Ezere, *42* – Renava, *43* – Shakina, *44* – Paroveya, *45* – Butkunai, *46* – Salantai, *47* – Gargzai, *48* – Tolyai, *49* – Zharenai, *50* – Vidukle, *51* – Kryakyanava, *52* – Lyadai, *53* – Svedasai, *54* – Ukmyarge, *55* – Loliai, *56* – Stoniskiai, *57* – Krasnoborskaya, *58* – Ladushkino, *59* – Pravdinsk, *60* – Gusev, *61* – Shakyai, *62* – Kibartai, *63* – Sasnava, *64* – Kalvaria, *65* – Prenai, *66* – Paukshchyai, *67* – Kubilyai, *68* – Yachenis, *69* – Tauchenis, *70* – Ilgai, *71* – Vilkishkyai, *72* – Smorogon, *73* – Smołdzino, *74* – Łeba, *75* – Żarnowiec, *76* – Hel, *77* – Kościerzyna, *78* – Gdańsk, *79* – Krynica Morska, *80* – Henrykowo, *81* – Kętrzyn, *82* – Gołdap, *83* – Prabuty, *84* – Olsztyn, *85* – Kętrzyn, 86 – Jeleniewo, *87* – Suwałki, *88* – Druskininkai, *89* – Radun, *90* – Nidzica, *91* – Olszyny, *92* – Pisz, *93* – Ełk, *94* – Ostrów Mazowiecka, *95* – Zambrów, *96* – Tatarowce, *97* – Zabłudów, *98* – Rajsk, *99* – Svisloch, *100* – Wyszków, *101* – Łochów, *102* – Tłuszcz, *103* – Okuniew, *104* – Wrotnów, *105* – Stadniki, *106* – Krzyże, *107* – Mielnik, *108* – Deshevichi, *109* – Lesovchitsy, *110* – Novoselki, *111* – Orlya, *112* – Zhabinka, *113* – Brest, *114* – Kobrin, *115* – Girsk, *116* – Zembry, *117* – Łuków, *118* – Radzyn, *119* – Parczew, *120* – Wisznice, *121* – Shcherbin, *122* – Olkhovka, *123* – Mutvitsa, *124* – Nuino, *125* – Kaplonosy, *126* – Krowie Bagno, *127* – Padmanevo, *128* – Busówno, *129* – Berezhtsy, *130* – Chernyavki, *131* – Białopole, *132* – Stenzharichi, *133* – Vladimir Volynski, *134* – Litovezh, *135* – Lutsk, *136* – Kleven, *137* – Gorokhov, *138* – Berestechko, *139* – Brody, *140* – Peremyshlyany, *141* – Berezhany, *142* – Ivanovtsy, *143* – Buchach, *144* – Kamenets Podolski. For locations see Fig. 2

reconstruct the south-western boundary of the basin because of the deep occurrence of the rocks and inadequate evidence concerning the area. It is only known that along the Lublin slope of the Ukrainian Shield and in the Podlasie Depression (Polish People's Republic) the thickness of the Vergale – Rausve deposits usually exceeds 300 m and that clay content increases westward. This suggests that in the south-west the basin stretched to the Mediterranean geosynclinal belt. Whether the basin was separated from the geosynclinal sea by a landmass, and they were linked through a passage, or whether the part of the basin studied was a marginal sea, remains uncertain because of the paucity of data.

The north-western part of the Vergale – Rausve basin embraced, apart from the present Baltic Sea, most of continental Sweden where the Vergale – Rausve deposits occur as small patches; hence the type of the connection between the two basins is difficult to reconstruct. The Early Cambrian succession of the geosynclinal area, the mineralogy of the rocks and their fossil content, suggest that in the north-west the platform basin was linked directly with the Scandinavian geosynclinal sea.

Lithology and palaeontology of the Vergale – Rausve deposits show that the basin was shallow and that island topography persisted locally thoughout the stage. The Byelorussian-Mazury anteclise, occasional uplifts within the Baltic Basin, and other structures are related to the above areas (Muromtseva *et al.*, 1974). The presence of weathering crusts in the upper parts of the underlying (Lontova Talsy and crystalline) rocks indicates that prior to the Vergale – Rausve transgression most of the area was a peneplaned surface.

A relatively low content of coarse clastic rocks in the basal Vergale – Rausve beds over the entire area of their distribution suggests a relatively quiet marine transgression and a smooth topography of the sedimentary basin and of the source area. A quiet hydrodynamic regime at the beginning of the transgression is also indicated by the well-preserved weathering crust on the underlying rocks mentioned above.

The Vergale – Rausve marine transgression advanced from west to east, like the preceding Talsy transgression, but the former covered a wide area, and the whole western margin of the platform was subject to intensive and extensive subsidence. As a result, Talsy landmasses which in places had served as barriers to sea ingression eastward found themselves under water, for example, the Valmiera – Lokno uplift. Laterally the transgression developed unevenly as is evident from different degrees of stratigraphic completeness of the sections of that time. Thus, the pre-Vergale sand-silt sequence is certainly missing from the south-eastern parts of theBaltic Basin (western Lithuania and Kaliningrad Region), and the Vergale deposits rest directly on the basement rocks (Jankauskas, 1974). It is difficult to determine the time of transgression in the eastern regions of the study area, because appropriate deposits in the south-western subregion were eroded and sand-silt rocks of that age in the north-western subregion have not been properly studied as yet.

The thickness of the sand-silt sequence indicates that the western regions directly adjacent to the geosynclinal trough were first to subside. During the initial phase the downwarping was intense, particularly in the south-western subregion, almost completely compensated by sedimentation under shallow water conditions. This is shown by a relatively great thickness (up to 80 m) of these deposits, their sand-silt composition and the presence of powder of opaque minerals and fine flat, almost syngenetic clayey pebbles on bedding planes, and the absence of pronounced intraformational breaks. With the eastward ingression and washing out of more clayey and less weathered rocks from source areas, more fine-grained deposits started to accumulate in the areas distant from the coastline. A differential downwarping is suggested by an alternation of rocks of different grain size, the presence of intraformational breaks generally associated with the base of ferruginous oolith interbeds, an areal lithofacies zonation observed in the north-western subregion and the like. Inspite of a high clay content (locally in excess of 50%) in this part of section, the lithology of the rocks (ferruginous oolith interbeds, glauconite) shows that sedimentation took place in a shallow water-environment. This is also confirmed by fossils dominated by benthic forms with abundant soft-bodied deposit-feeders. The composition and structure of the Vergale and Rausve horizons allow us to conclude that the maximum extent of the transgression fell within Vergale Stage, while the Rausve deposits have evidence of regression. This is indicated by a high proportion of silty or rarer sandy rocks, predominance of inarticulate brachiopods, and an increase in glauconite in the Rausve horizon deposits, apart from the absence of rocks rich in ferruginous minerals.

The peneplaned regions of the Baltic and Ukrainian Shields, adjacent at that time to the Vergale—Rausve marine basin were source areas in addition to the unflooded eastern parts of the platform. Islands areas within the basin (Byelorussian-Mazury anteclise, occasional basement uplifts in the Baltic Basin and the like), which remained above sea level, served as local source areas as well. The mineralogy of clastic components implies that the material was mainly derived from the weathering crust. At the initial stage of sedimentation, when almost monomineralic quartzose kaolin-bearing sandstones and coarse grained siltstones accumulated, the upper zones of weathering crusts were eroded and replaced by less weathered rocks (oligomictic coarse clastic rocks and polymictic fine-grained rocks of the Vergale and Rausve).

Over most part of the area under consideration, the Vergale—Rausve deposits are overlain by clayey and sandy rocks of the Kibartu horizon containing Middle Cambrian trilobites and brachiopods. The structure and composition of the overlying deposits (rock type ratios, glauconite dustings on bedding planes, presence of intraformational breaks marked by conglomerate interbeds, abundant fossils of relatively uniform benthic fauna) unambiguously point to a regressive nature of these deposits. The absence of evidence showing non-deposition at the boundary of the Vergale—Rausve interval and the overlying deposits (Kibartu, Stavy Formations and others) may be caused by the fact that these overlying deposits represented a link in a single sedimentary cycle which started in the second half of the Early Cambrian and ended at the beginning of the Middle Cambrian.

## GENERAL PROBLEMS OF THE HISTORY OF THE EAST-EUROPEAN PLATFORM IN THE VENDIAN AND LOWER CAMBRIAN

Comparing litho-palaeogeographic maps for the Vendian and Cambrian, one gets an idea about the development of the western East-European Platform during certain epochs and can outline crucial events in its history. Of particular interest are events occurring at the Precambrian/Cambrian boundary. Litho-palaeogeographic maps for the Drevlyany Series (Blon-Vilchany and Volhyn Stages) show that the area of deposition inherited the structural framework existing in the Orsha Basin since the Upper Riphean. Although the present limit of the

Drevlyan deposits does not fully coincide with the outlines of the ancient depression, one can suggest a north-east trend for the depression which was then filled with tillite-bearing Vilchany beds and Volhyn effusive rocks. To the north the Vilchany and Volhyn deposits crop out almost to the latitude of the town of Nevel. Further north they were removed by the pre-Valdai erosion. Here we see no evidence for the continental glaciation named the Lapland Glaciation by N.M. Chumakov; the sections can be observed only in the most downwarped parts of the platform.

A volcanic terraine built up of the Volhyn deposits is known here as well. However, the epoch cannot be fully understood untill we have a proper correlation between effusive and coeval terrigenous rocks; therefore the palaeogeographic map for this time must be considered a tentative one. The litho-palaeogeographic map for Redkino Stage is believed to be much more informative. For example, an extensive trough situated between the Sarmat Shield in the east and the elongate Polish-Latvian (Baltic) Shield in the west can be outlined. The trough is separated by the narrow Łuków – Ratno uplift from the Moscov Basin located to the north. The basin is an extensive superimposed structure stretching from the region south of Vilnius through Smolensk, Podolsk and then north, westward. The most downwarped portion of the structure, where the thickness of the Redkino deposits reaches 250 m, is situated north-east of Moscov within a large triangle formed by the towns of Gorky, Vladimir and Kostroma.

Valdai time witnessed the emplacement of a new structural framework on the East-European Platform which existed throughout the Lower Palaeozoic. The time of its emplacement is a subject of controversy. E.P. Bruns (1964) considers that a pre-Volhyn* (i.e. pre-Blon-Vilchany) reorganization is of crucial importance, followed by a change from predominantly longitudinal to latitudinal strike; E.P. Bruns writes that at the second, i.e. Volhyn (s. 1) Stage of development "new structures were formed, such as gentle and extensive syneclises and anteclises typical of the subsequent history of the platform" (Bruns, 1964, p. 195). K.E. Yakobson does not hold this view. In 1966 he writes that: 1) at the Volhyn Stage the western part of the Russian Platform continued to develop following the structural framework typical of the Late Precambrian (Proterozoic, Riphean); 2) in Valdai time the development of the territory took place already within the Lower Palaeozoic structural framework. Taken together, the Valdai and Baltic Series represent a major transgressive cycle; 3) the Volhyn and Valdai Series are separated by a large structural unconformity, and the Proterozoic//Palaeozoic boundary can be drawn along this unconformity (Yakobson, 1966). These conclusions are based on palaeogeographic maps compiled for the Volyn, Valdai, and Baltic Series. The first map shows a longitudinal trough stretching trough the entire western part of the East-European Platform. The second and third maps depict a different structural framework where latitudinal troughs can be easily recognized.

The litho-palaeogeographic maps presented here are more comprehensive and confirm important changes in the structural framework during pre-Valdai time. At the same time they show that the Valdai structural framework is more inherited in nature as compared to the maps compiled by K.E. Yakobson.

In Kotlin time the development of the East-European Platform followed the structural framework of the preceding Redkino Stage. Some changes in the framework can be seen in the north-west where sedimentation spread over the entire territory of Estonia. However, as in earlier times, a zone where the Kotlin

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* Previously the Volhyn Stage comprised the Vilchany and Volhyn Stages of the modern scheme.

deposits are missing embraces extensive regions within Latvia, Lithuania, and adjacent Poland.

E.P. Bruns was the first to show that "the deposition of the Valdai (Redkino and Kotlin) Series took place in a large inland basin marked by peculiar sedimentary features. Inspite of the size, it seems to have been shallow water with weak hydrodynamics, local stagnation, and predominantly reducing conditions" (Bruns, 1964, p. 16). The authors also believe that it was a shallow basin with stagnant hydrodynamic regime, variable salinity (with freshening along the marginal parts of the basin), and with conditions varying from oxidizing to weakly reducing. The Redkino Stage is characterized by enrichment of clay rocks in organic matter. I.E. Postnikova (1977, p. 189) mentions a combustible shale unit up to 20 m thick recognized in the middle Redkino Formation of the Moscow Basin and Pachelma trough. Organic matter in the rocks amounts to 20%. The rocks are of the sapropelic type, and L.F. Solontsov names them "Vendian Domanik". It was Redkino Stage when multicellular forms of different types and classes became abundant in the basins of the East-European Platform. Among them are arthropods, annelids, hydromedusae, and a peculiar group of petalonamids assigned either to coelenterates or to a special type. These groups appeared after the Great Lapland Glaciation and inhabited a warm and shallow marine basin. All of them are represented by soft-bodied forms. D. Rhoads and G. Morse (1974) compare this type of ecological association of species with the mesopelagic fauna presently living on muddy substrates at a depth of more than 200 m in the Black Sea and in the Gulf of California under anoxic conditions. Some features of this peculiar environment are found also in the Redkino basin on the East-European Platform. However, the Recent fauna is represented by a poor assemblage whose species are adapted to unfavourable conditions. It is quite probable that similar conditions which proved to be the most favourable for the appearance of a distinctive fauna marking a qualitatively new stage in the development of life on the Earth could exist in the Redkino basin.

It is impossible to recognize how the Redkino fauna originated within the East-European Platform, since the older Drevlyany deposits consists of continental, glacial, or volcanic rocks which represent facies not favourable for the existence of marine multicellular organisms. The paucity of multicellular fossils in the Kotlin basin seems unexplained, because its hydrodynamic regime was similar to that of the Redkino basin. However, no trace fossils, except for vendotaenian flora, have been found in the Kotlin basin.

The transition from the Precambrian Kotlin basin to the Rovno basin was marked by important events. First, an extensive regression which took place neat the close of Kotlin Stage enhanced the erosion of uplifted parts of the landmass, and red sandstones known as the Reshma Formation began to accumulate in some relict basin (Moscow syneclise). Then the Rovno transgression started with the accumulation of quartz-glauconite sandstones followed by deposition of a distinctive clay sequence. The Rovno and Kotlin basins are very similar in outline, but the former became narrower in places. Its axial part, where the thickness of the Rovno Stage exceeds 50 m, seems to have displaced north--westward. It should be noted that the belt of the Kotlin deposits along a line from Leningrad to Smolensk is 650 km wide, while that of the Rovno deposits does not exceed 450 km. The Sarmatian and Baltic Shields are thought to have grown in size at that time.

The outlines of the Rovno basin did not change in the Lontova Stage, though the Lontova basin could have been somewhat broader; both the rock units are similar in type. The Rovno and Lontova Stages are made up of terrigenous rocks dominated by "blue clays". Siltstone and fine-grained sandstone interbeds are rare and subordinate. Glauconite grains are very common while in the Kotlin deposits glauconite occurs extremely rarely. The Rovno and Lontova sediments appear to have accumulated in a shallow, well aerated marine basin favourable for the development of organic life. Actually, it is in the Rovno Stage that abundant sabelliditids appear whose first occurrences are found in the Redkino deposits.

The acritarch assemblage is enriched owing to an increase in the diversity of Leiosphaeridia species and the appearance of *Teophipolia lacerata* and *Ceratophyton vernicosum*; and, finally, platysolenitids appear in the uppermost Rovno Stage.

The changes in life became even more important after the Lontova Stage as shown by various complicated crawling traces (Repichnia) abundant sabelliditids and platysolenitids, as well as gastropods, hyolithids, and hyolithelminthes. The acritarch assemblages became quite different and the most important genera among them are Granomarginata and Tasmanites.

Stratigraphic and palaeogeographic data for the East-European Platform do not permit us to unambiquously draw the Precambrian/Cambrian boundary there. The data suggest that geologically the Rovno and Lontova Stages form more or less a single whole, and the appearance of platysolenitids and sabelliditids in the Rovno Stage allows us to assign it to the Cambrian, rather than to the Vendian. At the same time the data obtained show that if we place the base of the Rovno Stage at the base of the Cambrian, then it would coincide with a major hiatus and the time of drastic changes in the marine epicontinental basin. On the other hand, the true Cambrian skeletal fossils typical of the Tommotian began to appear only from the Lontova level. A recently proposed correlation of the Rovno and Nemakit-Daldyn deposits suggests that the Precambrian/Cambrian boundary, as in the case of Siberia, should be placed at the top rather than at the base of the Rovno Stage.

All the above statements do not allow us to find a candidate for a lower boundary stratotype of the Cambrian on the East-European Platform. However, every effort should be exerted in the search for sections where the lower boundary is in a continuous succession with underlying Vendian formations represented by deposits of similar facies and containing a typical, non-skeletal fauna (even if only in the lower part).

In Talsy Stage the palaeogeographic setting of the East-European Platform drastically changed. Though the Rovno and Lontova basins inherited a general framework from the Valdai Series, and an extensive elongate trough stretched between the Sarmatian and Baltic Shields, in Talsy Stage the palaeogeographic environments becomes quite different. The Moscow Basin which earlier was an area of constant downwarping ceases to control the areas of deposition. The extensive Baltic Basin is formed in the western East-European Platform. In fact, there is only an eastern limb of this major structure where the thickness of the Talsy and younger deposits increases westwards. A slightly changed pattern continues at the Vergale – Rausve Stage, however, and a somewhat greater diversity in facies is observed. As stated above, the Talsy Stage is represented by alternations of clay and siltstone. The deposition took place in a shallow, quiet, warm basin favourable for the existence of different organisms, viz. trilobites, brachiopods, hyolithes, hyolithelminthes, various deposits-feeders, and abundant acritarchs. It is from this time that abundant species of the genus Baltisphaeridium appear on the East-European Platform. Like the overlying Vergale – Rausve

Stage, we find distinctive acritarch assemblages which allow detailed long-distance relation of the sections.

The history of the Vendian and Cambrian basins in the western East-European Platform shows important turning points which do not necessarily coincide with those in the development of life. They are as follows:

1. The deposition of the Vendian Valdai Series is reflected in the reorganization of the structural framework of the platform which coincides with the appearance and dispersal of the "White Sea biota" of multicellular organisms. Some workers consider this key change as marking the lower boundary of the Vendian.

2. The deposition of the Rovno Stage is marked by some palaeogeographic changes and a new transgression, as well as by certain changes in the dynamics and chemistry of the basin. This event coincides with the appearance of organisms which, as a rule on the East-European Platform, are considered as Cambrian in age (sabelliditids). At the same time, such conspicuous palaeogeographic changes have not been recorded at the Rovno/Lontova boundary marked by the appearance of true Lower Cambrian skeletal fossils.

3. The deposition of the Talsy Stage is marked by drastic changes in palaeogeography of the Baltic Basin and coincides with the appearance of trilobites (however, not the oldest among those known worldwide).

The recognition of the above historic and geologic boundaries and crucial epochs in the development of life over such an extensive area as the western East-European Platform enables us to reliably subdivide the Vendian and Cambrian deposits and assess the extent of the units recognized in the standard stratigraphic scale.

PART II

# PROBLEMS OF VENDIAN AND CAMBRIAN LITHOLOGY OF THE WESTERN EAST-EUROPEAN PLATFORM

## INTRODUCTION

Part II of this monograph deals with some problems concerning the lithology of the Vendian and Cambrian deposits of the western East-European Platform. The main object of the monograph is the Vendian and Early Cambrian stratigraphy and especially the Precambrian/Cambrian boundary, consequently lithology is not discussed here in great detail. Nevertheless, lithologic studies cannot be considered as secondary in importance. On the contraty, the study of the composition and regularities of sedimentation provides the main geological data about the structure of the platform cover and as such has not only theoretical but practical importance as well allowing us to understand general problems of the structure and development of the Earth's crust and in some cases to give a basis for the stratigraphic scheme accepted here. It concerns, in particular, the study of terrigenous deposits which compose the Vendian and Cambrian section of the East-European Platform. If we take into account the paucity of the palaeontological character of the Cambrian and especially Vendian deposits, and the fact that they occur mainly in different facies, then the importance of lithological data for the construction of a stratigraphic scheme becomes evident.

The lithological essays presented contain only one line of evidence available about these formations. The data concerning some specific aspects of lithogenesis (Vendian volcanism, genesis of Vendian tillites, weathering crust of laminarite clay and the like) have been published elsewhere. Some lithological data have already been used in regional stratigraphic essays (see Stratigrafia..., 1979) and others for the palaeogeographic reconstruction in this volume. However, the results listed cannot be considered as being complete because there are some recent data about the lithology of the deposits in question. Studies carried out during the last decade with respect to Vendian-Cambrian lithogenesis not only give an insight into sedimentation within ancient basins of the humid belt but allow a more detailed interpretation and solution of both scientific and practical problems.

Unfortunately, lithological studies are not always based on the stratigraphic scheme developed in the course of joint work. To a certain degree this makes it difficult to compare results presented in this section with those of the earlier volumes of (Stratigrafia..., 1979). However, reliable reference of lithological data to certain sections allows their future usage. There are also some differences in the usage of terminology and construction of some chapters. All the above mentioned drawbacks are due to the fact that there were no joint lithological studies and some authors in their works followed philosophy and techniques used in particular research institutions.

On the other hand, the data present illustrate the possibility of a wide usage of lithological evidence for the solution of stratigraphic and palaeogeographic problems.

It is noteworthy that different authors using various techniques, and studying various aspects of lithogenesis in different subregions, have obtained data allowing similar interpretation both of sedimentary environments and many stratigraphic problems.

The Vendian and Cambrian deposits in most subregions of the East-European Platform lie at a great depth and so can be studied mainly only from core material, therefore the techniques are aimed chiefly at the determination of their mineral composition to understand processes responsible for deposition in sedimentary basins and to get additional criteria for their formation. An exception is the evidence for the Vendian deposits of the Podolian uplift of the Ukrainian Shield (L.V. Korenchuk, V.A. Velikanov) where various rock types crop out in beautiful exposures. These data are much better than core material because they allow us not only to study the composition of rocks but also to trace transitions from one rock type to the other and establish their structural-textural features enabling a new interpretation of the influence of palaeorelief on the composition and structure of the basal beds of the sedimentary cover.

The mineralogical features of the Vendian-Cambrian deposits are considered in some detail.

In northern Poland one can recognize a regular change in feldspar composition and replacement of potassium varieties by albite up the section (K. Łydka; hereafter we refer to the subsequent sections of this chapter) which imply a new source area and become of regional importance for the deciphering of weathering processes within the source areas for clastic material.

The sections in eastern Poland are marked by a drastic increase of tourmaline in rocks of the Kaplonosy Formation (M. Juskowiakowa). This is of interest because the high proportion of tourmaline was earlier reported from the Early Cambrian sections (Tiskres Formation of the Lükati Horizon) of Estonia where it is of value for correlation (Mens and Pirrus, 1972). It is worth noting that the replacement of zircon by tourmaline in the group of allogenic transparent minerals is somewhat delayed in both subregions, viz., not from the beginning of the accumulation of the Cambrian trilobite beds which is marked by the changes in structural framework of the sedimentary basins. Hence it is chemical weathering, rather than a change in petrological composition of the rocks within a source area, that more strongly affects zircon than tourmaline.

The same is shown by the distribution of glauconite over an extensive area. Thus, in Poland this mineral starts to appear at the base of the fossiliferous Cambrian deposits (M. Juskowiakowa, K. Łydka) it was rearlier reported from sections of the Soviet Baltic area and other parts of the East-European Platform within the Soviet Union. Glauconite is known to be universally associated with phosphate formations (M. Juskowiakowa, L.V. Korenchuk, and V.A. Velikanov, K. Łydka, E.A. Pirrus). These two features anambiguously point to normal marine salinity of the basin. Unlike the Early Valdai (Redkino) basin, these features implying normal salinity and marine environment were found in all the Early Cambrian basins in the area discussed. It again emphasizes the importance of glauconite as a stratigraphic indicator which should be more widely used when particular sections are being studied. On the other hand, the sudden appearance of glauconite and phosphate deposits at the base of the Cambrian and their absence from rocks of the Kotlin Stage suggest a different facies of the Precambrian/Cambrian boundary beds at least hydrochemically in the study area. This makes the solution of the Precambrian/Cambrian boundary problem on the basis of data available for the East-European Platform difficult. However, we should mention the data by M. Juskowiakowa on the distribution of glauconite in the Lublin Formation (Kotlin

Stage) of Poland. These data should be checked with respect to the biostratigraphic age of the deposits, because similar results are known from study of the outcrops of the Podolian uplift (Kitaigorod) and one of the boreholes in the Podlasie-Brest Depression (Stradech-17). In the latter, glauconite-bearing siltstones are interbedded with thin-bedded clays of the underlying Kotlin Stage. However, the study of acritarch shows to the Rovno assemblage in the glauconite-bearing beds which allows their assignment to the Cambrian.

The distribution of clay minerals, both along the section and across the area gives valuable information. These minerals, like authigenic deposits can reflect physical and chemical sedimentary environments. It becomes obvious when we take into account that at some stratigraphic levels (Redkino, Kotlin, Rovno, Lontova) accumulation of clays prevailed over coarse sediments. The data obtained from key sections (E.A. Pirrus) suggest both vertical and lateral change in the composition of the clay minerals. Main trends of influx of major clay minerals can be recognized for all the four stratigraphic units of the Vendian Valdai Series and Cambrian Baltic Series in the basis of data obtained by the authors and allow definition of the basins and show the sources for mixed-layered minerals attributed chiefly to volcanic activity. A high content of mixed-layered varieties within the clay mineral group is a peculiar feature of the Lower Valdai deposits in all the regions discussed (M. Wichrowska, L.V. Korenchuk, V.A. Velikanov, E.A. Pirrus).

The sedimentological analysis of terrigenous beds has provoded many interesting data. The work by K. Jaworowski illustrates new methodological approaches and usage of geological data based on the primary description of boreholes for palaeogeographic reconstructions. However, since the biostratigraphic subdivision of sections is not complete, some conclusions are inconsistent with those for adjacent regions.

There are a few original data about geochemical features of the deposits. It is interesting to note the variation of such an important geochemical indicator of palaeosalinity as boron in rocks of marine origin in Poland, which has been reported from some sections of the Baltic area as well (Bityukova and Pirrus, 1978). It means that this element in clay deposits of humid type of such ancient basins as the East-European Platform should be given more attention in the future.

The lithological data presented show that opinions differ as to the location of a source area for clastic material and to the non-deposition at the Vendian/Cambrian boundary. The publication of the volume was not aimed at the unification of opinions on unsolved problems, but called for the examination of ways for their unambiguous solution.

## MINERAL COMPOSITION OF THE LOWER FORMATIONS OF THE VENDIAN REFERENCE SECTIONS OF THE PODOLIAN UPLIFT ON THE UKRAINIAN SHIELD

New data obtained during the past 10–15 years as a result of prospecting surveys and research work have revealed the vital importance of the Vendian section of the Podolian slope of the Ukrainian shield for studies of the Late Precambrian.

A stratigraphic scheme worked out for the Podolian section is unparalleled with respect to minute subdivisions as compared to other regions of the East-European

Platform and it meets the requirements of the large scale geologic mapping. A complete, well differentiated succession with distinct stratigraphic boundaries, easily discernible beds owing to characteristic mineral composition and distinctive fossils, enables direct correlation of sections in Podolia and similar deposits in adjacent areas and other regions of the East-European Platform. Excellent outcrops and numerous boreholes allow study of the relationships between structures of the sedimentary cover and those of the crystalline basement and show how the latter affected sedimentation and lithology of the Upper Precambrian succession.

The crystalline basement and typical pre-Vendian landforms, such as palaeo-valleys traceable down slopes of the shield for tens of kilometres and marked by relict "recesses" of the Vendian deposits deeply incised into the shield, as well as primary local basement uplifts have predetermined the mode of occurrence and the present structural and litho-facies features of the Upper Precambrian deposits.

The study area known as the Podolian uplift of the Ukrainian shield embraces a slightly subsided slope of the shield extending from the Rusava River in the south-east to the town of Khmelnitsky in the north-west; the basement surface is complicated here by dozens of extensive palaeo-valleys and local uplifts which gave rise to the formation of synsedimentary (enveloping folds, fans, palaeo-channels and the like) and tectonically activated structures of the sedimentary cover responsible for the composition and structure of the Upper Precambrian succession (Fig. 10).

The following data successively characterize major lithological types of the rocks composing the Vendian section and hence allow us to see lateral variations in textural and structural features, as well as in mineralogical composition along a monoclinal structure of the Podolian uplift. Because these changes are most obvious in the lower part of the sequence, deposits of the Volhyn Stage (Grushka Formation) and those of the lower Valdai Series (Mogilev and Yarushev Formations) are discussed as well.

In the Dniester River area, the Upper Precambrian deposits are well exposed down the Lyadova River starting from the village of Katyuzhany, where the Vendian succession can be traced from the boundary with the basement rocks to the phosphorite-bearing Kalyus Beds. Hence, the Lyadova River section can be considered as an easily accessible reference section allowing correlation with other borehole sections in Podolia.

The oldest sedimentary deposits known in the Lyadova Valley (northern outskirts of the village of Verkhniy Olchedaev) are coarse clastic variegated rocks resting directly on the crystalline basement and belonging to the Grushka Formation. The base is built of clayey unstratified loose rubble and gravel breccia containing angular fragments (up to 15 cm) of migmatite, gneiss, pegmatite, quartz, and altered mafic effusives. Large fragments constitute up to 50% of rocks and are cemented with fine-grained sand-silt material containing about 20% of volcanics represented by angular fragments (0.8 – 0.3 mm) and rounded drop-like forms (up to 0.25 mm) of light brown transparent volcanic glass with obscure crystallites or pelitic inclusions of opaque minerals, and fragments of altered basalts replaced by chlorite and serpentine. The bed is 0.5 – 0.7 m thick. Above come coarse clastic rocks with more fine-grained terrigenous material, and the amount of large fragments decreases up the section; the rocks grade into gravelstones and gritstones. The thickness varies from 1.2 m to 1.5 m. The section is crowned by a 0.7 m thick bed of fine-grained sandstone, relatively well sorted. The apparent thickness of the Grushka Formation is about 4.5 m here.

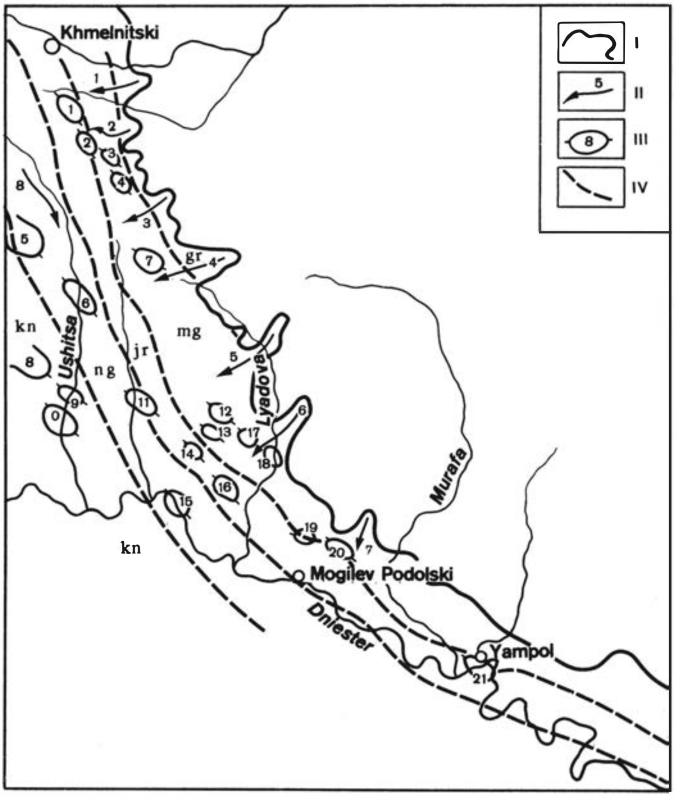



Fig. 10. Location map showing paleovalleys and local uplifts of the crystalline basement on the Podolian uplift

*I* – eastern limit of the Upper Precambrian deposits; *II* – paleovalleys: *1* – Bogdanovtsy, *2* – Korzhevets, *3* – Bozhikovets, *4* – Bar, *5* – Bakhtyn – Mikhailovtsy, *6* – Lyadova, *7* – Derlov; *III* – local uplifts: *1* – Balamutovo, *2* – Mikhailovo, *3* – Maznikovo, *4* – Manikovets, *5* – Proskurovo, *6* – Dzhurzhevka, *7* – Dashkovtsy, *8* – Katerinovo, *9* – Tymkov, *10* – Sokoletskoe, *12* – Posukhov, *13* – Murovan – Kurilovetskoe, *14* – Vonogradnenskoe, *15* – Bernashevka, *16* – Rovno, *17* – Perekorinets, *18* – Vinozh, *19* – Nemiy, *20* – Karpovski, *21* – Kosoutskoe: *IV* – outcrops of the pre-Cretaceous erosion surface: *gr* – Grushka Formation, *mg* – Mogilev Formation, *jr* – Yaryshev Formation, *ng* – Nagoryany Formation, *kn* – Kanilovka Formation

The lower part of the section discussed is dominated by volcanic rocks, but they are missing from the upper part of the section. Polycrystalline quartz with isometric and elongate crystals also gradually disappears up the section.

The clay component is persistent throughout the section and is represented by hydromica and some kaolinite.

Along the southern slope of the Podolian uplift the lower Grushka Formation is more widespread, but its thickness does not exceed 6 m; coarse clastic rocks, breccia and gravelstones dominate the section. Volcanics are present as highly altered ash in matrix.

The lower part of the Grushka Formation recognized here as the Lower Grushka Member is most widespread in the northern and north-western parts of the Podolian uplift, in the upper stream of the Ushitsa River. Coarse rubbly dark brown or variegated breccia is locally encountered in valley-like troughs of the crystalline basement and along their flanks. Fine rubbly breccia occurs in more uplifted parts of the basement. More fine-grained rocks, viz. clay gravelstones and fine sandstones, do not persist along the strike, and their thicknesses differ widely. In these parts of the Podolian uplift the rubble and gravel clay breccia is dominated by fragments similar in composition to basement rocks such as granite, migmatite, polycrystalline grey and dark grey quartz, and cataclastic feldspar. The content of foreign rocks, such as semi-rounded and angular fragments of basalt, gneiss, and occasional sandstone increases northwards.

Volcanics from the base of the Lyadova River section in the northern and north-western parts of the Podolian uplift occur in sandstones of the middle part as small fragments of brown and light brown volcanic glass, very weakly crystallized and partly replaced by chlorite. Near the town Khmelnitsky, in a zone transitional to type sections of the Volhyn-Polesian depression, this level is marked by the appearance of interbeds of tuffaceous sandstones and tuffs, 0.4 – 0.6 m thick. Volcanics amount to 50% of sandstone; they are represented by fragments of mafic glass, fine sans and silt in size, brown to dark brown, very weakly crystallized, with amygdales filled with chlorite. The fragments are in an ash matrix which is almost solely replaced by chlorite, although relicts of ash structure can be seen. Tuffs area psammitic and silty, heteroclastic and vitrophyric. Mafic glass fragments are brown to light brown, with evidence of primary crystallization; colourless, light greenish glass with rare acid spherulites is rarer. There are rare perlitic cracks in a matrix of hydromica and hydrogoethite developed after ash material. Tuff is highly chloritized.

As compared to the central Podolian uplift (Lyadova Valley), in the north-west and north, sandstones dominate the lower part of the formation. In general they grade into underlying gravelstone. The sandstone mineralogy is shown on a triangular diagram (Fig. 11a). The sandstones are classified as feldspathic, quartz-feldspathic, and extramictitic rocks. Fragments are granitoid in composition; quartz and feldspar amount to 20 – 35% and 30 – 70% of the rock, respectively; potassium feldspars, such as microcline, microcline-microperthite, and myrmekite predominate; plagioclase is felsic, albite-oligoclase. The sandstones also contain biotite, up to 8%, single grains of garnet, zircon, and leucoxene.

Breccia, gravelstone and sandstone are cemented with sandy clay and clayey material, a clay component dominates the base of the section (42 – 27%) and decreases in the upper part (23 – 14.5%). The X-ray data show that the clay component consists of almost equal amounts of hydromica (trioctahedral and dioctahedral) and kaolinite.

The lower part of the Grushka Formation is crowned by a small siltstone unit, maximum 2 m thick. The unit occure in sections of isolated areas associated with valley-like lows in the crystalline basement, particularly near the Proskurov uplift, along the north-western slope of the Podolian uplift. Not only the structure, but also the lithology and mineralogy of the upper member of the Grushka Formation consisting chiefly of fine clastic rocks, reflect to a large degree the topography of the underlying deposits. In the central Podolian uplift the upper member is not exposed along the Lyadova River, but boreholes passed through it in the river mouth area where it is related to the basement low and made up of a silty claystone sequence up to 6 m thick.

In the south-eastern Podolian uplift the upper member of the Grushka Formation is composed of sands and sandy siltstones in which the proportion of clay material varies from 10 to 50% and clastics are poorly sorted, mainly medium-coarse, rounded, and semi-rounded. The bedding is obscure or distinct

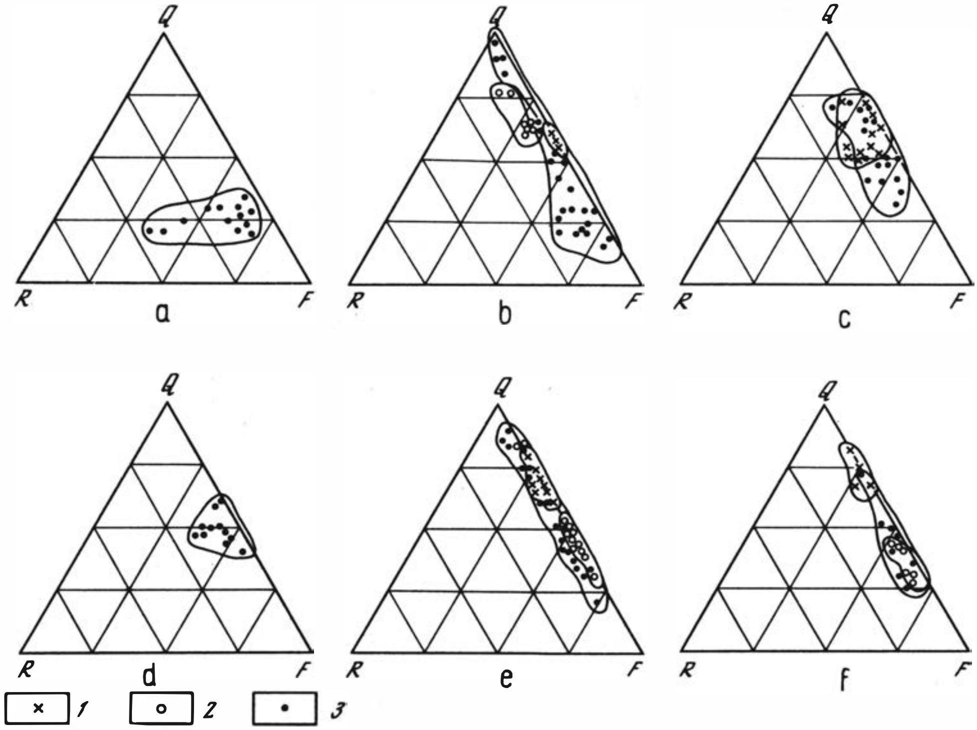



Fig. 11. Mineral composition of Upper Precambrian sandstones

*a* – Lower Grushka Formation, *b* – Upper Grushka Formation, *c* – Olchedaev Beds of Mogilev Formation, *d* – Lomozov Beds of Mogilev Formation, *e* – Yampol Beds of Mogilev Formation, *f* – Bernashevka Beds of Yaryshev Formation; *1* – in central Podolian uplift, *2* – on south-eastern slope of the uplift, *3* – on north-western and northern slopes of the uplift; *Q* – quartz, *F* – feldspar, *R* – rocks fragments

and thick due to alternation of rocks containing different amount of clay material or various structural features. Clay oolite beds easily traced in the south-eastern part of the Podolian uplift (near the town of Yampol) are related to the upper member. The clay constituent of oolitic sandstones is kaolinite and hydromica with an admixture of montmorillonite derived from ash material. Their thickness in uplifted and subsided parts ranges from 4.5 m to 12 m, respectively.

In the north-western and northern parts of the Podolian uplift the upper member shows the widest distribution. It is made up of alternations of fine-grained sandstones, siltstones, and claystones, interbeds are 0.1 to 1 cm thick. The lower part of the member contains bands of coarse-grained sandstones, gritstones, some gravel and small pebbles in siltstone matrix. Volcanics occur in the form of small fragments of weakly crystallized basalt. Besides, there are two or three bands of bentonite clays which are light-grey or bluish-grey, and highly plastic; X-ray and electron microscopy show that they are represented by a mixed-layered clay mineral of montmorillonite series and kaolinite.

In this part of the Podolian uplift the upper member is dominated by claystones. They grade into siltstones and fine-grained sandstones and only very thin laminae (up to 0.5 mm) are free from silty material. Claystones are composed mainly of hydromica and kaolinite with minor chlorite, quartz, feldspar, hematite.

Claystones are crowded with round bacteria-like forms 0.0025 to 0.024 mm in size (mainly 0.006 to 0.008 mm) infilled by pyrite, they occur as chains, spheres, and irregular masses. The number of bacteria-like forms depends on the proportion of silt; in silty claystones they are uniformly distributed, but amount to not more than 3–5%; they account for 15% in claystones and locally their proportion increases to 70%. They are not uniformly distributed across the section, forming bands in the upper- and lowermost parts, and show a sporadic occurrence in the middle part. As a rule, sections yielding bacteria-like forms are related to the lows in the crystalline basement and there the lower and upper members of the Grushka Formation have a sharp contact.

Sandstones and gritstones are minor in the upper member, forming interbeds in the claystone-siltstone succession, but near the Ukrainian shield boundary and within local uplifts and their slopes (for example, Proskurovo uplift) they constitute the entire section. Rounded clastics, especially in gritstones forming the base of the section, are very common. Fragments are mainly medium and small in size, clasts above 5 mm occur occasionally. Unlike the lower member, fragments of acid rocks constitute not more than 5% of gritstones. Clastic material is represented also by quartz (up to 55%), microcline, microcline-perthite (up to 30%), acid plagioclase (up to 25%), biotite (up to 7%), garnet and zircon (single grains).

Sandstones are more common than gritstones. They chiefly are fine-to medium--grained, clasts are subrounded and angular. Oolitic sandstones similar to those known from the south-eastern slope of the Podolian uplift occur in the upper parts of the section in the uplifted areas of the basement where coarse clastic rocks compose the entire upper member. Oolite-bearing interbeds are 0.2–0.4 m thick and oolites up to 2 mm in size amount to 30%.

Figure 11b shows the mineral composition of the Upper Grushka sandstones. It varies greatly with respect to a quartz and feldspar content, the trend is from feldspar varieties at the base of the section to more quartz in the upper part. Quartz sandstones contain well-rounded clasts and minor cement, i.e. they approach mineral and structural maturity. Comparison of mineral composition of rocks of the south-eastern and those of northern slopes of the Podolian uplift shows that the former are not so variable in composition and more mature.

Above the Grushka Formation come coarse clastic rocks of the Olchedaev Beds of the Mogilev Formation. In the central part of the Podolian uplift, along the Lyadova River, they can be easily traced in outcrops and quarries where structures grade from large oblique to horizontally bedded and rock textures range from psephitic to psammitic. In outcrops at the upper reaches of the river, the Olchedaev Beds are represented by dense massive gritstones and fine-clastic breccia containing fine-clastic gritstones and coarse-grained sandstones impersistent along the strike and in thickness (0.05 to 0.5 m). They are very similar in mineral composition. Granitoid clasts are common both in breccia and gritstones. On the basis of composition, sandstones (see Fig. 11c) are classified mainly as feldspar--quartzose rocks; varieties having the largest number of quartz grains occur in the upper part of the section. The Olchedaev Beds contain lenticular bands of micaceous sandstones (biotite, 35%) within the upper parts of obliquely bedded series.

Coarse clastics universally dominate the Olchedaev Beds in the central part of the Podolian uplift, this is attributed to an ancient well-developed drainage system (Lyadova, Bakhtyn–Mikhailovtsy, Dankovtsy, and other palaeovalleys) which controlled the distribution of fluvial and fan facies of the Olchedaev Beds, and also explains the great thickness of the latter. The omission of beds from the section and decrease in thickness are found on numerous local uplifts (Rovno, Vinozh, Vinogradnenskoe, Murovan – Kurilovetskoe, Sokoletskoe, and others).

The north-western and northern slopes of the Podolian uplift contain a section of Olchedaev Beds having minor coarse clastic rocks; locally – in subsided parts of the crystalline basement – the entire succession is composed of sandstones of various grain size and roundness of clasts. The grain size increases near or on local basement domes (Balamuty, Daskovtsy, Manikovets, and others). The grain size increases up the section by a vertical distribution of clastic material, viz., median grain size varies from 0.38 to 0.82 mm, and the sorting coefficient changes from 1.27 to 1.56.

Conglomerates, breccia-conglomerates, and gritstones on the north-western and northern slopes of the Podolian uplift within the Olchedaev Beds are small--pebbled, fine-clastic and represented mainly by fragments of granitoids, rare biotite gneisses, sandstones, basalts, and felsite. Fragments are more numerous in gritstones than in conglomerate and breccia-conglomerate.

Sandstones are feldspathic, quartz-mictitic and feldspar-quartzose in composition (see Fig. 11c). Feldspars are dominated by microcline, microcline perthite; plagioclase averages 5 – 7% and does not exceed 10%; dark-coloured minerals are minor, viz., hydrated biotite and single muscovite plates. Clay content of sandstones accounts 2.6 – 4.8%, rarely up to 20%. Muscovite is represented by hydromica (dioctahedral) and chlorite; kaolinite occurs at the base of the section.

Comparison of mineral composition of sandstones from the central Podolian uplift and those from the north-western and western slopes shows the great variability of the latter, but similar average composition.

The Olchedaev Beds of the Mogilev Formation are overlain by the Lomozov Beds made up of sand-silt rocks. In the central Podolian uplift, along the Lyadova River (near the village of Vinozh, Lomozov) they form a sharp contact with underlying sandstones and are represented by dark-grey micaceous siltstones and clay-stones interbedded with lenticular fine-grained sandstones and coarse siltstones up to 0.4 m thick. Laminae of coarse-grained sandstones up to 5 cm thick, consisting of angular, relatively well sorted fragments are found at the base of the section. Up the section the alternation of micaceous siltstones and claystones form laminae, 1 to 4 mm thick, with admixture of coarse-grained sand, and there is also alternation of fine-grained sandstones and micaceous siltstones, 2.5 to 0.5 mm thick. Sandstones in the Lomozov Beds constitute not more than 20% of the section. The apparent thickness of the Lomozov Beds is 17 m.

On the north-western slope of the Podolian uplift the amount of sandstone is controlled by palaeogeographic environments of the sedimentary area. Within the Tymkov, Sokoletskoe, and Katerinovo uplifts the sections of the Lomozov Beds consist solely of sandstones, hence, in the Mogivel Formation on these uplifts the Lomozov Beds can be recognized tentatively by the predominance of thin silty laminae as compared to the underlying and overlying rocks.

On the northern slope of the Podolian uplift the Lomozov Beds are similar in composition to the deposits of the central part. The section is dominated by siltstones, often grading into fine-grained sandstones and claystones. Sandstones and siltstones are very similar in mineral composition, they are mainly quartz--feldspathic and quartz-feldspar-mictitic (see Fig. 11d). Opacitized and chloritized biotite is rather common, it amounts to 5 – 7% and up to 30% in micaceous varieties; it forms separate laminae up to 2 mm.

The clay constituent of siltstones and claystones of the Lomozov Beds is similar in mineral composition and represented by kaolinite, hydromica, and minor mixed-layered minerals with admixture of quartz, feldspar, and haematite. They vary slightly in composition across the section, viz., chlorite is found as an impurity at the base, but disappears in the upper part.

Siltstones contain round bacteria-like forms infilled by pyrite which build up round or chain accumulations or laminae 0.16 – 0.25 mm thick, the latter being solely made up of such forms. These forms are similar to those from the Upper Grushka Formation and imply similar sedimentary environments.

The structure of the overlying Yampol beds clearly reflects the topography of the underlying surface. In the central Podolian uplift, along the Lyadova River, the base of the Yampol beds is made up of small-pebbled conglomerates in the form of occasional lenses up to 30 cm thick, they are cross-bedded and contain fragments of grey claystones in sand-gravel matrix. They in turn are overlain by dense, massive, fine- and medium-grained sandstones, horizontally bedded with nemian impressions in the lower part. The thickness of this unit is 3 m, and it is impersistent along the strike. Above come coarse-grained, inequigranular gravel, obliquely bedded sandstones with gradational sorting within laminae, sandstones form several cross-bedded series totalling 5 m in thickness.

In mineral composition they are feldspar-quartzose sandstones (see Fig. 11e). Unlike the Olchedaev sandstones, they do not contain rock fragments; plagioclase is a stable constituent among the rock-forming minerals, its small grains account for 3%. Another feature in common is the presence of polycrystalline quartz with elongate isometric growths.

Such a section of the Yampol beds is known from the Murovan-Kurilovetskoe uplift; the total thickness of sandstones reaches 12 m.

The sandstones rest directly on the crystalline basement along the south-eastern slope of the Podolian uplift, the type locality for the Yampol Beds, as well as on the Bernashevka, Nemiy, and Balamuty local uplifts.

The base of the type section is built, up of gritstones, small pebbled conglomerates and inequigranular sandstones, cross and horizontally bedded, gradationally sorted, up to 6 m thick. Above come massive, fine-grained sandstones, up to 5.5 m thick. They are overlain by rhythmical alternation of fine-grained homogeneous massive and coarse-grained gravel intensely ochreous, cross-bedded sandstones, individual beds being 1 m thick.

In mineral composition they are feldspar-quartzose and quartz-feldspathic sandstones, some varieties are extraquartz in composition (see Fig. 11e).

On the northern and north-western slopes of the Podolian uplift the Yampol sandstones are more uniform – it is a monotonous succession of light, almost white, massive rocks differing in grain size and degree of roundness. Basal gritstones or fine clastic conglomerates are not more than 20 cm in thickness. There are thin claystone interbeds in the middle part of the section. There are no claystone interbeds among the Yampol sandstones within the local uplifts (e.g. Balamuty).

The Yampol Beds retain a tripartite structure only in some places (for example, Verkhnyaya Ushitsa palaeovalley). In this case their middle part has a unit of thinly bedded claystones, silty claystones, and siltstones showing gradual transitions to overlying and underlying medium-grained sandstones. There the thickness of the Yampol Beds reaches 20 m.

The Yampol sandstones of the north-western and western slopes or the Podolian uplift differ greatly in composition and can be classified as quartz-feldspathic, quartz-feldspar-mictitic, feldspar-quartzose, and extraquartzose (see Fig. 11e). They contain sporadic fragments of light-brown microlithic basic effusives. Such a wide range of composition seems to suggest a repeated redeposition of clastic material and considerable rock weathering.

Comparison of mineral composition of the Yampol sandstones deposited in different parts of the Podolian uplift shows that the most mature are sandstones deposited on the northern slope.

At the top of the Mogilev Formation (or at the base of the Yaryshev Formation in the sense of one of the authors) one can recognize the Lyadova Beds composed mainly of claystones and siltstones. In the central Podolian uplift, along the Lyadova River (Zherebilovka, Yastrebna, and other villages), the Lyadova Beds have rather thin (up to 10 cm) basal sandstones. Above come variegated, thinly and horizontally bedded claystones and silty claystones where three units differ in colour viz., the upper, bluish-grey, light-grey; the middle, brown, dark brown, and the lower, greish-green. The thickness of the Lyadova Beds is 6 m. Such a section is rather persistent in the central part of the uplift and on its south-eastern slope.

North-west of the Lyadova River, the section slightly varies within the terrane of positive structures owing to the increase in sandstones at the base of the section. The unit of interbedded claystones and sandstones reaches 5 m on the Bernashevka uplift and the overlying claystone unit contains up to 30% of sandy and silty material.

The same section typical of the Lyadova Beds is known on the slopes of the Proskurovo uplift where medium- and coarse-grained sandstones form laminae 2 mm thick at the base. These are poorly sorted feldspar-quartzose sandstones with angular fragments. Clastic medium-grained material constitutes up to 10% of the claystone interbeds. The size and amount of clastic material gradually decrease up the section, and muscovite plates, hydratized biotite and chlorite up to 20% appear in claystones. The upper part is marked by the appearance and increase in glauconite (up to 20%) uniformly distributed through the rock. The total thickness of the Lyadova Beds is about 10 m.

In the northern Podolian uplift deposits similar to those of its central part were drilled mainly, but the rocks are chiefly violet-grey and greenish-grey. An exception is a sequence exposed in the Verkhnyaya Ushitsa paleovalley area. The Lyadova Beds here show the tripartite structure due to the presence of a 6.5 m sand unit in the middle part of the section; sandstones grade both into under- and overlying claystones; the thickness is 20 m.

The Lyadova sandstones are mainly fine-grained, clayey with non-uniformly distributed well sorted clastic material. They are quartz-feldspathic in composition and contain 50–55% of quartz and 50–25% of feldspar (mainly microcline). The Lyadova siltstones are coarse-grained, they contain some sandy material and are interbedded with and grade into claystones. The latter are represented by hydromica and kaolinite, chlorite with admixture of mixed-layered minerals, carbonate and haematite. The upper part of the section contains finely dispersed clay material, mixed-layered minerals are missing.

The change in the Lyadova Beds reflects a general tendency in the Upper Precambrian deposits, viz., they are persistent in composition and strike of fine-clastic clay rocks, however, clastic rocks – siltstones and sandstones – show stronger structural variability.

The Bernashevka Beds are recognized within the Yaryshev Formation, their section is known from the central Podolian uplift along the Lyadova River (near Yastrebna, Sloboda Yaryshevskaya and other villages). The base is composed of massive dense coarse- and fine-grained sandstones with variegated claystone laminae (3–7 cm). The thickness of rocks reaches 1 m. Up the section sandstones are overlain by a mainly claystone unit (0.5–0.7 m) grading into fine-grained sandstones and gritstones, also dense and massive with well rounded clastics. Above there is a unit of interbedded psammitic pelite crystals of vitroclastic acid tuff (3.5 m thick) containing angular fragments of microfelsitic effusives with weak current marks. There is acid and intermediate brownish-green lightly crystallized microfelsitic glass, it often shows spherulite structure and is replaced by chlorite, which accounts for 28% of it.

Above tuff and tufogenic rocks come dense massive sandstones, fine-grained at the base and coarse-grained at the top, with rounded and angular clastics, respectively, in the lower and upper parts. Effusive clastic material amounts to 5%, it disappears in the upper part of the section. The contact between sandstones and underlying rocks is sharp and has a wavy, rough surface; there are rare pebbles of grey claystones.

Sandstones underlying and overlying the unit of tuffaceous rocks are feldspar-quartzose and extraquartzose (see Fig. 11f) in composition approaching mineralogically mature rocks. The formation of volcanic rocks disrupts sedimentation and seems to give way to separation of the sandy unit.

Within the central Podolian uplift the Bernashevka Beds are rather thin, viz., 8.5–9.0 m thick. On the south-eastern slope of the Podolian uplift the thickness of sandstones increases to 10.5 m owing to the lower unit of medium- to coarse-grained rocks obliquely bedded at the base with gritstone laminae, the unit underlies tuff. There is no tuff in the Bernashevka Beds of the south-eastern slope, a siltstone unit separating sandstones contains about 5% of tuffaceous material.

On the northern slope of the Podolian uplift the Bernashevka Beds are similar to those of the central part. The lower part consists mainly of medium- and fine-grained sandstones associated with tuffaceous claystones and bentonite clay; the upper part is represented by more massive rocks containing single small subrounded grains of effusives of felsite texture. Sandstones do not show a universal distribution, in places they are replaced along strike by sandy siltstones, often interbedded with coarse-grained sandstones. In this case they, are related to basement lows and far removed from source area for clastic material.

Tuffaceous claystones in this part of the Podolian uplift are usually dark, variegated, and crowded with bent fragments of volcanic glass. Bentonite clays underlying or overlying tuffs occur more often here than in the Lyadova River basin. They are represented by mixed-layered minerals of montmorillonite series and contain some kaolinite.

The Bernashevka sandstones on the northern slope of the Podolian uplift are feldspar-quartzose and quartz-feldspathic in composition (see Fig. 11f). Comparison with sandstones from the central part shows an increasing amount of feldspar which suggests rapid burial of sediments.

Sandstones accumulated within long-lasting highs of the crystalline basement in the western part of the Podolian uplift and, since they do not contain tuff interbeds and tufogenic formations, form a unit of homogeneous massive coarse-grained rocks with some fine gravel material at the base. Clastic material is usually angular, not rounded and poorly sorted. Similar sandstones were deposited on the Bernashevka uplift and on the slopes of the Proskurovo uplift. The Bernashevka Beds of the Strugy uplift consist solely of sandstones. Their thickness is about 10 m.

The upper Yarushev Formation composed of Bronnitsy and Zinkov Beds is very uniform in composition throughout the Podolian uplift. The Bronnitsy Beds are composed of ash tuffs altered into rocks with a complex – quartz-hydromica-kaolinite-montmorillonite – composition. This slightly changes across the section, probably reflecting a primary variability in composition.

The base of the Bronnitsy Beds is composed of quartz containing some hydromica, haematite, feldspar, and carbonate. Higher ash tuffs consist of quartz containing mixed-layered minerals and kaolinite. The section of the Bronnitsy Beds is capped by rocks consisting of quartz and kaolinite which dominate all the clay minerals of hydromica and haematite. Individual laths of opacitized biotite and chlorite solely replacing small fragments of acid glass are easily recognized in siliceous tuffs.

The composition of the Bronnitsy Beds remains constant, but their thickness varies greatly from 2.5 to 25 m depending on the palaeostructural setting of the particular section.

The overlying sequence of the Zinkov Beds, like that of Bronnitsy Beds, has a constant composition; however, there is a gradual transition between them. The Zinkov Beds in this region are considered as the uppermost stratigraphic unit whose structure and composition are controlled by the crystalline basement. For example, on the Proskurovo uplift the Zinkov Beds rest directly on the basement. The thickness of the Zinkov Beds varies from 14 to 33 m, the smaller thicknesses being found on the arches or resulted from post-Zinkov erosion.

The Zinkov Beds are made up of siltstones, argillaceous siltstones, and fine-grained interbedded sandstones showing gradual transitions. Fine-grained sandstones occur mainly in the central Podolian uplift; on its north-western and northern slopes the Zinkov Beds are composed of siltstones and argillaceous siltstones. Quartz accounts for 70% of the Zinkov siltstones, they contain feldspar as well; occasional fragments of altered light brown effusives with weak felsitic texture have been found. Biotite and hydrated clastic chlorite amount, respectively, to 20% and 40%. Glauconite – from single grains to 15% – is a permanent constituent of the siltstones.

The Zinkov claystones are represented by kaolinite and hydromica with quartz admixture. Up the section, the amount of kaolinite increases; carbonate is associated with clay material. Single filaments resembling bacteria occur sporadically.

A large proportion of clastic chlorite suggests that source areas for the Zinkov and pre-Zinkov rocks were different; shale rocks seem to be exposed by erosion.

The data presented above allow us to make the following conclusions:

1. A similar mineral composition of coarse and fine clastic deposits implies a common source for clastic material of the Grushka, Mogilev, and, partly, Yaryshev Formations and that the source (Ukrainian Shield) and sedimentation areas were not far from each other away. The presence of tuffaceous and tuff rocks within the Bernashev Beds, primary tuffaceous nature of the Bronnitsy Beds, and foreign nature of clastic material in the Zinkov Beds suggest that volcanic material and distruction products of the Baikalian fold areas within the Galician geosyncline, in particular the Dobrudzha area with which the basin was directly connected, played an important role in the deposition of the Yaryshev Formation.

2. The completeness of the section, distinctive lithology, and thickness of the deposits were controlled by palaeogeomorphologic structures of the sedimentary area.

3. The presence of volcanic material in the Grushka Formation and its increase towards the Volhyn-Podlasie Depression allows reliable correlation between the normal sedimentary section of Podolia and volcanic sections of the type locality.

# LITHOLOGY OF THE NON-METAMORPHOSED PRECAMBRIAN AND LOWERMOST CAMBRIAN SEDIMENTS OF THE PERIBALTIC SYNECLISE

## INTRODUCTION

In the Polish part of the Peribaltic syneclise the crystalline basement built of various igneous and metamorphic rocks is covered by a variously thick weathering crust developed in an environment favourable to chemical weathering. As evidenced by the overlying sediments, the crust must have been formed during a long time span. In the eastern part of the syneclise these sediments are of Lower Cambrian age and have been recognized in the following deep- boreholes: Gołdap, Kętrzyn and Prabuty. The deep borehole Żarnowiec located in the north reveals that in this area the weathering crust is overlain by Vendian formations. In the west and south-west the weathered basement, reached by the Darżlubie, Kościerzyna and Słupsk boreholes, is covered by anchimetamorphic series followed by Vendian sediments. The former are classified by the present author into the Riphean, the latter thought to be equivalent of the Vendian series in the Podlasie area (Areń, Lendzion, 1974).

The Lower Cambrian sediments resting directly upon the crystalline basement as well as on the non-metamorphosed Precambrian contain detrital material showing evidence of intense chemical weathering: of kaolinitic type on the granitoids and of smectitic type, leading to the formation of mixed-layered minerals, on basic rocks rich in alkalies.

The distribution of the studied profiles is shown in Fig. 12, and the lithostratigraphic correlation scheme of the uppermost Precambrian in the Polish part of the Peribaltic syneclise in Figs. 13 and 14.

The drilling material, kindly made available to the present author by the Geological Institute, permitted a thorough study of the differentiation of the main rockforming minerals content. The core samples proved representative for the sedimentary cover of the crystalline basement in the Polish part of the Peribaltic syneclise (Łydka, 1973–1975).

It should be emphasized that, due to the fact, that the sedimentary cover is built of relatively thin (usually less than 130 m) series, the non-metamorphosed Precambrian in the cover has been regarded by geologists in the field as one conti-

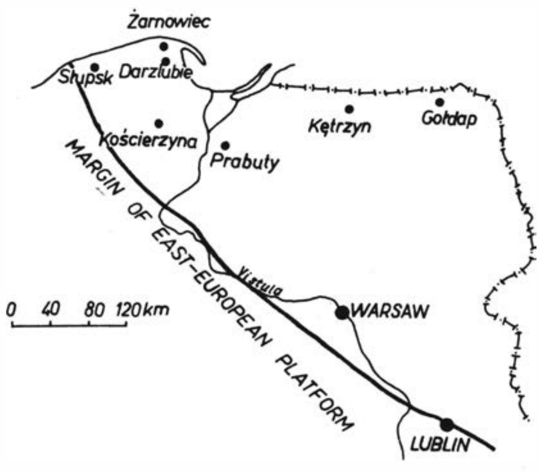



Fig. 12. Sketch map showing the location of the investigated boreholes

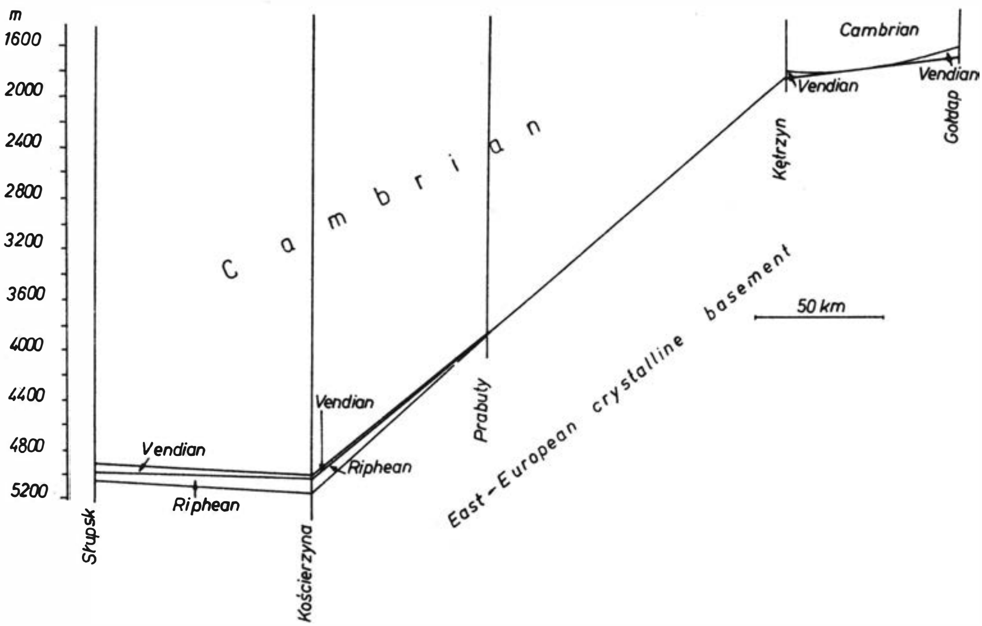



Fig. 13. East-west section across the oldest sedimentary cover of the Precambrian basement in Northern Poland

nuous member called the Żarnowiec Beds. Today these rocks occur at the depth of 3000–5000 m beneath younger sediments within which processes operated leading to hypabissal intrusions (e.g. Olsztyn, Pasłęk – M. Juskowiakowa, O. Juskowiak, 1974). All these rocks have been subjected to a variety of epigenetic processes such as kaolinitization, sericitization, chloritization and carbonitization with an intensity varying with depth. But it is not possible to define the degree of alteration in a hand specimen. Sediments belonging to different formations and characterized by different original features, now discernible only under the microscope, have been homogenized by secondary processes and therefore described by geologists in the field as one continuous series.

Comprehensive laboratory examinations – optical and electron microscope, thermal and X-ray analyses – permitted to distinguish Riphean and Vendian series within the sediments underlying the Cambrian.

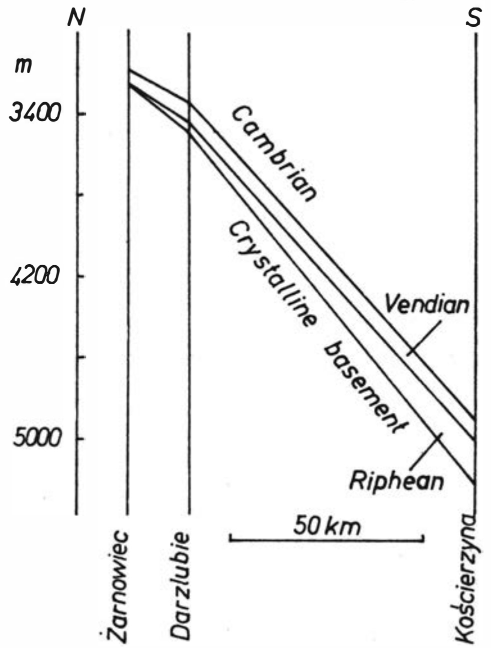



Fig. 14. North-south section across the oldest sedimentary cover of the Precambrian basement in Northern Poland

**The Riphean.** Drilling material of the deep borehole Słupsk IG-1 revealed anchimetamorphic series of the upper Precambrian to occur at the depth 5075–4991 m. With a subhorizontal attitude of the layers the series is about 84 m thick.

These rocks are variously coloured – red, brown, grey, frequently spotty – and they represent residual sandy-gravel breccias either *in situ* or transported along a very short distance. They are made up of unsorted sharp-edged material of different grain size reaching up to several centimetres. The main mineral constituents are quartz, microcline, biotite, rock fragments analogous to those of the immediate crystalline basement as well as very rare sedimentary rocks of the arkosic type. The coarser material contains irregular opaque thin streaks of iron hydroxides often blurring into the coarse crystalline sericite cement. In these laterite-like streaks newly-crystallized chlorite with the optical properties of pennine occurs besides the recrystallized sericite. The neogenic sericite of the cement adheres directly to the identically developed sericite filling spaces between cleavage planes in the microcline.

Locally, within the series described, e.g. at the depths of 5043, 5031, 4995 and 4991 m, individual thin laminae are observed forming placers of iron oxides and sphene grains accompanied by subordinate zircon.

In addition, in the regolithic series described, thin layers enriched in parallel oriented scales of partly weathered and locally almost completely discoloured biotite have been found to occur at the depths of 5060, 5038, 5031 and 4991 m.

**The Vendian – Sławatycze Formation.** Within the 4991–4937 m depth interval lies a 54 m thick series formed in an environment different from the underlying one. The graded layering implies an aqueous environment. The mineral grains distincly differ among each other in the degree of rounding, well- and semi-rounded fragments being predominant. The main mineral constituents in this series are identical with those of the underlying series, but their proportions change in that the amount of basement rock fragments and lateritic constituents decreases. Another characteristic feature of this rock assemblage is the presence of laminae containing pyroclastic material and attaining the thickness of a few centimetres. These are tuffite laminae composed mainly of eu- and subhedral brown biotite scales accompanied by subordinate sharp-edged quartz and feldspar grains with frequent convex faces as well as of volcanic glass fragments. Both the feldspars and the volcanic glass are fairly sericitized. Such laminae have been found in samples from the depths of 4988 and 4986 m. Throughout the sequence separate pyroclastic grains are dispersed in detrital material. A further distinctive feature of the pelitic fraction in the Vendian-Sławatycze Formation is the presence of mixed-layered clay minerals with spacings (d) of 12–10.8 Å.

**Lublin Formation.** Further up in the sequence (4937–4927 m) lies a series of purely quartzitic sandstones with a sericitic cement. Here the quartz grains are very well rounded. Within these sandstones built of grains very well sorted by weathering occurs a several centimetres thick and finely laminated layer of sapropelic shale. It is dark, almost black, and its mineral constituents identified under the microscope are: dark brown amorphous sapropelitic substance, fine sharp-edged quartz and feldspar grains, finely pelitic carbonates – calcite and dolomite – and brown iron oxides of the appearance of goethite.

**The Cambrian.** From 4927 to 4518 m occur typical Cambrian sediments developed as finely layered shales, mudstones and quartz sandstones composed of well sorted material, and frequently, varying amount of glauconite. In the lower portion of the Lower Cambrian sequence, in addition to quartz, the sandstones contain also feldspars with a decisive predominance of potassium feldspar represented chiefly by microcline. In the middle portion the amount of feldspar drops close to zero, while in the upper part of the Middle Cambrian plagioclases – mainly albites and less frequently the more basic members – appear gradually. Also the clay mineral assemblage shows a distinct differentiation throughout the Cambrian sequence: the middle portion contains distinctly higher kaolinite concentrations, in the lower minerals of the illite group prevail, and in the upper one considerable chlorite amounts appear besides other clay minerals.

Further studies of the mineral differentiation in the Precambrian and Cambrian sequence of the Słupsk IG-1 borehole seem very promising and therefore their continuation is envisaged in the nearest future.

## BOREHOLE KOŚCIERZYNA

**The Riphean.** Overlying the weathering products of quartz diorites are sandy-gravel regoliths composed of sharp-edged rock fragments derived from the immediate basement. As a whole the material is unsorted and has been produced by mechanical-chemical disintegration *in situ* or transported along a short distance. Therefore neither a selection nor a spatial orientation of elongated fragments could have taken place. A subhorizontal 114 m thick series has been encountered in the 5145–5031.5 m interval. Within this series formed at the main under mass transport conditions appear sediments with a fabric distinctly oriented due to diluvial processes which led to the formation of thin laminae composed of heavy minerals, chiefly iron oxides, accompanied by individual zircon grains. Such thin placers have been encountered e.g. at the depths of 5050 and 5033.6 m.

The sediments of this series contain material sorted by intensive chemical weathering which caused the removal of less resistant constituents. As a result a lateritic mass has formed in irregular streaks winding among the granular material and partly playing the role of the cement. Secondary processes have altered in partly into coarse crystalline kaolinite, partly into sericite and chlorite, while relicts of the lateritic have been preserved as cryptocrystalline iron hydroxides. Among the feldspars the most resistant proved to be albite which, besides micas- chlorite and quartz, is the main mineral constituent of this series.

**The Vendian.** Drilling material obtained from the depth of 5031.5–5021.0 m represents a conspicous rock complex. It commences with sediments made up of very strongly weathered material and impoverished in constituents less resistant to weathering. From the depth of 5031 m upwards feldspars (mainly albite) make their appearance to be accompanied by potassium feldspars (mainly microcline) from the depth of 5027 m. At this depth not only mineral grains but also basement rock fragments are noted. Distinctive of this complex are thin pyroclastic layers with brown biotite, characteristically developed sharp-edged quartz, volcanic glass and feldspars. They have been found at the depths of 5025.5 and 5022.0 m. To a considerable degree both the volcanic glass and feldspars have been replaced by a coarse sericite mass. In the rocks of the described complex the cement is sericitic, often recrystallized into biotite and locally accompanied by chlorite. The complex is terminated with a thin lamina of finely dispersed sapropel with pelitic carbonates – calcite, dolomite and siderite – as well as quartz and albite.

**The Cambrian.** From the depth of 5021.0 m commences a typical Cambrian series. The Cambrian deposition commences with well-sorted quartz sandstones with a sericite cement on the whole and local nest-like aggregates of carbonate cement. The basal beds contain micas (chiefly biotite) decomposed by chemical weathering. To the depth of 4791.5 m sediments have been noted containing relatively fresh detrital material derived directly from the provenance area, which is inferred from the relatively high amounts of both microcline and plagioclases, (mainly of albitic composition) in the sandstones and mudstones.

From the depth of about 4790 m upwards a distinct change is noted in the terrigenous material: all the feldspar varieties disappear almost completely, quartz accompanied by varying amounts of glauconite being the predominant constituent.

In the basal part of the series described conglomeratic sandstones have been encount red and samples from the depth of 4749 m contain fine phosphate pebbles. In sandstones and mudstones, beside the sericite-kaolinite cement and nest-like carbonate aggregates, also quartz plays the role of the cement. Samples from the 4633 – 4502 m interval contain distinctly higher amounts of kaolinite prevailing over other finely dispersed constituents. Another change in the mineral composition of the Cambrian sequences is marked in the 4433 – 4427 m depth interval by the appearance of sediments rich in carbonates and distinctive of the uppermost Cambrian of this area.

### BOREHOLE DARŻLUBIE

**The Riphean.** The amphibole-bearing plagioclase-microcline gneisses, showing evidence of supergene weathering such as chloritization of amphiboles, sericitization of feldspars and carbonatization of all secondary products, are overlain by a complex of coarse unsorted conglomeratic sandstones sampled at the depth of 3510 – 3498 m. They are interbedded with analogous, though finer grained, oriented material composed of predominating sharp-edged quartz and fragments of crystalline bassement rocks as well as of subordinate feldspar, as a rule showing a high degree of sericitization. The brown biotite, strongly discoloured in the redeposited material, accentuates the directional structures. The cement, of lateritic appearance, is strongly altered by epigenetic processes and in the main replaced by coarse crystalline sericite accompanied by chlorite. Locally, nest-like aggregates of coarse crystalline kaolinite are visible in larger cement patches. The coarse crystalline cement is built of 0.05 – 0.1 mm grains. Occasionally, cryptocrystalline, brown, poorly translucent iron oxides of goethitic appearance have been found in the cement.

**The Vendian – Sławatycze Formation.** At the depth of 3502 m a several centimetres thick, bedded tuffite layer has been recognized. It is built of eu- and subhedral scales of brown, partly discoloured biotite, volcanic glass fragments, quartz and feldspars. The glass and feldspars are sericitized almost completely, but their habit – elongated dagger-like grains with convex faces – has been preserved. The grain size of the pyroclastic material varies from 0.1 to 0.5 mm and there is no evidence of mechanical reworking. In samples from the depths of 3509, 3502 and 3498 m thin placers have been found to occur in the unsorted material.They are composed of oriented heavy mineral grains, most often iron oxides and less frequently zircons.

**Lublin Formation.** Sediments occurring in the 3497 – 3402 m depth interval are distinctive by both their mineral composition and orientation of their detrital material. The series commences with sediments containing strongly chemically weathered material and, as evidenced by graded layering, redeposited in an aqueous environment. The hydromicas are the weathering products of discoloured biotite and the quartz grains show evidence of chemical reworking. The feldspars content in this series is very distinctive, as their supply to the depositional basin must have varied greatly: they are very rare in the lowermost layers, but higher up in the sequence (3492 – 3441 m) they are abundant enough to become one of the main constituents of the sandstones and mudstones. Initially, i.e. at a lower depth, potassium feldspars prevail over plagioclases represented mainly by albite, but from about 3421 m upwards they are outnumbered by albites. The cement of the series described is made up of quartz and coarse crystalline sericite with local nest-like carbonate aggregates.

**The Cambrian.** The typical Cambrian sediments commence with an approximately 2 m thick regularly stratified sandstone and shale series. In its lowermost portion it contains strongly decomposed material, all the constituents less resistant to weathering being removed and the preserved biotite streaks almost completely discoloured. In the lower portion of the Lower Cambrian potassium feldspars are fairly abundant, but from 3300 m upwards they occur only in trace amounts besides frequent plagioclases represented by albite. In the Middle Cambrian samples derived from the depth of 3204 – 3065 m show an increased kaolinite content. There is a visible regularity in the quartz distribution throughout the Cambrian sequence: the lower and upper horizons are fairly rich in quartz, while in the 3270 – 3150 m depth interval the quartz content drops considerably.

The Upper Cambrian sediments have a totally different composition. The predominating carbonates composed of calcite and subordinate dolomite are developed as very distinctive algal limestones. The latter are accompanied by marly sapropelic shales.

### BOREHOLE ŻARNOWIEC

**The Vendian.** On the biotite-bearing microcline-plagioclase gneisses lies a subhorizontal approximately 33.5 m thick sedimentary series recognized in samples from the 3234.5 – 3202.0 m interval. In the main, these are coarse grained sandstones of variously sized sharp-edged constituents occasionally interlayered with fine and medium grained sandstones. In these sediments quartz is predominant, the singular feldspar grains are sericitized, and the rare biotite is considerably discoloured. Crystalline rock fragments analogous to those known from the immediate crystalline basement are a stable, though subordinate constituent. The cement is composed mainly of coarse crystalline sericite in which, particularly in its larger accumulations, occur coarse crystalline kaolinite and less abundant chlorite. Locally, sandstones of this complex have a scarce opaque cement composed chiefly of iron oxides goethite and hydrogoethite. Drilling samples from the depths of 3211 and 3207.5 m reveal the presence of thin laminae with high heavy minerals contents, mainly iron oxides and zircon. These laminae have been formed due to local washing of the not yet cemented material. At the depth of 3164.8 m occur mudstones built of quartz, illite and chlorite. Their K – Ar ages have been found to be 645 ± 18 My (Łydka *et al*.., 1984).

**The Cambrian.** Sediments occurring higher up in the sequence contain derittal material different from that in the lower layers. Both in sandstones and aleuritic sediments the grains are very well sorted and rounded. At the depth of 3202 m coarse grained sandstones have been encountered containing rounded quartz pebbles and rounded fragments of crystalline basement rocks. Among the coarse material dispersed are numerous fairly well rounded heavy minerals with prevalent iron oxides – magnetite, titanomagnetite and ilmenite. A sericite-kaolinite matrix constitutes the cement of the sandstones. Overlying this series are alternating sandstones and shales whose main mineral constituent is quartz, feldspars and clay minerals being only subordinate.

The quartz content has been found to vary throughout the entire Cambrian sequence. Samples from the 2950–2825 m interval reveal a lower quartz content and a higher amount of kaolinite clearly prevailing over other clay minerals such as hydromicas and chlorite. Distinctive of the Cambrian sediments is a considerably high amount of well rounded quartz grains, while constituents less resistant to weathering have been almost completely removed. The weathering effect is also reflected in the decomposition of micas in the lowermost Cambrian horizons. As evidenced by samples from the depth of 3199 m higher amounts of potassium feldspar appear in the lower layers to be accompanied by plagioclases, chiefly albite, from 3164 m upwards. But from the depth of 3046 m albite is practically the only representative of feldspars.

A further regularity in mineral distribution has been noted in the uppermost Cambrian horizon where slightly dolomitic marls and algal limestones accompanied with sapropelic shales occur. Upper Cambrian sediments have been studied in samples from the 2733–2724 m interval.

### BOREHOLE PRABUTY

**The Cambrian.** Cambrian sediments rest directly upon the weathered amphibole-biotite-microcline-plagioclase gneisses with heavily sericitized feldspars and chloritized biotite and green hornblende. The characteristic variability of the mineral assemblage in the Cambrian sequence reflects the geotectonic development of the area. The history of the Cambrian depositional basin is recorded in the contents of quartz, feldspars and all sorts of clay minerals. The most essential findings are: a) the tri-partite nature of the Cambrian sequence evidenced by the quartz contents – maximum quartz amounts are noted in the lower and upper portion of the sequence (130 m thick each) while in the middle portion of comparable thickness (about 200 m) this amount drops considerably; b) the distinct variability of the potassium feldspar content – the highest amounts of potassium feldspar (microcline) occur in the lowermost Lower Cambrian and gradually decline upwards to reache trace amounts in the uppermost layers, and c) the increased kaolinite contents in the upper portion of the Middle Cambrian indicative of a higher rate of chemical weathering in the adjacent provenance area.

### BOREHOLE KĘTRZYN

**The Vendian.** The anorthosites, considerably altered by chloritization and carbonatization, reached at the depth of 1839.6 m are directly overlain. by an approximately 20 m thick complex of brown-red sandstones alternating with greenish-grey and brown mudstones. The sandstones are poorly sorted and contain very well rounded quartz grains and accessory microcline. The main constituents of the mudstones are illite, kaolinite and quartz, while dolomite, siderite and pyrite are only accessory. The K–Ar dating of a mudstone sample from the depth of 1817.5 m yielded 718±18 My.

**The Cambrian.** The lowermost Cambrian of the Kętrzyn area is represented by sandstones and mudstones almost completely devoid of material less resistant to weathering than quartz. The presence of lustrous quartz grains and thin placers composed of iron oxides and minor zircon evidences that this material has been repeatedly reworked and washed in an aqueous environment. The cement in the sandstones and mudstones is scarce and composed of opaque iron oxides, goethite and nest-like carbonate – calcite and dolomite – aggregates. The thickness of these highly reworked and chemically weathered sediments is about 15 m. The overlying series contains only trace amounts of feldspar. The lower feldspar content in the Cambrian sequence is paralleled by a decline of the goethite and siderite amount, and the iron minerals disappear together with feldspars. With the exception of the lowermost layers totalling 15 m in thickness, a stable constituent of the pelitic fraction is kaolinite of a highly ordered structure. Noteworthy is the presence of mixed-layered clay minerals in the lower portion of the sequence examined.

### BOREHOLE GOŁDAP

**The Vendian.** The crystalline basement reached at 1629.3 m is built of heavily weathered, carbonatized and kaolinitized granitoids. Resting directly on the crystalline rocks is a sedimentary series originated by reworking of the granitoids weathering products. As compared with the underlying layers, the Lower Cambrian sediments, commencing at the depth of about 1600 m, show a change in their mineral composition expressed in the appearance of microcline grains, goethite ooliths and siderite in the sandstone cement.

A mudstone composed of illite, kaolinite and quartz sampled at the depth of 1623 m has been selected for K – Ar dating. The age of this sample representing sediments below the Cambrian has been found to be 658 ± 18 My.

**The Cambrian.** The Cambrian sequence begins with medium- and fine-grained sandstones alternating with shales. The predominant sediments are sandstones in which potassium feldspar (microcline) is a stable subordinate constituent, plagioclases of albitic composition being accessory. In the lower portion of the Cambrian (to the depth of about 1521 m) siderite forms the cement in the sandstones but occurs also in the alternating mudstones layers. The local goethite seems to be the product of secondary post-depositional alternations. Dolomite is a minor constituent in the cement of sandstones and mudstones, and calcite occurs only in traces.

The Middle Cambrian is distinctive by a minimum content of ferruginous minerals – siderite and its oxidation products practically disappear. The Middle Cambrian quartz sandstones are in fact monomineralic with a minor glauconite admixture and feldspar traces. Often the sandstone cement is composed of quartz while carbonates – chiefly dolomite – form nest-like aggregates. The main constituents of the clay fraction are kaolinite, illite and glauconite. Mixed-layered minerals are rare.

The amount of quartz can serve to divide the Cambrian sequence in the Gołdap area into four parts: the lowermost, about 50 m thick, with a low quartz content; the second, about 25 m thick, with a high quartz content; the third, about 40 m thick, with a low quartz content; and the fourth, about 30 m thick, with a high quartz content.

Noteworthy is the presence of a several centimetres thick horizon containing decomposed micas and cryptocrystalline oxides at the top of the Cambrian.

### LITHOSTRATIGRAPHIC CORRELATION

The distinctive features permit to compare the sediments directly overlying the crystalline basement in the western part of the Peribaltic Syneclise with the non-metamorphozed Precambrian sediments known from the adjacent platform areas.

The composition and structure of the sediments from the lowermost portions of the Słupsk, Darżlubie and Kościerzyna boreholes correspond to the series underlying the Lower Cambrian sediments encountered in the borehole on the Gotska Sandön island (Middle Baltic Sea) and described by R. Gorbatshev (1962). Their microfacies development along with other features suggest that they have been formed in a comparable environment of lateritic weathering indicative of a warm climate. Noteworthy is that in sediments from the Gotska Sandön borehole material affected by recrystallization has been encountered along with authigenic micas positively identified under the microscope. K – Ar dating of the Gotska Sandön sediments yielded 1490 – 1540 My. Processes very similar to those of the Gotska Sandön island have been recognized unquestionably in the lowermost parts of the Żarnowiec Beds in the Słupsk. Darżlubie and Kościerzyna boreholes. The upper part of the Żarnowiec Beds, containing pyroclastic material indicative of coeval volcanic activity, can be paralleled with the Vendian Sławatycze Formation of the Lublin area. In the western part of the Peribaltic syneclise above the Sławatycze occurs a set of layers – particularly conspicuous in the Słupsk and Kościerzyna boreholes – which can be compared with the Lublin Formation described by B. Areń and K. Lendzion. A scheme of regional distribution of various stratigraphic units is given in Figs. 13 and 14. Certain regional regularities have been found also in the extent of microfacies in the Cambrian sediments e.g. the presence of the distinctive weathering crust corresponding to the lowermost Lower Cambrian horizon.

## PETROGRAPHIC CHARACTERISTICS OF MARINE DEPOSITS OCCURRING AT THE PRECAMBRIAN – CAMBRIAN BOUNDARY IN THE PLATFORM AREA OF POLAND

### LIMITS OF STUDIES AND ANALYSIS METHODS

Petrographic studies have been carried out on the material from 11 deep boreholes situated in the platform area of eastern, central and northern Poland and selected to the complex geological examination (Fig. 15). In the region under discussion there occur marine deposits of Upper Vendian – Lower Cambrian age as: medium and fine-grained sandstones, siltstones and claystones. The rocks themselves display interlayering and varying proportions. The marine deposits under examination lie on volcanogenic formation and sedimentary deposits of Vendian age (Sławatycze and Siemiatycze Formations) in the southern part of the area studied, directly on crystalline basement in the central part and on Żarnowiec Beds, as well as directly on the basement – in the northern region.

The depth limits for borehole column parts selected to petrographic studies have been set up basing on biostratigraphic studies. Those intervals include deposits of Lublin Formation and Klimontów Formation, as well as partly those of Kaplonosy Formation (Areń, Lendzion, 1974).

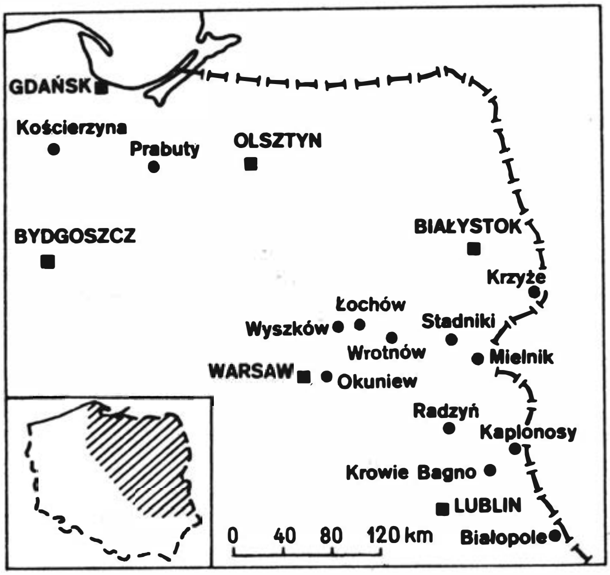



Fig. 15. Sketch of the boreholes considered in the petrographic studies

The petrographic studies in the present paper are based on the quantitative characteristics of detrital material of the deposits under discussion, i.e. they concern sandstones and siltstones even in cases when they occur as subordinate intercalations in clay-silty complexes. The main method of examination was the microscopic analysis of 909 thin sections. The main numerical parameters concerned the size of quartz grain (the most frequent and maximum one), as well as mineral composition of the rocks and their heavy fraction. Basing on samples depth, the graphs of analytic results have been compiled in order to observe some distinct changes in borehole columns as well as to distinguish some lithologic horizons of similar petrographic data patterns. The following criteria were applied to set up the limits of differentiation:

a) change in average size of maximum and the most frequent quartz grain,
b) decrease in the size difference between the most frequent and maximum grain – which corresponds to better sorting of detrital material,
c) decrease in feldspars percentage as compared to quartz and accessory mineral content – proving that no more fresh material has been delivered from non-covered crystalline basement area,
d) content of glauconite and carbonates, as well as that of sulphates (barite, anhydrite), pyrite and iron hydroxides – which reflects the specific sedimentation environment,
e) mineral composition of the heavy fraction.

Some general conclusions might be drawn comparing petrographical results with the sedimentologic ones published by K. Jaworowski (1975, 1978):

a) number of horizons distinguished as a result of petrographic studies of sandstone samples is in general higher than that of sandy sedimentation episodes recognized in sedimentologic description of the borehole column,
b) individual horizons have in general concordant boundaries, not always, however, are they correlated taking mineral content and granulation into account.

When comparing the present paper results with biostratigraphic ones obtained by K. Lendzion, an obvious concordance of the boundaries of detrital material horizons may be observed. There occur also distinct similarities in mineral content for some faunal zones. Such consistency permitted the construction of generalized maps of the examined series bassed on the average grain size value and mineral composition of sandstones, as well as synthetic sequences reflecting detrital material horizons changes occurring with time (Figs. 16–21). Mineral

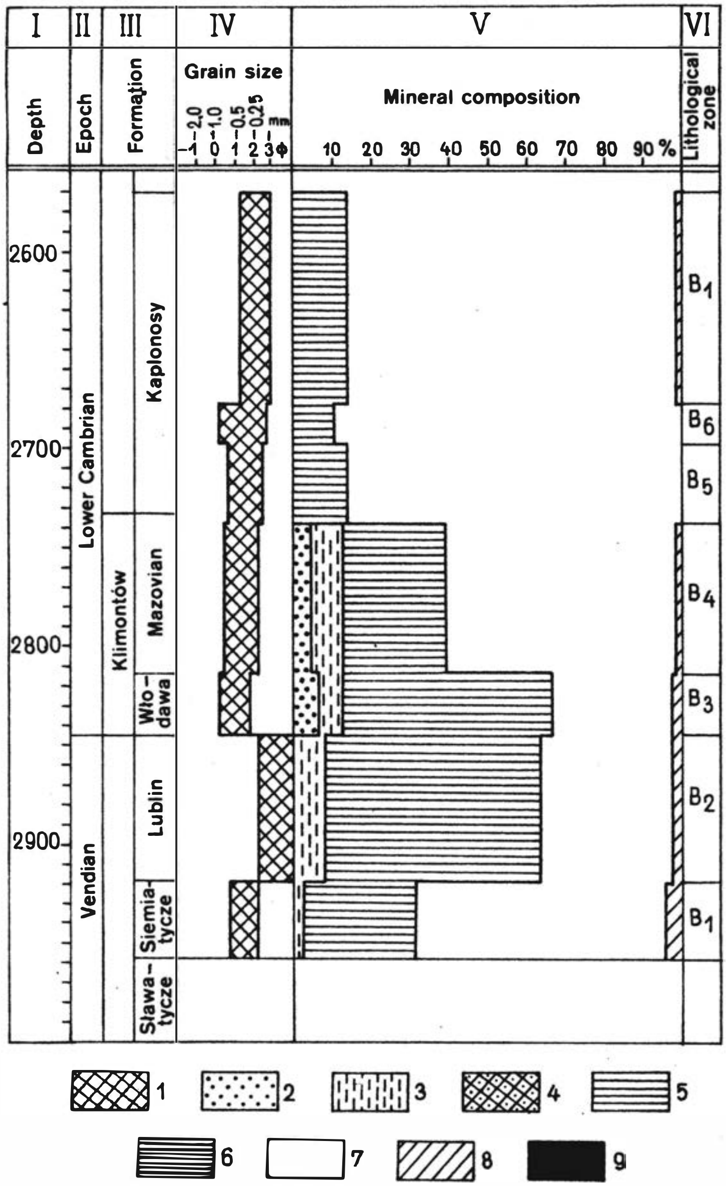



Fig. 16. Average size of the maximum and the most frequent quartz grain and average mineral composition in the distinguished detrital rocks horizons from the Białopole borehole column

*1* – average size of the maximum and the most frequent quartz grain and the difference between these values, *2* – glauconite, *3* – orthochemical constituents (carbonates, sulphates), *4* – chlorite, *5* – clay minerals, *6* – neogenic micas, *7* – quartz, *8* – feldspars, *9* – accessory minerals

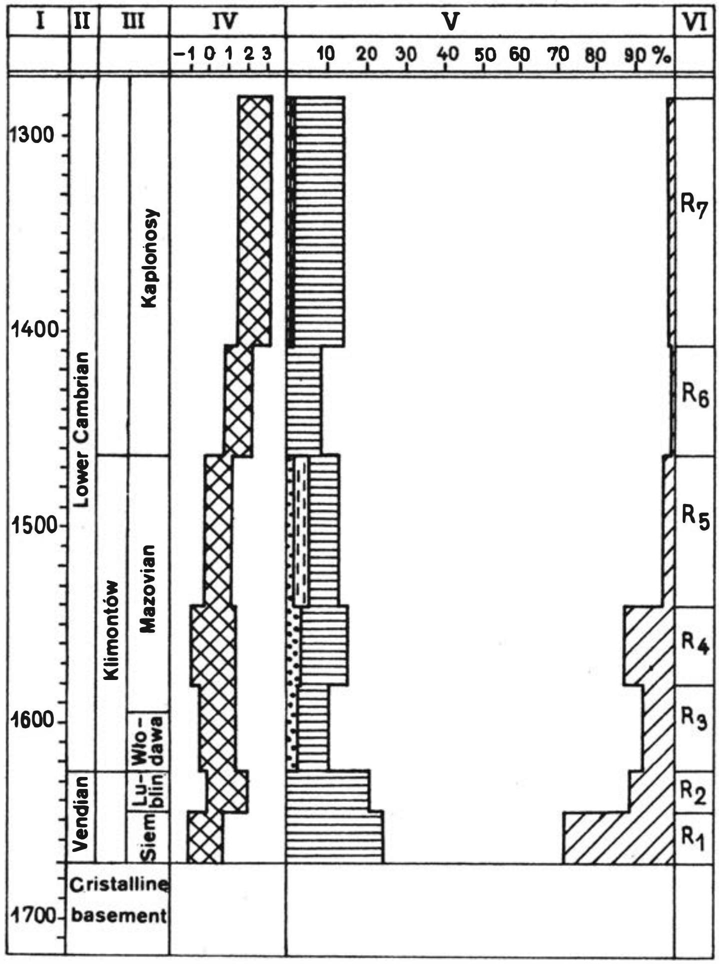



Fig. 17. Radzyń borehole
Explanations see Fig. 16

composition of sandstones examined has been showed on the generalized graph for all the series (Fig. 22) according to R.L. Dott's classification modified by F.J. Pettijohn *et al.* (1972).

## PETROGRAPHIC CHARACTERISTICS OF THE ROCKS UNDER EXAMINATION

### LUBLIN FORMATION

The Lublin Formation deposits have been recognized in Białopole, Krowie Bagno, Kaplonosy and Radzyń boreholes. The rocks lie there on Siemiatycze Formation arkoses and feldspar sandstones (subarkoses), relatively differentiated taking their mineral composition and granulation into account (Phots. 1–3). The maximum thickness of Lublin Formation has been observed in Białopole bore-

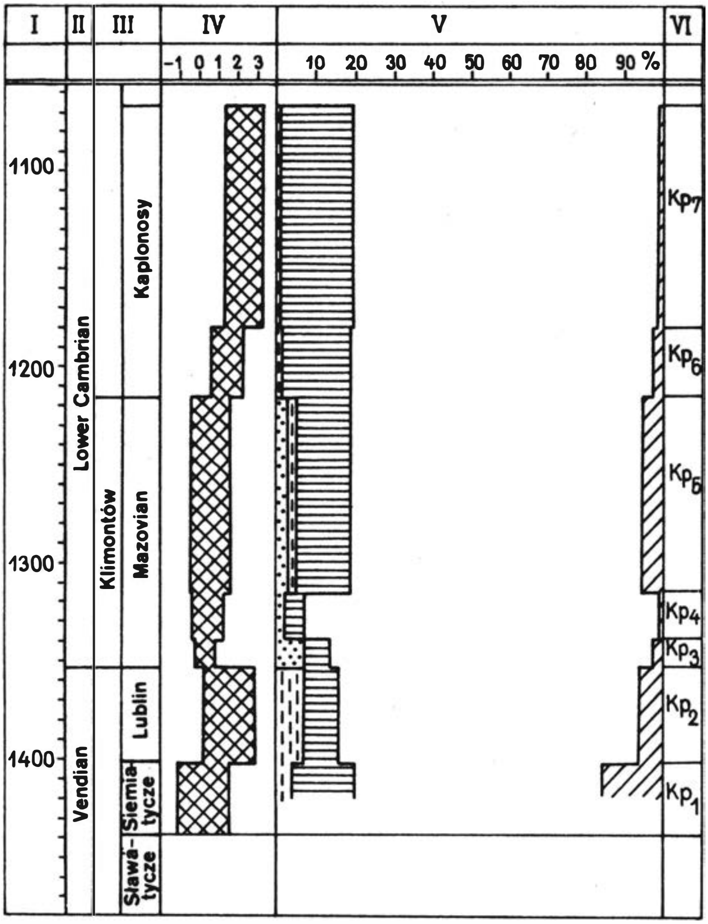



Fig. 18. Kaplonosy borehole

Explanations see Fig. 16

hole. Predominantly there occur fine-grained rocks (Phots. 4, 5) – siltstone with claystone or fine-grained sandstone intercalation and lamines. The thickness of deposits decreases northwards, whereas sandstone contribution increases (Phot. 6).

Mineral composition of Lublin Formation sandstones has been presented on Fig. 22. Projection points lie in feldspar sandstone (subarkoses) and quartz sandstone fields displaying – thanks to increase of clay material content – a distinct continuity from arenites through wackes to claystones (siltstones). The average size of the most frequent quartz grain ranges between 0.06 mm and 0.25 mm, which results in classification of detrital material as represented mostly by the fine-grained sandy fraction.

The main mineral constituent of that fraction is quartz. Acid plagioclases occur parallely to microcline in varying amounts. Quite numerous are fine amines of detrital micas, as well as distinctly secondary big blasts of neogenic ones. Illite represents the main component of the rock's cement, accompanied by greenish, secondary chlorites occurring subordinately. The characteristic com-

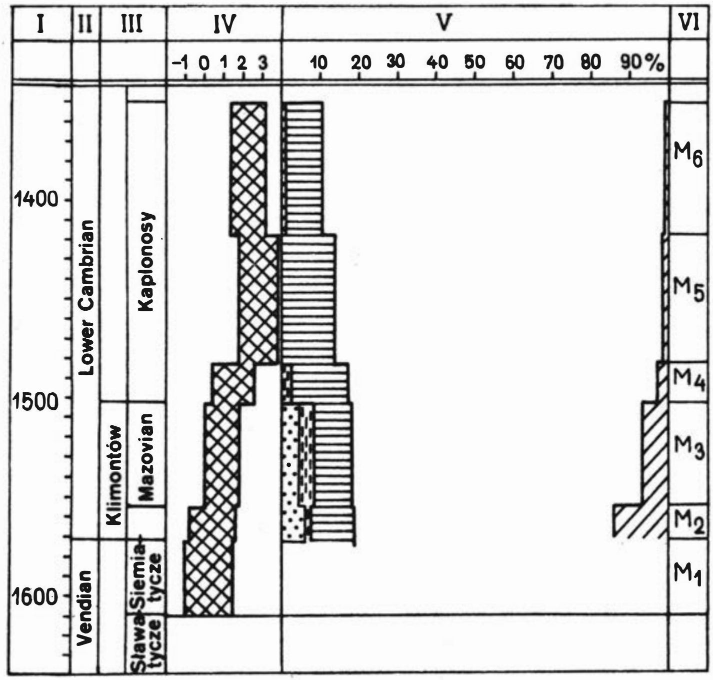



Fig. 19. Mielnik borehole
Explanations see Fig. 16

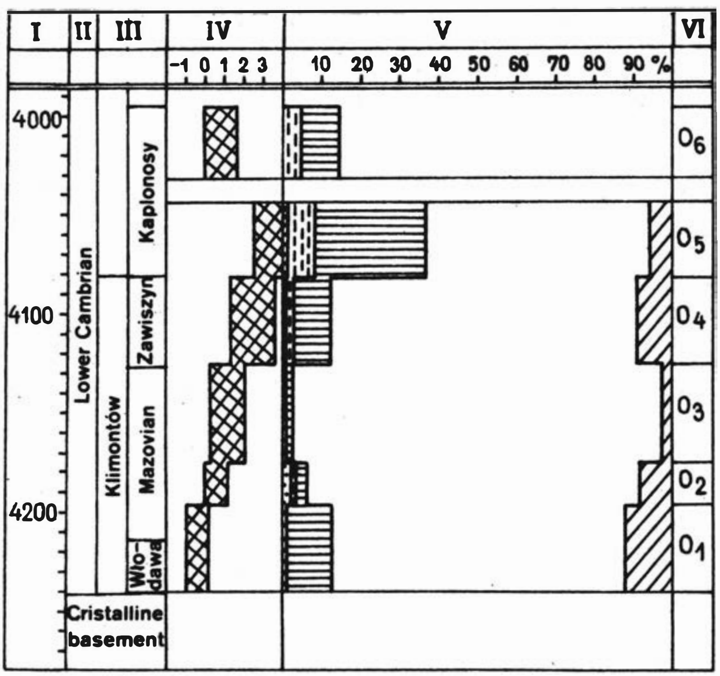
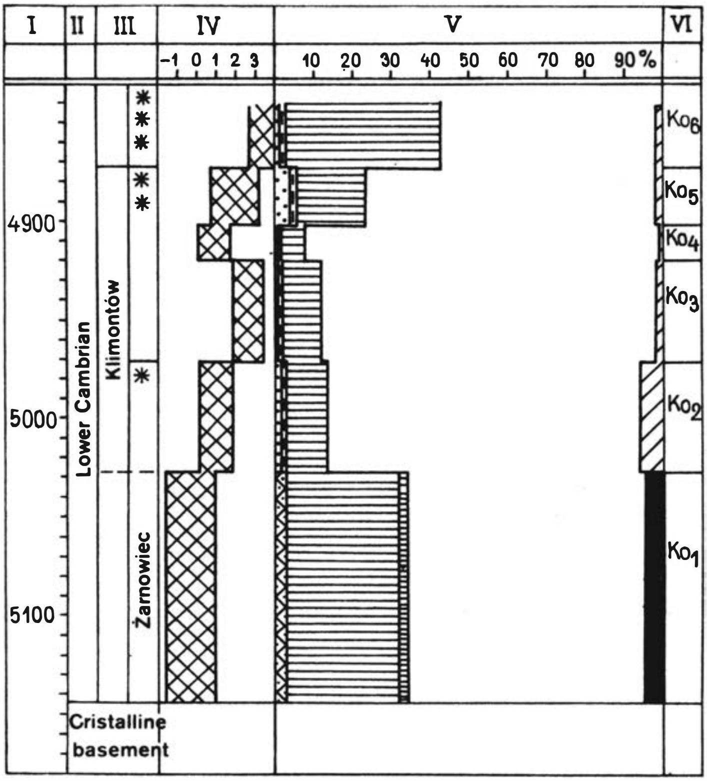



Fig. 20. Okuniew borehole
Explanations see Fig. 16




* Equivalents of Mazovian Formation

** Equivalents of Zawiszyn Formation

*** Equivalents of Kaplonosy Formation

Fig. 21. Kościerzyna borehole
Explanations see Fig. 16

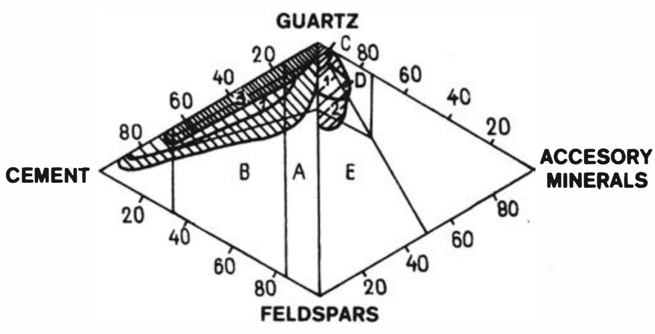



Fig. 22. Mineral composition of the rocks under consideration

*1* – Lublin Formation, *2* – Klimontów Formation, *3* – Kaplonosy Formation, *A* – arenites, *B* – wackes, *C* – arenites and quartz wackes, *D* – subarkoses, *E* – arkoses ponent of cement is calcite (in average 0–7 per cent of volume). Its content increases up to 44 per cent in fine-grained sandstone (Białopole, depth 2869.8 m).

Zircon, monazite, as well as non-transparent and leucoxenized minerals, tourmaline and rutile represent the main recognizable constituents of the heavy fraction.

### KLIMONTÓW FORMATION

Klimontów Formation deposits have been found in all the boreholes petrographically studied. They lie on Lublin and Siemiatycze Formations rocks in the southern part and directly on crystalline basement in central and northern part of the area discussed. They represent lithologically varied complex of detrital rocks such as coarse, medium and fine-grained sandstones, siltsones and claystones, as well as sandy-silty and clay-silty rocks, so called "layer-cakes" (Phots. 7–15). The mineral composition of the Klimontów Formation sandstones is differentiated too. It corresponds mainly to the fields of feldspar sandstones (subarkoses) and quartz sandstones, as well as partly to the arkoses field on Fig. 22. The cement content varies in general from 0 to 30 per cent by volume, corresponding to cement-poor arenites and wackes, although in the extreme cases its amount exceeds detrital material percentage. The average size of the most frequent quartz grain in individual boreholes ranges from 0.06 to 0.68 mm, which corresponds to fine-medium and coarse grained sandy fractions of detrital material.

Quartz represents the detrital fraction's main component. Feldspars occur mostly as twinned microcline, more rarely as acid plagioclase. Detrital micas are rarely observed, while glauconite is common, in variable amounts, however. Phosphatic chips occur quite often too. The detrital material rounding displays the distinct differentiation – it varies often even in one borehole section column.

Both cement amount and its mineral composition show variety. The most common are hydromicas, kaolinite and chlorite, as well as clay-ferrous material and occasionally – crystalline silica or regeneration quartz in form of rings on detrital quartz grains. Regeneration rings are observed also on feldspar grains in the rocks with low percentage of clay cement. Carbonates (calcite, more rarely dolomite or syderite) and sulphates (barite, anhydrite) are the minor constituents of rocks cement.

The composition of heavy minerals fraction seems to be very poor. As in the rocks of Lublin Formation – zircon and monazite are those of predominance over tourmaline in co-existance with relatively common allogenic opaque minerals and low amounts of rutile, corundum, apatite and garnet, anatase, barite and pyrite as well.

In the borehole columns of Klimontów Formation deposits some zones with various characteristics of mineral composition and granulation of sandstones might be distinguished (Figs. 16–21), which – in general – are convergent with Klimontów Formation division made by K. Lendzion (it op.).

### KAPLONOSY FORMATION

The Kaplonosy Formation deposits are typically developed in the southern and centrap part of the area studied. They correspond there mearly exclusively to fine-grained sandstones (Phots. 16–18). In the northern part of the area (Kościerzyna, Prabuty) they occur as silty-clay and sandy rocks. Concerning the average quartz grain size and clay content the distinct quality of the Kaplonosy Formation deposits may be observed nearly in all boreholes studied with exception of Okuniew, Wyszków and Mielnik (Figs. 16–21). The lower part of series displays slightly higher size (0.1 – 0.2 mm) of the most frequent quartz grain in comparison to the upper one (0.06 – 0.13 mm).

The sandstones are monotonous in their mineral composition with small amounts of feldspars and occassionally present detrital micas. On Fig. 22 Kaplonosy Formation deposits – with exception of feldspar – richer Prabuty borehole rocks – lie in the field of quartz sandstones. The average cement content ranges from 8 to 20% by volume (arenites, wackes) with extremal values 0 – 60%. Hydromicas, regeneration quartz, subordinately occurring kaolinite and ferrous material form that cement. Carbonatic (calcitic), sulphatic impregnations are present in some cases, as well as clay clasts. Glauconite occurs – in general – occassionally in small amounts, whereas it is more abundant in Kościerzyna and Prabuty boreholes deposits. In that last case – phosphatic clasts are more common.

Comparing to the subjacent sandstone series, the mineral composition of the heavy fraction of Kaplonosy Formation deposits seems to be more varied. Zircon, monazite and tourmaline are those of domination similarly to the case of Lublin Formation and Klimontów Formation deposits. Tourmaline is often more abundant than the other minerals, there occurs anatase in high percentage. Opaque allogenic minerals (illmenite, magnetite) display lower abundance. Quite subordinately grains of corundum, rutile, staurolite, epidote, garnet, sphene, spinel and brookite might be observed.

## REGIONAL SCATTER OF SOME PETROGRAPHIC PARAMETERS OF SANDSTONES FROM LUBLIN FORMATION KLIMONTÓW FORMATION AND KAPLONOSY FORMATION

The general petrographic characteristics presented above permits to underline some vertical column variations of petrographic features within relatively monotonous sandy-silty rock series. Differences might be noticed in horizontal extent of the sediments of individual series too.

The changes of some parameters analysed permitted the construction of generalized maps. In that number the most interesting seem to be those of average size of maximum quartz grain (Fig. 23), average clay content cement in detrital rocks (Fig. 24), average glauconite content (Fig. 25), as well as average feldspar content in the detrital material of sandstones (Fig. 26). The scatter of each parameter values illustrates approximately the general tendency. It is different, however, for individual series resulting from the different time-dependent conditions of sedimentation.

For Lublin Formation an increase in size of maximum quartz grain and enrichment in feldspars (Figs. 23 – 26) in the Radzyń – Kaplonosy area possibly defines vicinity of coastline and uncovered crystallinic. Relatively low detrital material content in Białopole with corresponding high abundance of clay material (Fig. 24) might be an evidence of low hydrodynamic energy of basin, deposition on morphologically not very differentiated basement and lack of more resistant metarial supply (quartz, acid feldspars). Such a situation might be, possibly, connected with partly denuded Sławatycze Formation basalt cover occurring in the basement and non-typically developed Siemiatycze Formation deposits (Juskowiakowa, 1974). From time to time, in Białopole and Kaplonosy region there occurred carbonate precipitation permitting conditions (in average 8%).

The situation seems to be more complicated for Klimontów Formation deposits. Coastline zone in there shifted northwards (Figs. 23, 26). Mielnik –

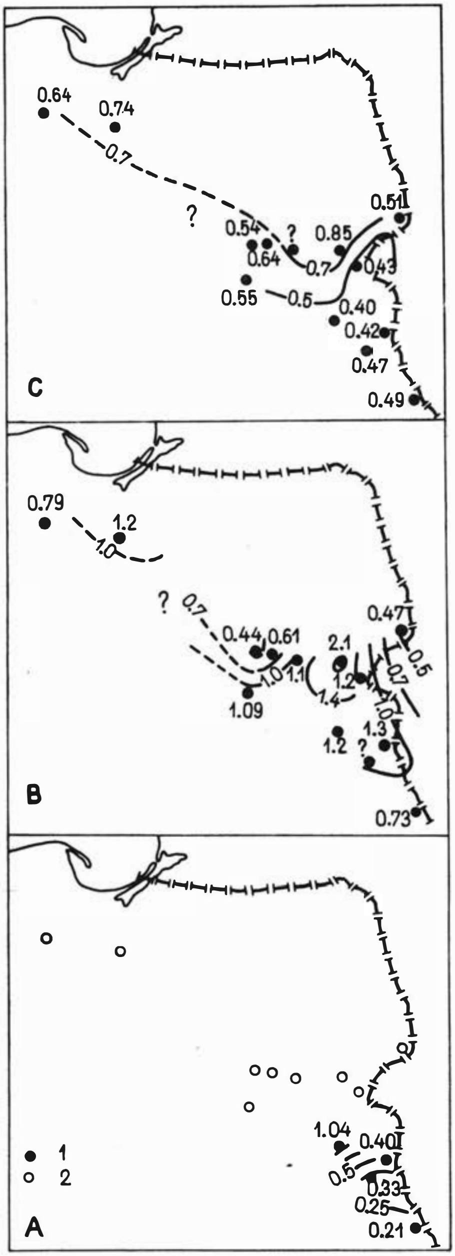



Fig. 23. Average size of the maximum quartz grain (in mm) in rocks of the Lublin Formation (*A*), the Klimontów Formation (*B*) and the Kaplonosy Formation (*C*)

*1* – boreholes with rocks of the given series, *2* – boreholes without rocks of the given series

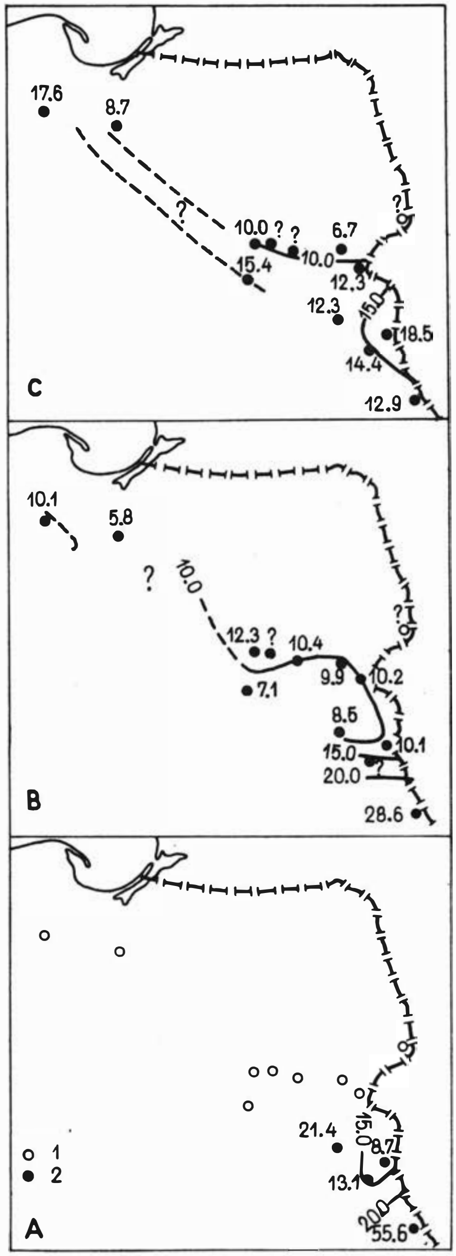



Fig. 24. Average clay cement content (in % by volume)

Explanations see Fig. 23

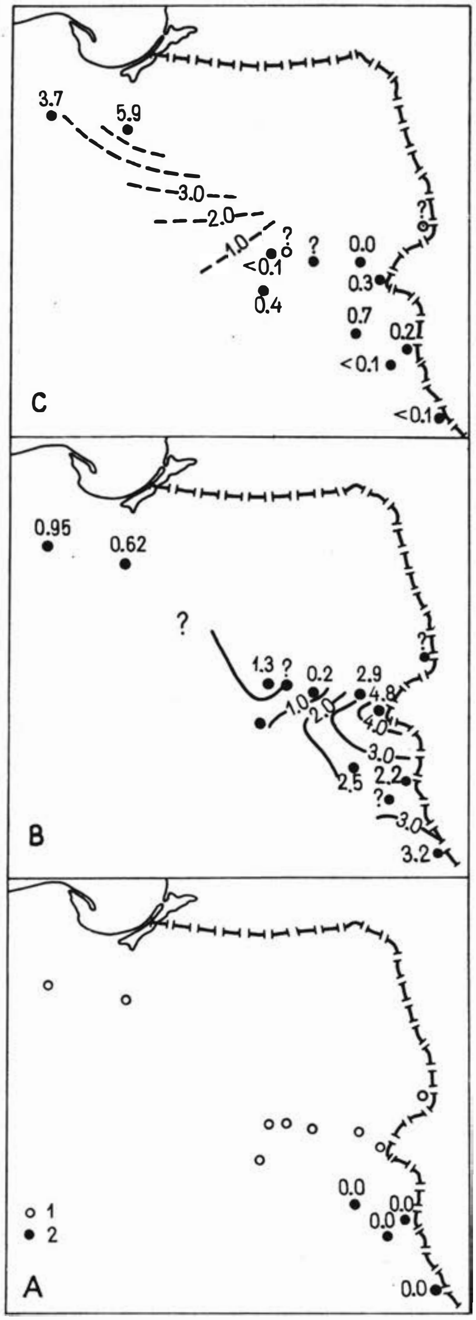



Fig. 25. Average glauconite content (in % by volume)
Explanations see Fig. 23

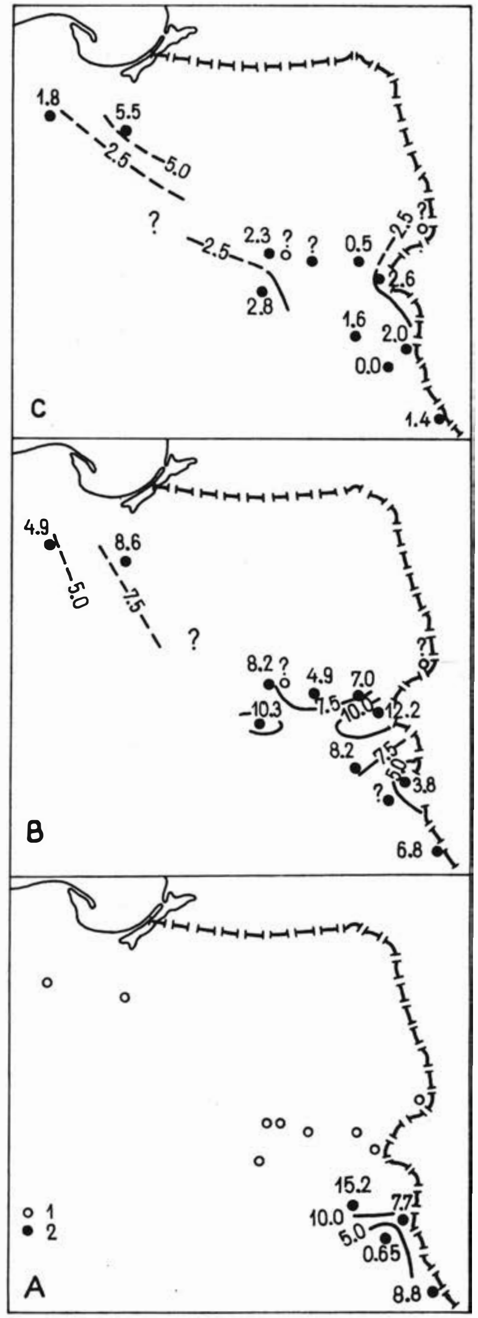



Fig. 26. Average feldspar content (in % by volume) in the detrital material
Explanations see Fig. 23

## EXPLANATIONS OF PLATES

### PLATE I

Phot. 1. Arkose (arkosic wacke) with carbonate impregnations. Siemiatycze Formation, Mielnik, depth 1603.3 – 1611.3 m; × 14

Phot. 2. Arkose (arkosic wacke) with kaolinite. Siemiatycze Formation, Kaplonosy, depth 1437.5 m; × 14

Phot. 3 Subarkosic sandstone with clay-carbonate cement. Białopole Formation, Białopole, depth 2946.9 m; × 14

Phot. 4. Subarkosic clay-sandy siltstone from the Lublin Formation. Białopole, depth 2880.9; × 14

Phot. 5. Fine-grained quartz sandstone with clay cement. Lublin Formation, Białopole, depth 2869.8 m; × 14

Phot. 6. Fine-grained subarkosic sandstone (arenite) with clay-carbonate cement. Lublin Formation, Kaplonosy, depth 1382.0 m; × 14

### PLATE II

Phot. 7. Quartz sandstone with glauconite, clay cement and carbonate admixture. Klimontów Formation, Włodawa Beds, Krowie Bagno, depth 3334.0 m; × 14

Phot. 8. Quartz sandstone (arenite) with glauconite and carbonate admixture Włodawa Beds. Białopole, depth 2812.0 m; × 14

Phot. 9. Arkosic sandstone with glauconite; clay cement with carbonate admixture. Klimontów Formation, Mazovia Beds. Mielnik, depth 1570.0 m; × 14

Phot. 10. Subarkosic sandstone with glauconite; clay cement. Klimontów Formation, Mazovia Beds. Kaplonosy, depth 1275.5 m; × 14

Phot. 11. Arkosic sandstone with glauconite; clay cement. Klimontów Formation, Mazovia Beds. Radzyń, depth 1566.5 m; × 14

Phot. 12. Quartz sandstone (arenite) without glauconite. Klimontów Formation, Mazovia Beds. Wrotnów, depth 2003.5 m; × 14

### PLATE III

Phot. 13. Quartz sandstone (arenite) without glauconite. Klimontów Formation, Zawiszyn Beds. Kościerzyna, depth 4906.9 m; × 14

Phot. 14. Subarkosic sandstone (arenite) with glauconite. Klimontów Formation, Zawiszyn Beds. Prabuty, depth 3872.7 m; × 14

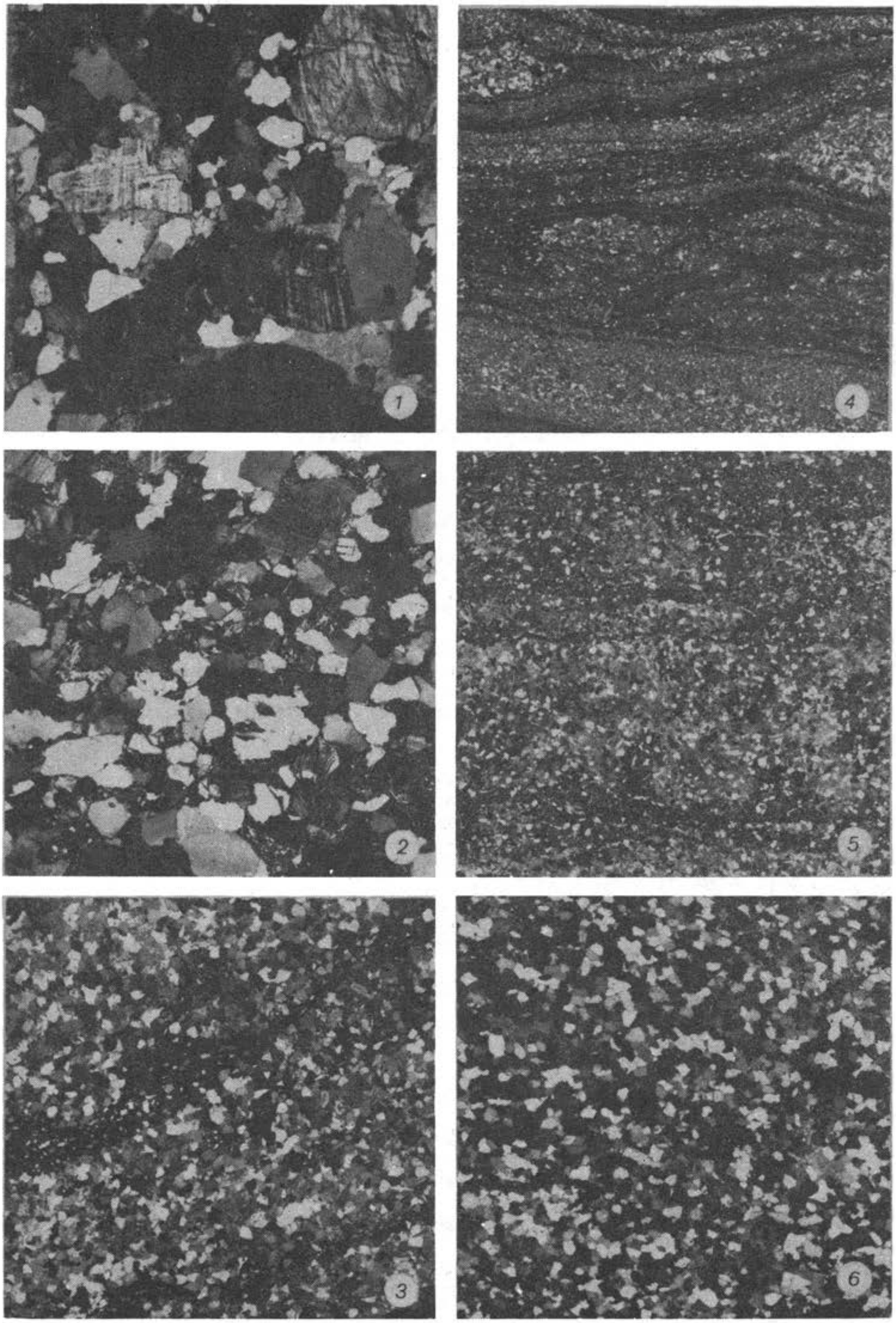
Phot. 15. Subarkosic sandstone (arenite) with glauconite. Klimontów Formation, Zawiszyn Beds. Okuniew, depth 4090.0 m; × 14

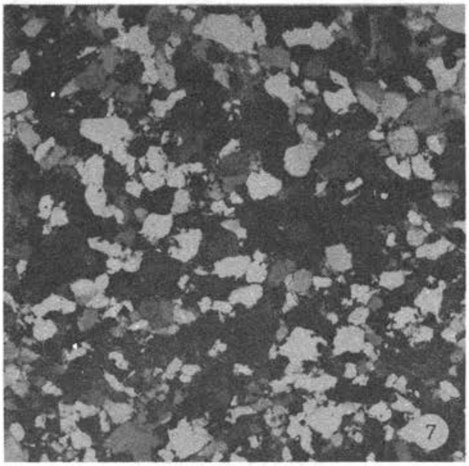
Phot. 16. Quartz sandstone (arenite). Kaplonosy Formation. Białopole, depth 2645.3 m; × 14

Phot. 17. Quartz sandstone (arenite). Kaplonosy Formation. Kaplonosy, depth 1122.5 m; × 14

Phot. 18. Quartz sandstone (arenite). Kaplonosy Formation. Mielnik, depth 1418.0 m ; × 14

PLATE I

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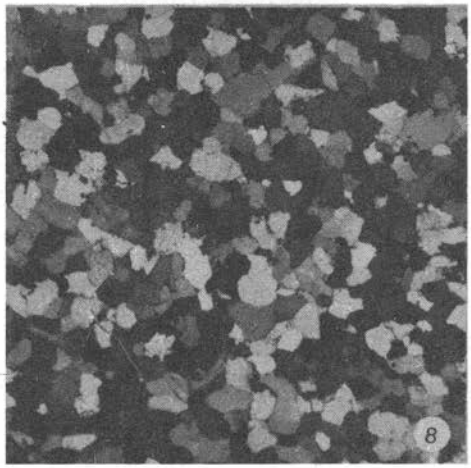
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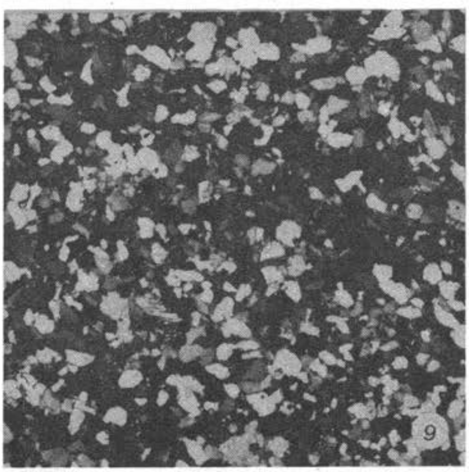
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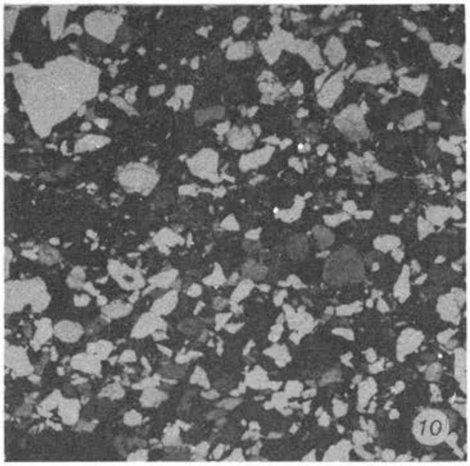
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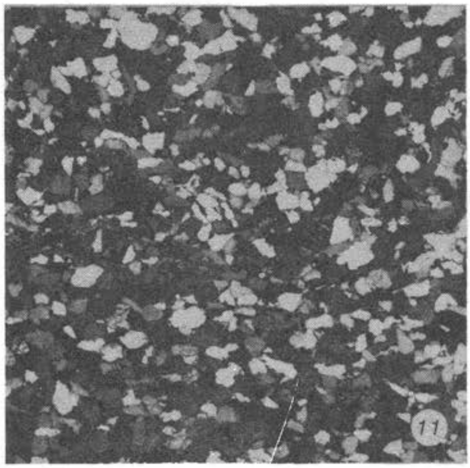
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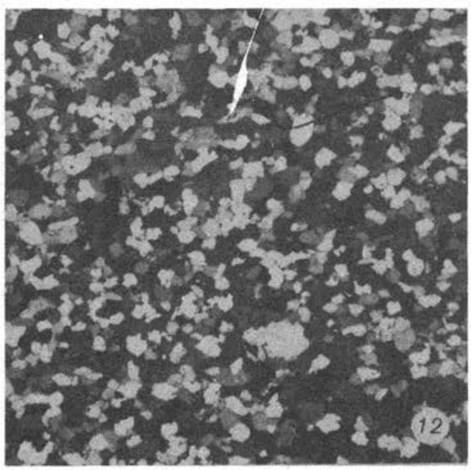
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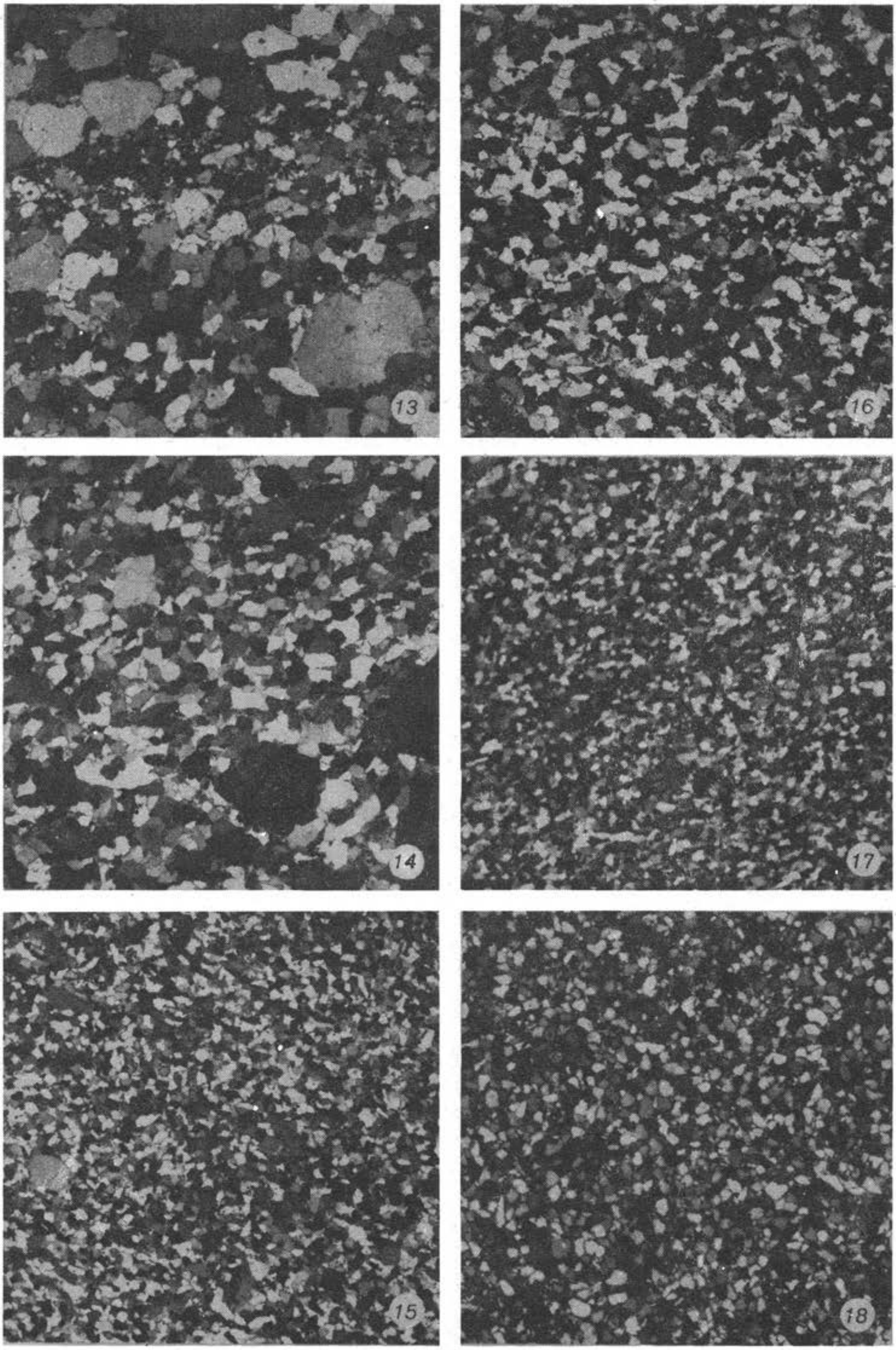
PLATE III



Okuniew region is characterized by directions running evenly with a parallel of latitude and proving existence of tectonic foundations of Brześć – Podlasie depression. The fact is seen evidently from feldspars, glauconite and clay cement contents (Figs. 24 – 26). The best conditions for glauconite's formation and precipitation of carbonates occurred in Mielnik vicinity. In the north – Klimontów Formation sedimentation took place in the open area of uncovered crystallinic with differentiated morphology, which is proved not only in Kościerzyna by Żarnowiec Beds deposits presence but also by different running of grain size and mineral composition isolines (Figs. 23 – 26).

Sedimentation period of Kaplonosy Formation deposits in southern and central part of the area studied (only with Okuniew exception) was characterized by rekatively stable conditions of shallow open sea, which is proved by homogeneous grain sizes, as well as low and stable values of clay cement, glauconite and feldspars contents. Worth mentioning is very low percentage of both last constituents (Figs. 23 – 26). In the northern part of the area discussed the grain parameters of that series deposits differ distinctly from those of the central part. They are generally higher and more differentiated, maximum of glauconite occurrence is shifted to Prabuty region and the rocks are enriched in feldspars, which suggests alimentation region's neighbourhood.

## FINAL REMARKS AND CONCLUSIONS

The following final remarks and conclusions result from the petrographic studies of the clastic deposits occurring at Precambrian – Cambrian boundary:

a) Selection of detrital material and the methods of its quantitative characteristics employed in this work proved useful is recognizing variability in the apparently poorly differentiated clastic rocks complexes.
b) Horizons distinguished basing on granulation and mineral composition remain in good correlation with zones resulting from biostratigraphic analysis. They permit mineralogical characteristic of the biostratigraphic zones and occassionally imply more detailed subdivision.
c) Petrographic studies of the rocks occurring at the Precambrian – Cambrian boundary from platform area of Poland permitted the quantitative characteristics of marine clastics deposits of Lublin Formation, Klimontów Formation and Kaplonosy Formation. The studies resulted also in observation of some differences in development of the deposits under discussion.
d) The petrographic results do not permit a reliable definition of the boundary between the Precambrian and the Cambrian.
e) Differences in the petrographic features noted within Klimontów Formation do not imply any drastic changes in the depositional conditions of the Formation. They are rather indicative of local variations related to facies changes of advancing marine transgression.
f) A relationship has been recognized between the regional features of the deposits and the geological structure and topography of the basement, as well as its lithology and tectonics.
g) The variation of granulation and composition parameters has been observed resulting from advancing marine transgression expressed mainly by time-dependent shifting of the zones of increased grain size, those enriched in feldspar and zones of glauconite formation and carbonates precipitation. The carbonates, however, are a minor constituent of detrital material.

It might be summarized that the petrographic studies carried out on marine deposits of Upper Vendian – Lower Cambrian gave some interesting results, which proves the necessity to conduct such studies in the apparently poorly differentiated rock complexes.

## MINERALOGY AND GEOCHEMISTRY OF CLAY SEDIMENTS OCCURRING AT THE PRECAMBRIAN/CAMBRIAN BOUNDARY IN THE POLISH PLATFORM AREA

### INTRODUCTION

The claystones and mudstones form intercalations of varying thickness in the Upper Vendian and Lower Cambrian sandstones of the Podlasie Depression and the Lublin slope of the Platform (Juskowiakowa, Fig. 15). A < 2 μm clay fraction has been separated from these rocks by means of sedimentation analysis. Attempts have been made to define the paleofacies depositional environment, the type of the parent rocks and the kind of material supplied to the depositional basin on the basis of mineralogical and geochemical differentiation of the clay minerals.

Mineralogical-geochemical studies revealed that, due to their distinctive properties, clay minerals best reflect the variability of the facies conditions. The mineralogical studies of the clay minerals have been supplemented by X-ray analysis. X-ray diffraction pattern of the original samples have been compared with those of the same samples saturated in glycol and baked at a temperature of about 490°C.

The content of trace elements such as boron, lithium, vanadium, gallium, nickel, lead, barium, strontium, and copper has been defined by spectrochemical analysis.

### RESULTS

The < 2 μm clay fraction is composed of illite, kaolinite, chlorite and mixed-layered minerals occurring in varying proportions (Fig. 27a). Usually, illite largely prevails over kaolinite and chlorite, and in some cases the sample contains exclusively illite (Fig. 27b). The vertical mineralogical variability is most pronounced in samples derived from the Wyszków series (Warsaw area). The clays of this series are purely illitic, but transformations towards mixed-layered minerals are noticeable (Fig. 27c). The basal line for illite equalling 10 Å is widened, often blurred and inflects towards lower 2θ angle values. This process is particularly well pronounced in clays of the Białopole and Lublin Formations of the Białopole area (Fig. 27d).

The amounts of essential elements determined in the clay fraction indicate, that the composition of the almost monomineralic clays corresponds to the average composition of illite (according to Stoch, 1974). The percentage of illite has been calculated from the $K_2O$ content in the sample. Its average contents in the clays are given in Tab. 3.

The X-ray diffraction patterns and the amounts of illite calculated from chemical analysis reveal the clays of the northern part of the Podlasie depression (Okuniew IG-1) and of the western part of the Lublin slope of the Platform to be

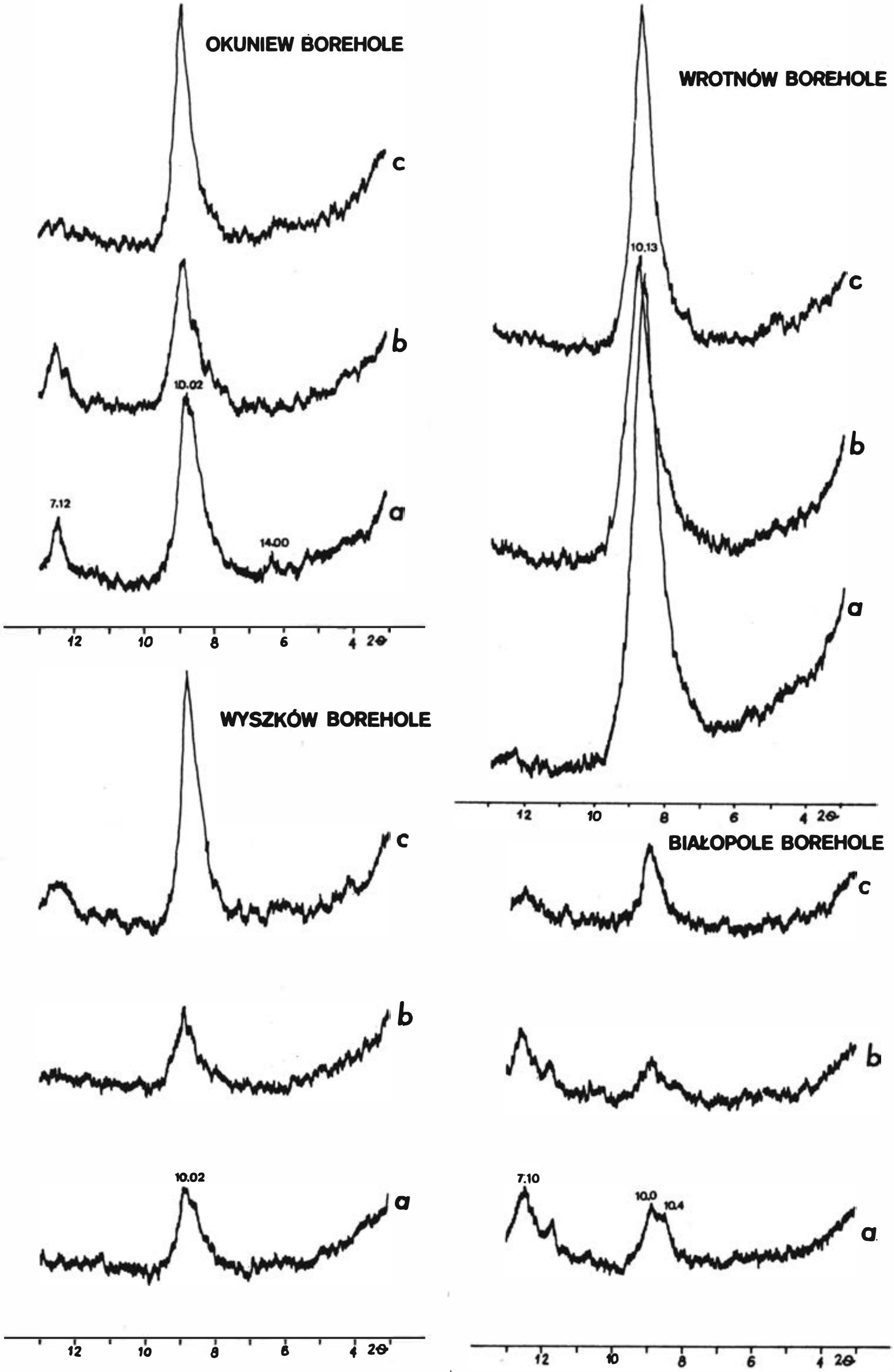



Fig. 27. Diffractograms of the clay fraction

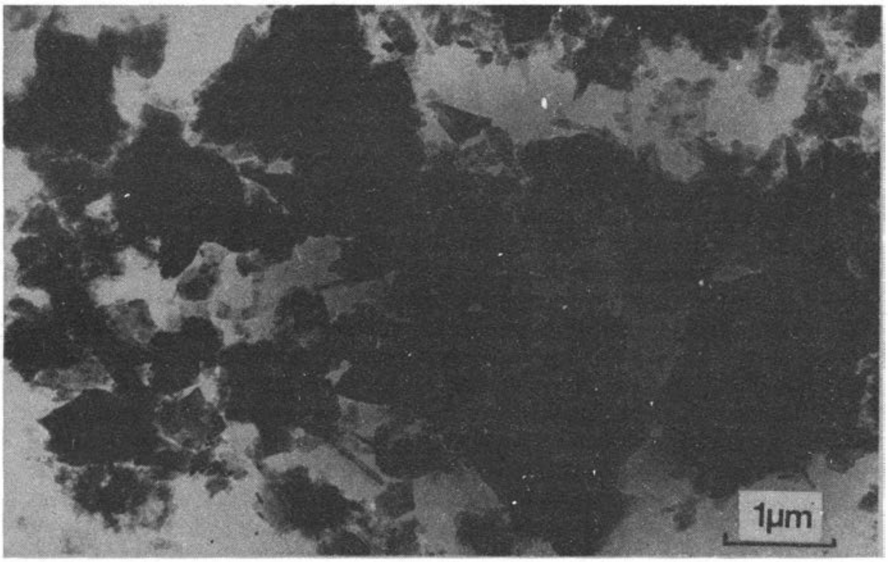
*a* – original sample, *b* – sample saturazed with glycol, *c* – sample heated at the temperature of 490°C almost monomineralic. Illite contents ranging from 70 to 80% have been recognized in the Podlasie depression and found to decrease towards the Lublin slope of the Platform.

As evidenced by micrographs of powder mounts and replicas taken in the transmission electron microscope, the majority of clay minerals are allogenic (Fig. 28a). The illite aggregates have blurred contours and a scaly, sometimes elongated, habit (Fig. 28b). It can not be excluded, however, that a small percentage of illite and kaolinite certain grains may suggest that they originated directly from solutions (Fig. 28c). The majority of kaolinite observed on micrographs is of detrital origin, although some individuals, e.g. the pseudohexagonal scale with sharp contours shown in Fig. 28c, seem to be authigenic (Sarkisyan, 1972).

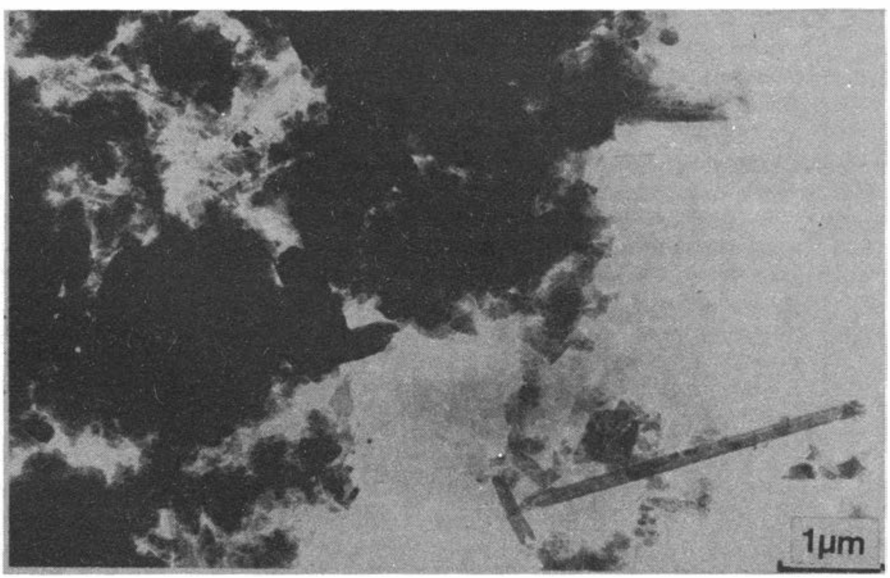
The distribution of essential and trace elements in sediments is greatly dependent on the grain size. The clay fractions contain chiefly alkaline elements: aluminum, calcium and magnesium. Trace elements such as boron, lithium, gallium, vanadium, chromium, nickel, lead, barium and strontium enter the clay minerals structure. Due to their limited migration ability, some of them (chromium, nickel, lead and barium) are more confined to coarser clays deposited in the peripheral parts of the basin. Occasionally, copper has been found to be dispersed in clays. Besides, the distribution of trace elements in the clay fraction is controlled by the following factors: 1) the nature of parent rocks and type of weathering they have been subjected to; 2) the way of transport of the minerals from the weathering crust to the depositional basin; 3) the mineral composition of clays; 4) the nature of the depositional environment; 5) the degree of transformation at the time of diagenetic and epigenetic changes (Kraus, 1975). The most sensitive indicator of the changes in the depositional environment is boron concentrated largely in illite. Marine illites are considerably richer in boron than those of continental or brackish origin. Consequently, this elements can sometimes serve as a facies indicator for the depositional environment. The boron content in the clay fractions of the Polish Platform area exceeds $100 \times 10^{-4}\%$ which may suggest a marine origine of all the sediments examined. The average distribution of the boron and lithium contents in the samples has been established on the basis of the Keith and Degens diagram (Polański, 1969). With this approach all the samples represent a marine, though rather differentiated facies (Fig. 29). An exceptionally high ($1000 \times 10^{-4}\%$) boron content, accompanied by only slight differentiation in the lithium content, has been found in the Mielnik IG-1, Wrotnów IG-1 and Stadniki IG-1 boreholes. A similarly high amount of boron has been reported from clays of the salt-bearing formations. According to the findings by W. Ernst (1970) and H. Harder (1972) the boron content can serve as a salinity indicator for a depositional basin. R.C. Reynolds (1965) has attempted an estimation of the palaeosalinity in old depositional basins based on the boron content. Among the clay minerals illite is the most suitable for this purpose, as it readily takes boron into its crystal lattice. One of the essential requirements for the application of boron as a salinity indicator, which seems to be met in the sediments examined, is the monofacial development. The sorption of boron in the illite lattice is further influenced by: 1) disintegration of the mineral; 2) degree of ordering of the illite structure; 3) intensity of diagenetic processes; 4) climatic factors and 5) rate of deposition. Of particular importance is the origin of illite, as only authigenic illite is an ideal salinity indicator. Detrital illite contains a certain initial amount of boron dependent on the composition of the parent rock. Micrographs of the clay fractions from samples derived from the area discussed reveal the vast majority of clay minerals to be of detrital origin. But the presence of a minor, though indefineable amount of authigenic illite can not be excluded. Summing up the above, one can conclude that boron can be used as an salinity indicator for comparison of lithologically equal sediments formed at a sufficient distant time and laid down at an approximately equal rate in absence of substantial temperature variations. The pressumption is that the degree of transformation of illite is always the same (Reynolds, 1965).

The distribution of the average **boron** content in illites from the clay fractions examined shows a considerable rise in the northern zone of the Podlasie depression in the Stadniki – Wrontów – Mielnik area (Fig. 30). This could be explained

A




B



C


Fig. 28. Electron micrographs of the clay fraction
*A*, *B* – powder mount from the Wyszków borehole, *C* – replica from the Okuniew borehole

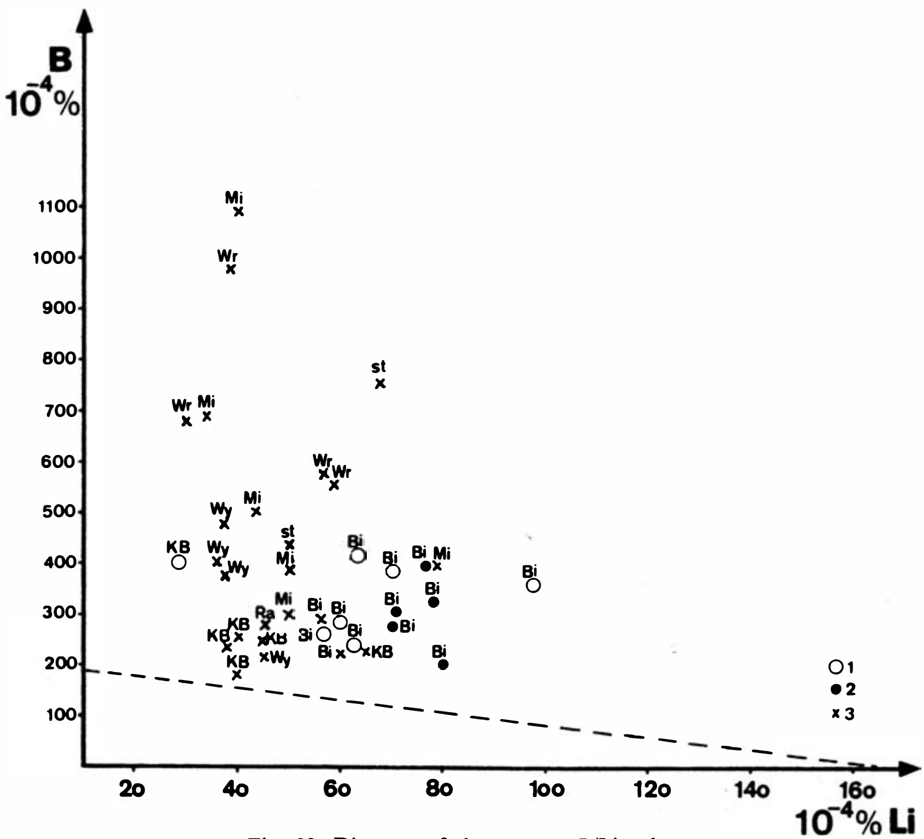



Fig. 29. Diagram of the average B/Li values
*Wy* – Wyszków, *Wr* – Wrotnów, *St* – Stadniki, *Mi* – Mielnik, *KB* – Krowie Bagno, *Bi* – Białopole, *Ra* – Radzyń, *1* – Lublin Formation, *2* – Białopole Formation, *3* – Klimontów Formation

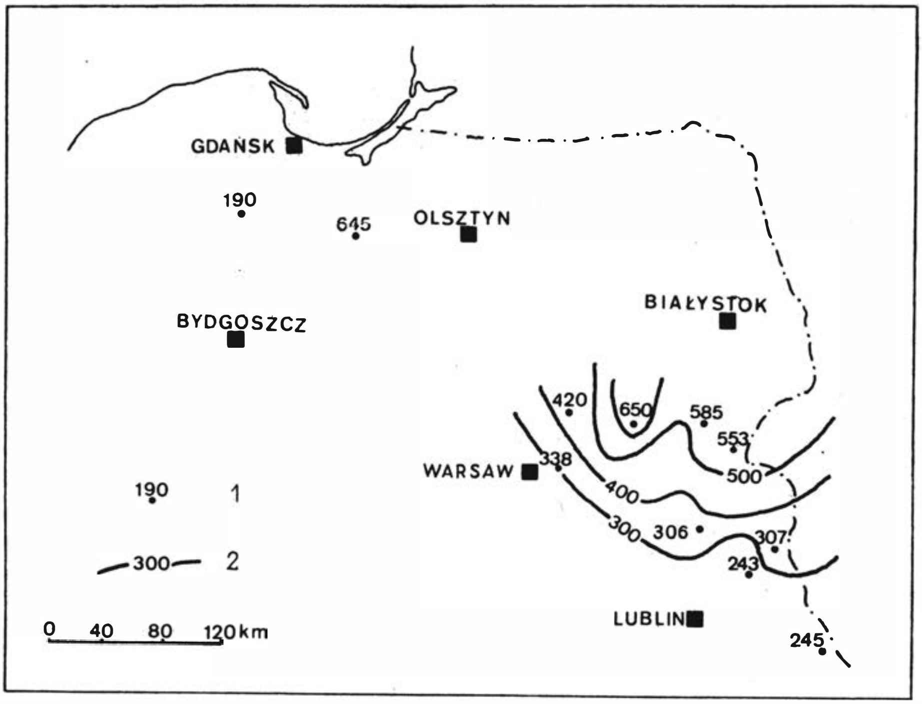



Fig. 30. Map of the average boron content (ppm) in clays of the Klimontów Formation
*1* — boron content in the < 2 μm grade, *2* — isarithms of the boron content

by a temporarily increased salinity due a short-lived cutting off form the main basin.

Unlike boron, **gallium** concentrates mainly in clays rich in kaolinite where it substitutes $Al^{+3}$. Marine illites contain only small amounts of gallium and only slightly higher values have been reported from fresh-water clays. The gallium concentration in clay sediments is largely dependent on the nature of the parent rock. It is fairly uniform in the samples examined and falls in the $15-25 \times 10^{-4}\%$ range (Tab. 3).

**The vanadium and chromium** concentrations depend on the nature of the parent rock and the intensity of alteration of the original minerals. The vanadium is more closely related to kaolinite clays. The highest vanadium ($100 \times 10^{-4}\%$ or more) and chromium ($100 \times 10^{-4}\%$) have been noted in the Podlasie depression (Tab. 3) and the Lublin slope of the Platform (Tab. 3).

The nature of the parent rock has a decisive influence on **the nickel** content. In the samples examined this content is rather uniform and averages ($50 \times 10^{-4}\%$, Tab. 3).

**Lead** accumulates in kaolinite clays redeposited from acid intrusives and metamorphic complexes and its amount is strictly controlled by the nature of the parent rocks.

The differentiation in **the barium** content results directly from the mineral composition of the eroded rocks, where it concentrates in feldspars as a diadochy substitute of potassium. It is more abundant in kaolinite clays than in illite clays.

Table 3

Distribution of illite and trace elements in the clay sediments

| | Borehole | Illite percentage | Average content of the trace elements in $10^{-4}\%$ | | | | | | | | | | Formations |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | B | V | Cr | Li | Ga | Pb | Cu | Ba | Sr | Ni | |
| Clay fraction <2 µm | Białopole IG-1 | 67 | 245 | 33 | 12 | 57 | 9 | nb | 25 | 330 | 125 | 40 | Klimontów |
| | Krowie Bagno IG-1 | 76 | 243 | 225 | 130 | 43 | 22 | 5 | 36 | 202 | 113 | 69 | |
| | Kaplonosy IG-1 | 71 | 307 | 106 | 112 | 74 | 23 | 15 | 11 | 323 | 125 | 40 | |
| | Mielnik IG-1 | 70 | 553 | 135 | 118 | 52 | 18 | 11 | 100 | 170 | 103 | 46 | |
| | Radzyń IG-1 | 92 | 306 | 151 | 150 | 41 | 17 | 29 | 8 | 150 | 106 | 75 | |
| | Stadniki IG-1 | 78 | 585 | 88 | 90 | 50 | 22 | 13 | 5 | 185 | 172 | 55 | |
| | Wrotnów IG-1 | 85 | 650 | 143 | 68 | 49 | – | 9 | – | 144 | 145 | 36 | |
| | Wyszków IG-1 | 86 | 420 | 95 | 112 | 35 | 27 | nb | 9 | 310 | 22 | 40 | |
| | Okuniew IG-1 | 93 | 338 | 113 | 106 | 41 | 23 | 27 | 8 | 218 | 105 | 39 | |
| | Białopole | 61 | 306 | 84 | 106 | 71 | 14 | nb | 38 | 472 | 104 | 39 | Lublin |
| | Kaplonosy IG-1 | 64 | 235 | 128 | 107 | 86 | 23 | 22 | 20 | 340 | 92 | 37 | |
| | Kaplonosy IG-1 | 85 | 542 | 130 | 120 | 42 | 27 | 11 | 16 | 190 | 130 | 54 | Kaplonosy |
| | Mielnik IG-1 | 74 | 640 | 205 | 162 | 37 | 25 | 10 | 24 | 260 | 187 | 53 | |
| | Radzyń IG-1 | 87 | 316 | 145 | 97 | 99 | 16 | 18 | 9 | 150 | 115 | 41 | |
| | Prabuty IG-1 | 78 | 615 | 152 | 78 | 81 | – | 16 | – | 337 | 80 | 35 | |

**The strontium** content is influenced by the nature of the parent rock, the mineral composition of the clay fractions and the salinity of the depositional basin. It is less than $100 \times 10^{-4}\%$ in the fresh-water clays and gradually increases in brackish and marine sediments. In the samples examined it exceeds $100 \times 10^{-4}\%$ (Tab. 3).

**The copper** concentration does not depend on the weathering environment in the provenance area or the depositional environment. It is more abundant in illite clays redeposited from zones of polymetallic mineralization. A high copper content ($100 \times 10^{-4}\%$) has been found in clay sediments from the Mielnik IG-1 borehole (Tab. 3).

## DISCUSSION AND CONCLUSIONS

The claystones and mudstones occurring in the Upper Vendian and Lower Cambrian sandy sediments are built of detrital micas and clays minerals. They contain varying amounts of quartz, carbonates, pyrite and glauconite. In the clay fraction the main constituent is the illite-kaolinite assemblage (illit predominating over kaolinite) accompanied by mixed-layered minerals and minor chlorite admixtures. Illite and kaolinite are regarded as weathering products of micas and feldspars, which can be variously affected by weathering in the denudation zone or transported by rivers into marine basins where, in a different hydrochemical environment, they undergo further alteration. The districution and type of clay minerals imply the nature of rocks subjected to denudation.

The illite-kaolinite-chlorite association is most often formed in the weathering crust of acid crystalline rocks. Such rocks predominate in the Mazury – Suwałki elevation regarded as the provenance area for the sandy-clay sediments of the Vendian – Lower Cambrian basin.

The mineralogy and geochemistry of the clay sediments indicate that during the Upper Vendian and Lower Cambrian the Polish Platform area constituted a vast marine depositional zone. Within this zone a minor differentiation in the type of clay sediments and some trace elements contents has been noted. This differentiation stems from a varying degree of transformation of the clay minerals, an uneven supply of the terrigenous material, the morphology and mobility of the basement, the rate of accumulation periodical outwash and erosion and local increase in salinity.

The depth of the basin in the north-eastern part of the Polish Platform area may be inferred from the map showing the average illite content (Fig. 31). The isarithm pattern indicates the existence of two zones: a) a shallower embracing the northern part of the Podlasie depression and the eastern part of the Lublin slope of the Platform and b) a slightly deeper one extending along the southern portion of the Podlasie depression and the western margin of the Lublin slope. Most probably the visibly lower amount of illite in the Białopole area is not related to the shallowing of the basin, but results from an advanced transformation of illite in a relatively deep aqueous environment. Besides, as evidenced by a fairly uniform mineralogy and geochemistry of the sediments examined, the deposition in this rather deep basin must have occurred without any gaps and interruptions.

A thorough analysis of the geochemical facies indicators (vanadium, chromium, barium) for the provenance area indicates that the material supplied to the Podlasie depression and the Lublin slope of the Platform derives from crystalline rocks of acid composition. These are found in the neighbouring Mazury – Suwałki

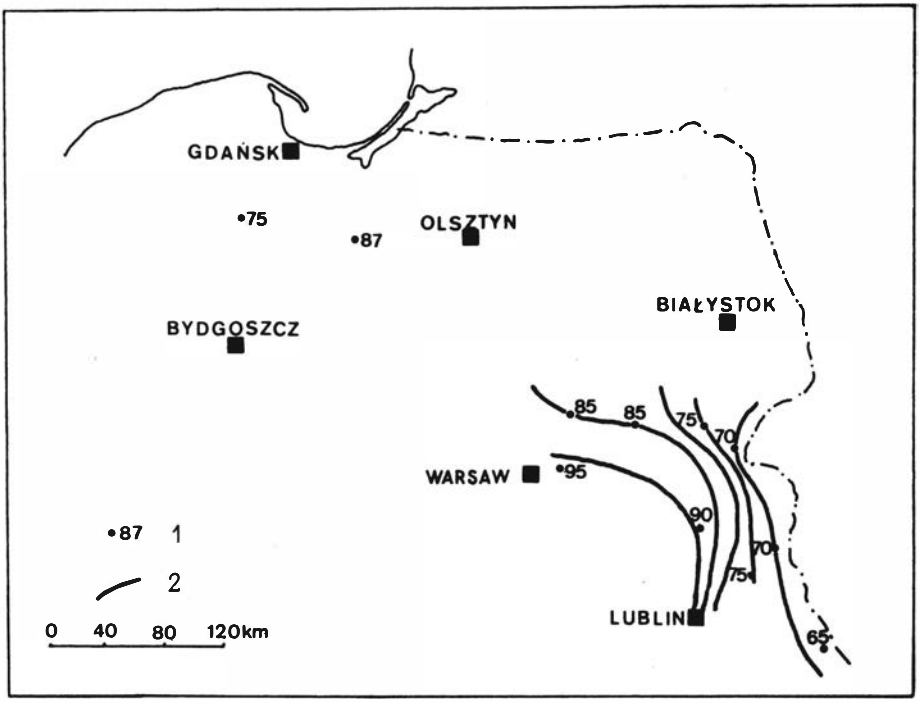



Fig. 31. Map of the average illite content (in %) in the clay fraction < 2 μm of the Klimontów i Formation deposits

*1* – average content of the illite in boreholes, *2* – isarithms of the average content of the illite

elevation where, besides the predominating Svecokarelian and Gothian complexes occur the more basic members of the Kampinos complex and the anorthosite-norite intrusives of the Mazurian complex. The provenance area for the south-eastern margin of the Lublin slope (Białopole area) must be looked for in the Podlasie metamorphic complex.

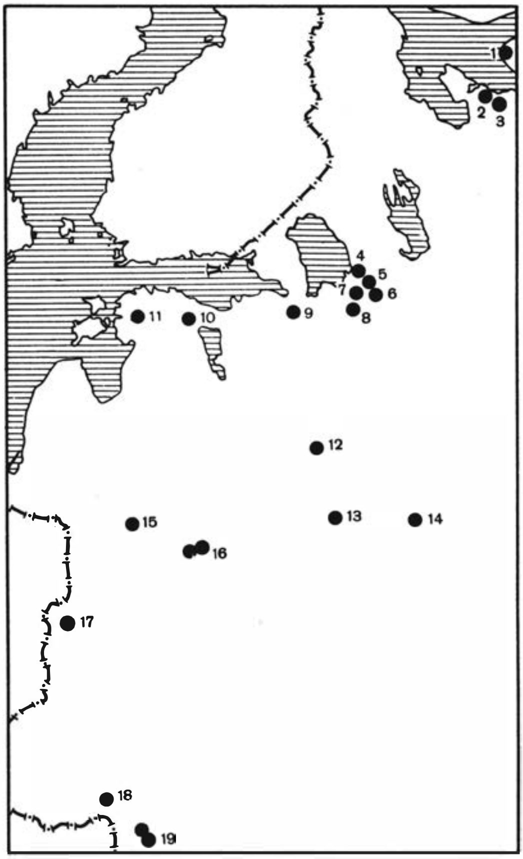
## CLAY MINERALS IN VENDIAN AND CAMBRIAN ROCKS AND THEIR IMPORTANCE FOR PALAEOGEOGRAPHY AND STRATIGRAPHY

Clay rocks compose a significant part of the Late Vendian and Early Cambrian terrigenous section throughout the entire East-European Platform, and they may run as high as 90% and over in some stages (Redkino, Kotlin, Lontova). Moreover, within the extensive Moscow Basin and Soviet Baltic area these rocks are rather poorly lithified due to secondary processes because these rocks give very stable suspensions without any essential chemical or mechanical action. Only in the south-western parts of the platform where the rocks are deeply buried, are they represented by typical claystones which were not reworked in an aqueous medium.

Therefore, stratigraphic and palaeogeographic studies involve all the informa-

Fig. 32. Location map showing sections discussed

*1* – Zimnegorsk outcrop, *2* – Solczersk borehole, *3* – Senzersk borehole, *4* – Pasha borehole, *5* – Maloshaty borehole, *6* – Kunevichi borehole, *7* – Usadishche borehole, *8* – Zarechie borehole, *9* – Kostovo borehole, *10* – composite section of north-eastern Estonia, *11* – composite section of western Estonia, *12* – Toropets borehole, *13* – Yartsevo borehole, *14* – Vorobievo borehole, *15* – Vilkishkyai borehole, *16* – boreholes C-012 and C-013 of Byelorussia, *17* – Stradech-17 borehole, *18* – outcrops in Podolia, *19* – composite section of Moldavia (boreholes 1-G and 2M)




tion available on clay constituents of the sediments, because it is just the minerals of the fine fractions, in addition to authigenic minerals, which best of all reflect physico-chemical conditions of sedimentation and, at the same time, can retain this information for millions of years. The clay constituent is of particular importance in the Vendian deposits which are not rich in fossils generally used for subdivision and correlation of sections. Due to high floatability of clay particles of catagenetically slightly altered sediments of ancient basins at the stage of sediment formation, they are very similar to planktonic organisms spreading throughout the basin. Consequently, some additional criteria for stratigraphic studies can be acquired from the recognition of distinctive features of separate groups of clay mineral and regular changes in their associations across the area. Some markers, for example tuffaceous montmorillonite interbeds in the Redkino Stage, as well as a distinctive chamosite occurrence in the Upper Vendian of the Baltic area, have already been reported (Aksenov and Volkova, 1969; Pirrus, 1973); they promote further studies.

Unfortunately, the clay constituent merits more systematic consideration than has been given to it as yet. Only a few papers on the eastern regions of the platform (Aksenov *et al.*, 1970; Volkova, 1976; Postnikova *et al.*, 1977) and on the condensed sections of the Baltic area (Apinite, 1971; Pirrus, 1970) can be listed. Other data on clay minerals of these deposits cited in a number of general lithologic and stratigraphic works are more random and cannot be reliably generalized because of difference in techniques.

To fill the gap the author, during the past few years, studied Upper Vendian and Early Cambrian clay minerals from 19 easily accessible key sections embracing the western part of the platform from north to south (Fig. 32). All in all 624 samples chiefly of clay rocks taken by the author from cores and large outcrops, for example, in the Winter (Zimnii) Coast and in Podolia were analyzed. In some cases samples collected from adjacent boreholes or outcrops were related to a single composite section of the region (Ladoga Lake area, Estonia, Byelorussia).

Clay minerals were analyzed in a fraction < 0.001 mm extracted from suspension following light mechanical pounding and ultrasonic processing. Quantitative estimation was performed on URS-50 IM diffractometer using a method of comparing with a reference mineral mixtures used at the Institute of Geology of the Estonian SSR Academy of Sciences. Reliability of X-ray data was checked selectively by chemical and, in part, thermal analyses which yielded unambiguous results in all the cases.

Rock samples to be analyzed were collected from the following sections: Zimnegorsk outcrop White Sea (Vendian); Solozersk-11 and Sinzersk-26 boreholes, southern White Sea area (Vendian); Pasha, Usadishche, Maloshaty, Kunevichi, and Zarechie boreholes, Ladoga Lake area (Vendian, Baltic Series of the Cambrian); Kostovo borehole, south of Leningrad (Vendian, and lower Cambrian); Kunda, Ukhta, Yaama, and Sinimyae boreholes, north-eastern Estonia (Vendian and Baltic Series of the Cambrian); Virstu, Koluvere, Haapsalu, Ardu, and Arukyala boreholes, western Estonia (as above); Toropets boreholes (Vendian and lower Baltic Series); Yartsevo and Vorobievo boreholes, south-western Moscow Basin (Vendian); boreholes C-012 and C-013 in Byelorussia (Vendian and lower Baltic Series); Vilkiškiai boreholes, south-eastern Lithuania (as above); Stradech-17 k borehole, Brest depression (as above); outcrops along the Dniester River in Podolia (as above); boreholes 2-M and 1-G in Moldavia (Vendian).

As no graphic representation of all the original data is feassible, the results obtained are presented below converted to arithmetic mean values for major stratigraphic units of the section which have been substantiated in the first volume of the monograph. Such a procedure makes a real distribution pattern of clay minerals in rocks less evident, eliminating many contrasting transitions in particular sections; however, on the other hand, it allows the use of a statistical approach and reliable estimation of any changes in composition of clay minerals for stratigraphic and palaeogeographic studies.

The data presented in such a form (Fig. 32) allow us to draw the following conclusions.

The clay component in both Vendian and Cambrian deposits is polymineralic in composition. Along with predominant minerals of hydromica and chlorite groups, which in fact occur ubiquitously, kaolinite and expanded-lattice minerals are also rather common, though their abundance is strongly variable. However, the latter are dominated by mixed-layer minerals of the hydromica-montmorillonite type. Chlorite-montmorillonite mineral assemblages, as well as pure montmorillonite phases, are scarce and negligibly small, except for the above – mentioned interbeds of altered tuffaceous material in northern and central sections of the Moscow Basin. In most cases montmorillonite and chlorite-montmorillonite are less than 10% of < 0.001 mm fraction. The largest amount of the minerals were recorded in some samples from the Vendian section in Moldavia and from the lower Vendian sections in the most northerly regions (Ladoga Lake and White Sea areas). These minerals are actually not present in the Cambrian deposits, and traces were found only in some samples from the Rovno Stage. As the minerals cannot be represented in columns on a definite scale they are grouped together with mixed-layer minerals of the montmorillonite-hydromica series. The latter are very diverse. Their presence can only be inferred from strong diffusivity of reflection 10 Å and from the appearance of some vague reflections within 11–12.5 Å range after treatment with ethylene glycol. In other cases even an initial diffractogram shows an independent additional reflection in the range 11–12 Å which disappears on heating and shifts towards narrow angles after treatment with ethylene glycol. Taken together these facts suggest that these deposits show gradual phases from montmorillonite to hydromica which may also differ in origin: they may either result from strong decomposition of micaceous minerals or, in contrast, they may be products of partial aggradation of primary montmorillonite minerals. Other minerals, particularly typical hydromicas, being common do not allow us to unambiquously solve the problem for certain samples. However, some conclusions can be also drawn if we trace clay mineral assemblages across the area (Fig. 33).

Vertical variations in the clay mineral composition can either be very sharp, or gradual and indistinct. Very contrasting and at first sight rather irregular lateral variations are also observed in coeval deposits. However, the opposite can be the case; for example, the Lontova and, to a less extent, Redkino deposits can be similar in composition over large distances.

Thorough examination of the most variable component of the clay fraction, such as kaolinite and expanding-lattice clay minerals, helps to have insight into many problems. The expanded-lattice clay minerals were found to be most common in the Redkino deposits, i.e. in the lower part of the sections studied. The minerals of this group amount to 20—40% and tend to increase south-westward. In the overlying deposits the content of mixed-layer minerals decreases drastically and sttains the above level only in a few places, for example, the Kanilovki Formation in Moldavia and in the Dniester River area. This suggests an important supply of unstable material of volcanic origin into the Redkino basin which was subject there to partial halmyrolysis and aggregation. This conclusion is in good agreement with the presence in the Redkino terrigenous beds of montmorillonite clays of apparent volcanic origin which was not taken into account in the converted data presented. Of interest is a negative correlation between mixed-layer phases and the amount of chlorite and, to a lesser degree, that of kaolinite in the Redkino deposits. Though the last mentioned features are rather uncertain and they are unlikely to be attributed to a low content of unstable mixed-layer phases, a high amount of mixed-layer minerals is a typical feature of the Redkino clays as the whole and, hence, can be used as an additional stratigraphic criterion.

The distribution of kaolinite across the section is not so regular, it often tends to sharply increase in the basal part of the Kotlin Stage. For example, the Gdov Formation in the North Baltic area which thins out eastward and grades into more deep water and less kaolinite-bearing deposits. Equivalents of the Gdov Formation are recognized on the basis of kaolinite in the western sections of the Moscow Basin (Toropets, Yartsevo) and, less evidently, in Byelorussia. In the Podolian Dniester area kaolinite is common in the Dzhurzhevka Formation, however this can be placed in the upper Redkino Stage. An increase in kaolinite supply to the sedimentation area at the onset of the last Vendian transgression is best explained, on the one hand, by the effect of deep humid weathering in the source areas, and, on the other hand, by a complete extinction of volcanic activity by that time.

It is quite natural that the most near-shore shallow water facies to a greater extent reflect the surrounding source area than more distant facies whose clay material was derived from different sources and was strongly affected by mechanical differentiation. This is well exemplified by a high kaolinite content in a section of south-eastern Lithuania which lies within a belt where the Late Vendian basin deposits wedge out. The units typical of the Late Vendian in the rest of the platform cannot be megalithologically recognized in this section (Sakalauskas, 1968).

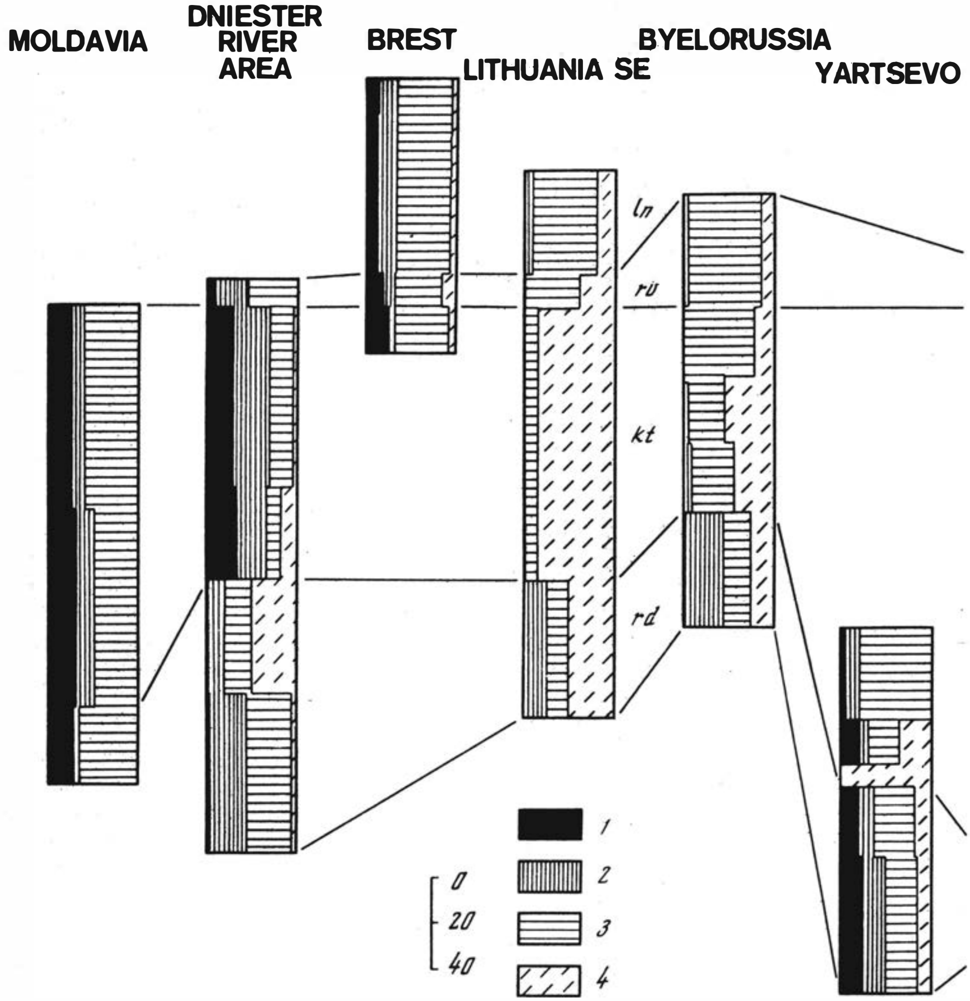
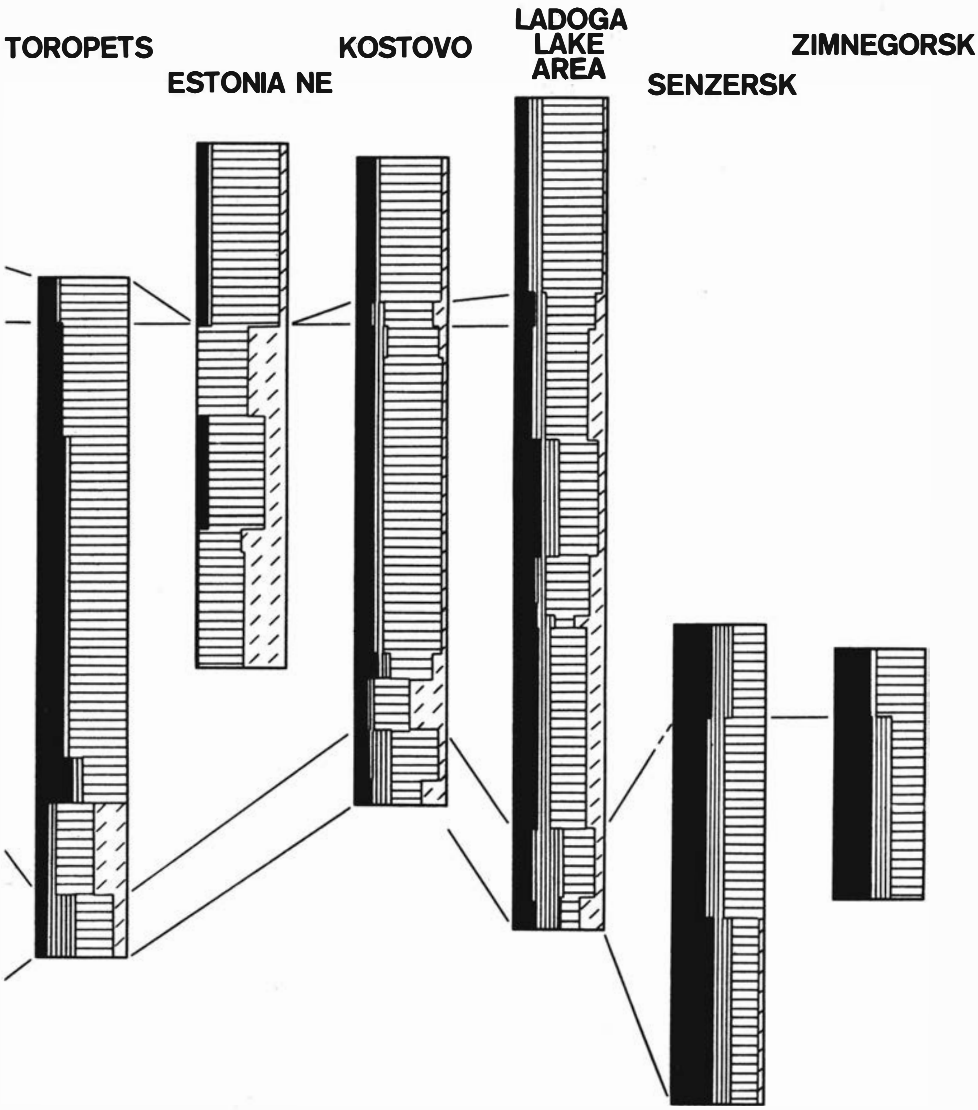



Fig. 33. Mean content of major clay mineral groups in sections

Stages: *rd* – Redkino, *kt* – Kotlin, *rv* – Rovno, *ln* – Lontova; minerals: *1* – chlorite, *2* – montmorillonite, and mixed-layer minerals of the montmorillonite-chlorite and montmorillonite-hydromica types, *3* – hydromica, *4* – kaolinite

The same is true for Estonia: though a sequence of laminarite clays – which is a marker in the Kotlin Stage – still occurs in the east, above it comes a new, separate, part of the section – the Voronka Formation – suggesting regressive features containing a distinctive clay mineral association rich in kaolinite and locally in chamosite (Mens and Pirrus, 1971; Pirrus, 1973). In western Estonia laminarite clays are missing from the section, and the section as a whole resembles that of South East Lithuania. It should be noted that the most complete sections of laminarite clays proper show a regular increase in kaolinite in their lower and upper parts (Ladoga Lake area, Kostovo, Estonia, Toropets, Byelorussia); this is in good agreement with the general lithology of the succession, i.e. with the appearance of silty and sandy bands suggesting shallower water deposition




in its upper and lower parts. Kaolinite is absent only from the Kotlin deposits in Moldavia. It remains uncertain whether this is due to the post-sedimentary argillitization of deposits or to the effect of another provenance in the region of the present mountain structures of the Alpine geosyncline. A high amount of mixed-layer minerals in deposits of Moldavia and Podolia argues for the latter (see Fig. 33).

The proportion of kaolinite markedly decreases in the overlying Cambrian deposits. Kaolinite is more common only in the lower part of the sections where it might have been redeposited from the Vendian (Pirrus, 1970). A high content of kaolinite is also observed in the most westerly sections of the Baltic Series (Lithuania, western Estonia) affected by the proximity of a landmass.

Thus, inspite of strong variations in kaolinite component of the clay fraction across the section, it can be used in stratigraphic studies with due regard for its lateral changes. On the other hand, the fact that this mineral occurs mainly in the Kotlin deposits suggests not a pure normal marine sedimentation for the period, as also evidenced by authigenic minerals, in particular, by the absence of glauconite and sedimentary phosphate. This also may explain the fact that neither trace fossils nor Ediacarian fauna have as yet been found in the rather well known Kotlin horizon, though they are fairly abundant in the underlying Redkino deposits showing persistent features of marine lithogenesis.

In the study area clay minerals of the Cambrian glauconite-bearing strata are monotonous and monomineralic in composition. This part of the section is characterized, along with a decrease in kaolinite, by an almost complete disappearance of mixed-layer minerals which are known to be hardly typical of slow marine sedimentation. The amount of chlorite is constant in all the sections, however it rarely exceeds 20% and thus does not attain the level reported from many Vendian deposits. Chlorite is highly decomposed and its relict occurrence in these deposits can be inferred from crystallochemistry of this mineral known from Estonian sections (Pirrus, 1970). The above data can be discussed also in terms of palaeogeography, thus permitting recognition of major trends in changes of clay mineral assemblages throughout the area (see Fig. 34). Mean contents of clay minerals for separate sections plotted on a sketch map show that in the Redkino Stage chlorite was supplied into the basin mainly from north-east and south-east. The proportion of the mineral regularly and persistently decreases in this direction, but we still cannot say where chlorite was derived from. Mixed-layer minerals were supplied into the Redkino basin from the east in the Moscow Basin area and from the south-west in Podolia and Byelorussia. These directions point to rather localized volcanic sources for these minerals, and location of volcanic centres inferred from clay minerals are consistent with those previously recognized directly from volcanic eruptions. Kaolinite was supplied into the Redkino basin extensively from west to east.

Hence, there was a pronounced asymmetric pattern of clay mineral supply into the Redkino basin: the most weathered material was derived from a vast zone landmass in the west of the territory, while the least weathered material came from the north-east and south-east. The latter regions are unlikely to have been highly elevated above sea level and represented mountain structures – such a regularity cannot be inferred from grain size distribution of the deposits. A more pronounced effect might have been produced there by a distinctive composition of eroded original rocks (chlorite-bearing shales and the like) and, primarily, a climatic factor which was then unfavourable for the formation of kaolinite-bearing weathering crusts in the eastern parts of the platform. The supply of material of volcanic origin into the Redkino basin to a certain degree makes the above asymmetric pattern more complicated, but cannot eliminate it completely.

During the Kotlin Stage the supply pattern of certain groups of clay minerals in general remained the same, showing only slight changes (see Fig. 34c). Owing to the expansion of the transgression, kaolinite was derived only from the west; its supply from the north-west has not been established. A high kaolinite content in the Yartsevo section points to a new source of kaolinite minerals in the Ukraine. Chlorite is still derived from the north-east and becomes more amply supplied from the south-east, from the surrounding Ukrainian shield. The supply is also known from the south-west (Brest depression). Mixed-layer minerals decrease in quantity, however their distribution shows two maxima

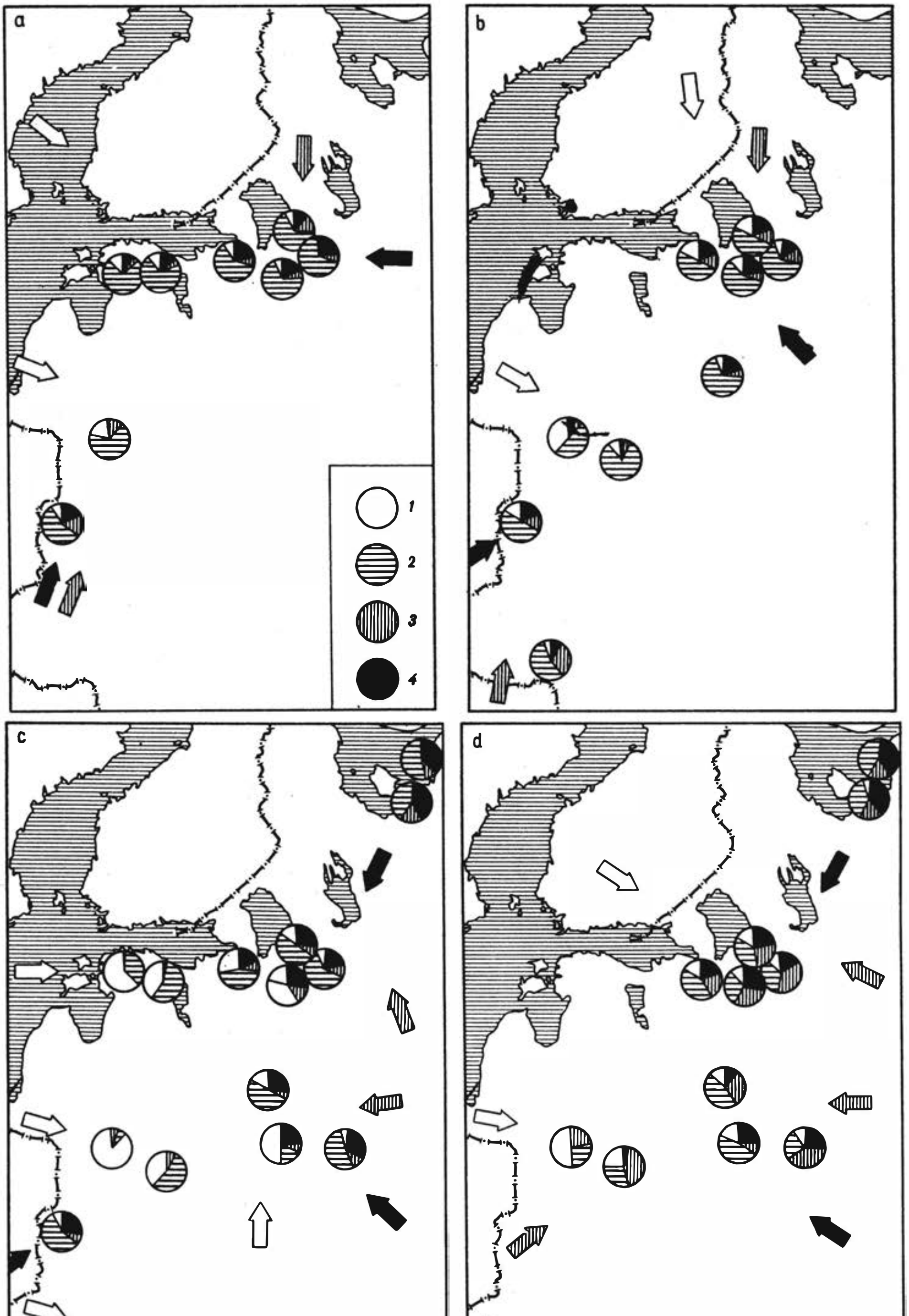



Fig. 34. Schematic diagrams showing changes in clay mineral assemblages across the area

Stages: *a* – Lontova, *b* – Rovno, *c* – Kotlin, *d* – Redkino; clay minerals: *1* – kaolinite, *2* – hydromica, *3* – montmorillonite and mixed-layer minerals, *4* – chlorite; arrows show main directions of supply of some clay mineral groups in the same regions as in the Redkino Stage. This may be attributed to the fact that Redkino sediments were partly redeposited into the Kotlin basin.

Two source areas of clay minerals, namely, the western-north-western zone and the south-eastern zone of supply of kaolinite and chlorite minerals, respectively, can be easily distinguished in the Cambrian Rovno basin (see Fig. 34). The north-eastern region of chlorite influx, highly typical of the Vendian, no longer exists there. Now chlorite is derived mainly from a new source area in the Carpathians which originated as early as the Kotlin Stage. In the northern part of the basin there is no distinct direction of mixed-layer mineral transport, one can only outline some north-south direction parallel to that of kaolinite in the northern part of the basin. This suggests only the cessation of intense volcanic activity within the platform by Rovno Stage, and the clay fraction of the sedimentary rocks could only be derived from redeposition of older sediments rich in mixed-layer minerals. In this case provenance areas should be found in outcrops of the Redkino Stage, just on the northern margin of the Rovno basin. The proportion of mixed-layer montmorillonite-hydromicas increases in the Podolian sections owing to a stronger influx of metastable phases of clay minerals from the Carpathians which took place at the same time. At present it is difficult to say whether they were derived from primary volcanic or earlier deposited eroded rocks.

During the Lontova Stage, when the Cambrian transgression spread over more westerly regions, the main pattern of clay material supply changes a little (see Fig. 34). Kaolinite supply from the west and north-west remains obvious for the period as well. As to chlorite it is not so clear, however, we know that it was derived from the north-east and south-west, while that from the south-east, noted for earlier periods, is not observed during the Lontova Stage. This may be due either to a paucity of analytical data available for the reconstruction, or it can be simply due to palaeogeography. It is interesting to note that both mixed-layer minerals and chlorite were transported from the north-east and south-west. These minerals may have resulted from erosion of the Vendian formations.

From the above two main factors responsible for Late Vendian and Early Cambrian sedimentation in the western East-European Platform can be inferred. First, is the existence of an extensive poorly dissected landmass to the west, within Fenno-Scandia and Central Europe where the processes of chemical weathering of the humid type were intensively operative, and from this area kaolinite was steadily supplied into the basins studied. Second, a quite different picture is observed on the east where chemical weathering could not have been so intense, probably due to an unfavourable more severe climate, more dissected topography and, possibly, more insular type of provenance. It should be noted that the adjacent Ural-Timan geosyncline with its foredeeps impeded transgression on the east and hence formed a barrier for a permanent supply of terrigenous material from the east into the platform basins on the west. Therefore we suggest that sources of clay material were intermittent in nature and erosion affected earlier sediments along the eastern margin of the Late Vendian and Early Cambrian basins discussed. The effect of erosion was strengthened by volcanic activity, particularly during the Redkino Stage sedimentation.

It is noteworthy that clay minerals show no evidence of the effect of the Ukrainian shield in the south-eastern rim of the basins. This source area seems not to have been of primary importance for the formation of the oldest sedimentary strata of the platform.

Naturally, the above conclusions drawn mainly from the analysis of clay constituent of the rocks are quite ambiguous and tentative and should be substantiated by new data. However, they have revealed some crucial and general trends in ancient clay accumulation which cannot be ignored in palaeogeographic reconstructions for certain periods of the Vendian and Cambrian in the western part of the platform.

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