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Glacioisostasy in northern Belarus: evidence and events

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Evidence of glacioisostatic rebound within the ice marginal zone of the last glaciation is presented. The largest glacial lake of Belarus, i.e. the Polotsk lake situated at a short distance from the maximum limit of the Poozerie (Weichselian) Glaciation, was chosen as an object. Spectrum of glaciolacustrine terraces as well as succession of glaciolacustrine series are described. Differences of proximal and distal sequences are defined. Morphological and geological peculiarities of the Polotsk basin are conditioned by the glacioisostatic downwarping. The amplitude of glacioisostatic movements reached up to 40 m. Reconstruction of the events related to the glacioisostasy (shore displacement and water body migration) is given. Glacioisostatic rebound in areas with relatively small ice-loading had a discordant character.

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INTRODUCTION

Glacioisostasy within marginal zones of the last glaciation in the Peribalticum has been studied very fragmentary. It is very difficult to distinguish the isostatic response within the areas where thickness of ice was relatively small and ice loading was not significant. Precise measurements of isostatic movements are not available there. It is also problematic to find indirect evidence of glacioisostatic influence. Quantitative determination of glacioisostatic movements amplitude is referred to as an especially difficult procedure. The papers concerning this problem consider mainly the possibilities of glacioisostatic effect. Nevertheless, there are some publications that concern the glacioisostatic up-gradient of the southern and southeastern part of the Peribalticum. Studies of glacioisostatic influence on the river network development were carried out by V. Gudelis (1973), M. Vigdorchik (1973), E. Bylinski (1985) and L. Marks (1988). These authors have concluded that amplitude of movements in marginal zones of an ice sheet reached up to 40 m, and sometimes even 50 m. In Belarus, influence of glacioisostasy on capture of river valleys, situated in a marginal zone of the last glaciation, was described by E. Levkov and A. Karabanov (1988). But the problem of influence of isostatic rebound on morphological and sedimentologic processes was considered there on a theoretical level only.

The object of this study is one of the largest glacial lakes within the Weichselian Glaciation area, i.e. the Polotsk glacial lake which was situated in northern Belarus (Fig. 1) where glacial lakes were widely distributed during the last glaciation. This basin is bounded by the end moraines of the Sventiany (Frankfurt) Phase in the south and by the Braslav (Pomeranian) Stage marginal formations in the north. The basin is dissected by the Zapadnaya Dvina river valley. The Polotsk lake appears to be the key site for understanding of the Late Pleistocene history as well as for development of the drainage network in the eastern part of the Peribalticum. The lake was a central unit of the ice-dam lake system of the Zapadnaya Dvina basin. Its influence extended eastwards as the local erosive basis for outlets of the northeastern glacial lakes in the territory of Belarus, and northwards as an abundant source of water for the Latvian glacial lakes.

The Polotsk lake had been forming during the Braslav Stage. Its southeastern outlets were active during initial phases of the lake drainage. The southwestern outlet through the Vilnius valley was formed after ice sheet retreat from the Braslav end moraines. Opening of the northwestern outlet took place during the Older Dryas and the Bölling. It should be emphasized that in this paper a special attention is paid to

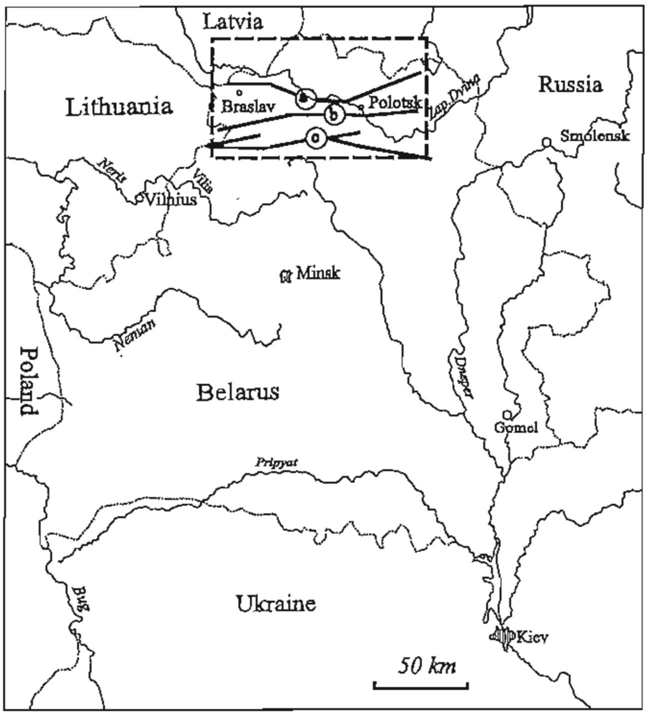

Fig. 1. Location map; rectangled is the studied area

a–c — geologic cross-sections (*cf.* Fig. 3)

effects of a glacioisostatic rebound, and a history of the lake drainage will not be considered further. A more detailed information could be obtained from the studies of A. Basalykas (1967), G. Eberhards (1972), V. Dvareckas and G. Eberhards (1978), J. Straume (1978), V. Vonsavicus *et al.* (1986), and I. Pavlovskaya (1994*a*). The glacial lake history was reconstructed on the basis of its littoral features and shorelines, sedimentary associations, and its outlet controls.

MORPHOLOGICAL FEATURES

Shorelines and terraces of the Polotsk glacial lake have been studied for more than 30 years. In spite of that, they are poorly known in details. The lake levels have been the subject of controversial opinions for a long time. They were described firstly by E. Ilyin (1967) who noted 5 levels, upper of them at 167 m a.s.l., and traced only in the northern part of the lake basin. Two shorelines were described by L. Puzanov (1967) at the southern shore of the lake, the upper one of which occurs at 140 m a.s.l.

Opinions of investigators differ on how to explain the variety of levels. E. Ilyin (1967) interpreted the altitude irregularity of terraces as a consequence of limiting by dead ice blocks in the south. But there is no morphological and geological evidence (e.g. kames and melt-out deformations) for southern bounding by dead ice blocks. The existing controversy on altitudes of shorelines can be derived from a poor knowledge of the terrace pattern.

Detailed studies of distribution of the Polotsk lake terrace surfaces brought additional evidence to a new interpretation and new constructions of the terrace spectrum (Fig. 2). Shorelines and glaciolacustrine terrace spectrum were defined on the basis of interpretation of aerial photos. The use of stereoscopic aerial images allows detecting a spatial distribution of the shorelines. All shorelines and terraces recognized at the aerial photos were identified by instrumental measurements of shorelines and cliffs in the field. This way allowed to carry out spatial mapping of shorelines and to distinguish them continuously. Seven shorelines were defined. The upper of them occurs at 70 m and the lower one at 132 m a.s.l.

Shorelines reflect the high (A1–2 at Fig. 2), middle (B3–6 at Fig. 2) and lower level phases (C7–8 at Fig. 2). There are 6 abrasive terraces, partly covered by thin glaciolacustrine deposits and 2 accumulative terraces. Two high levels, and terraces A1 and A2 attribute to the isolated lakes at the initial phases of basin infilling (I. Pavlovskaya, 1994*a*). Comparison of shorelines and glaciolacustrine terraces indicates essential distinction between different parts of the basin.

In the northern part the higher terraces are the water abrasive forms, and the lower ones are the accumulative forms. The younger accumulative terraces are lower than the older abrasive ones. The opposite situation is noted in a distal part of the lake basin. Only a single continuous lake level is recognized (except shorelines of local ice-dam lakes that were formed before the Polotsk lake). The highest shoreline in this part is located at 140 m a.s.l. There is only a single accumulative surface, and there are no abrasive forms of the Polotsk lake. Moreover, abrasive forms and beach-ridge formations buried under fine-grained glaciolacustrine deposits were found there. It may be an evidence of terrace inversion, when younger forms overlay the older ones.

Thus, the proximal part has a normal sequence of terraces. Such a sequence implies location of the younger accumulative terraees below the older abrasive ones. On the contrary, the distal part has the accumulative terrace only, and the glacioisostatic inversion of terraces, most probably, is traced there. Such an inversion implies deposition of the young accumulative terraces over the older abrasive ones. The most reasonable explanation of morphological divergences between proximal and distal parts of the basin is that the lake water levels could be changed by glacioisostatic movements. The distal inversion of shorelines may be considered as a result of the glacioisostatic tilting.

GLACIOLACUSTRINE SEQUENCES

The glaciolacustrine sequences were studied using the drilling data and recorded in details during field investigations. A spatial heterogeneity of deposits only is considered. It is made in order to understand better a relationship between the ice sheet retreat and the history of the lake development.

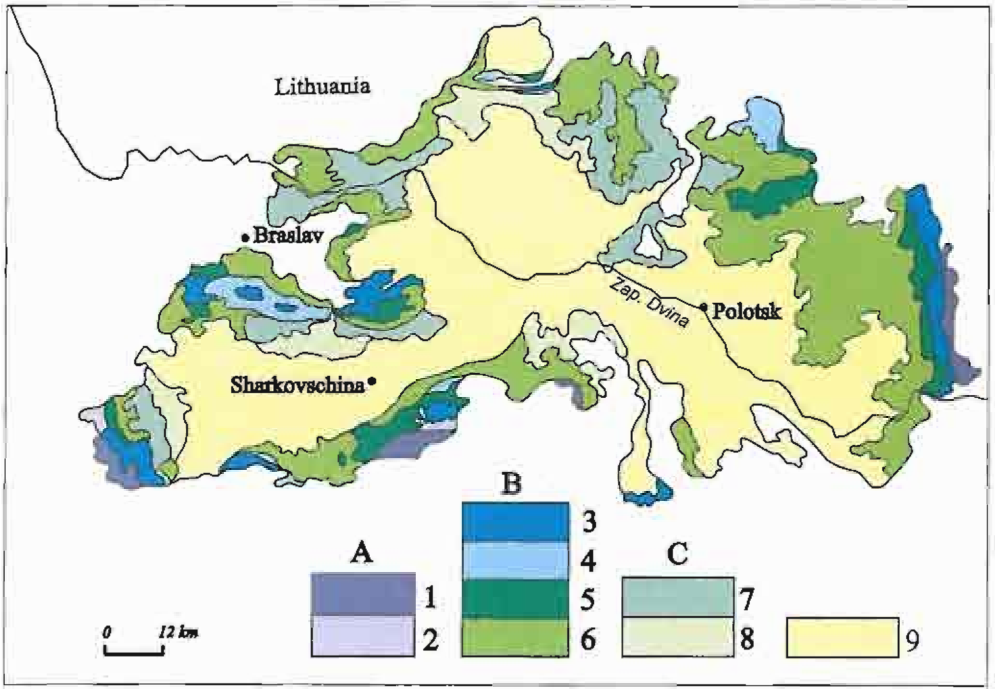

Fig. 2. Glaciolacustrine terraces within the Polotsk glacial lake area

A — local lakes of the Obol oscillation: 1 — 170–165 m a.s.l., 2 — 165–160 m a.s.l; B — abrasive terraces of the Polotsk lake: 3 — 160–155 m a.s.l., 4 — 155–150 m a.s.l., 5 — 150–147 m a.s.l., 6 — 147–140 m a.s.l; C — accumulative terraces of the Polotsk lake and residual lakes: 7 — 140–135 m a.s.l., 8 — 135–132 m a.s.l; 9 — bottom of the lake

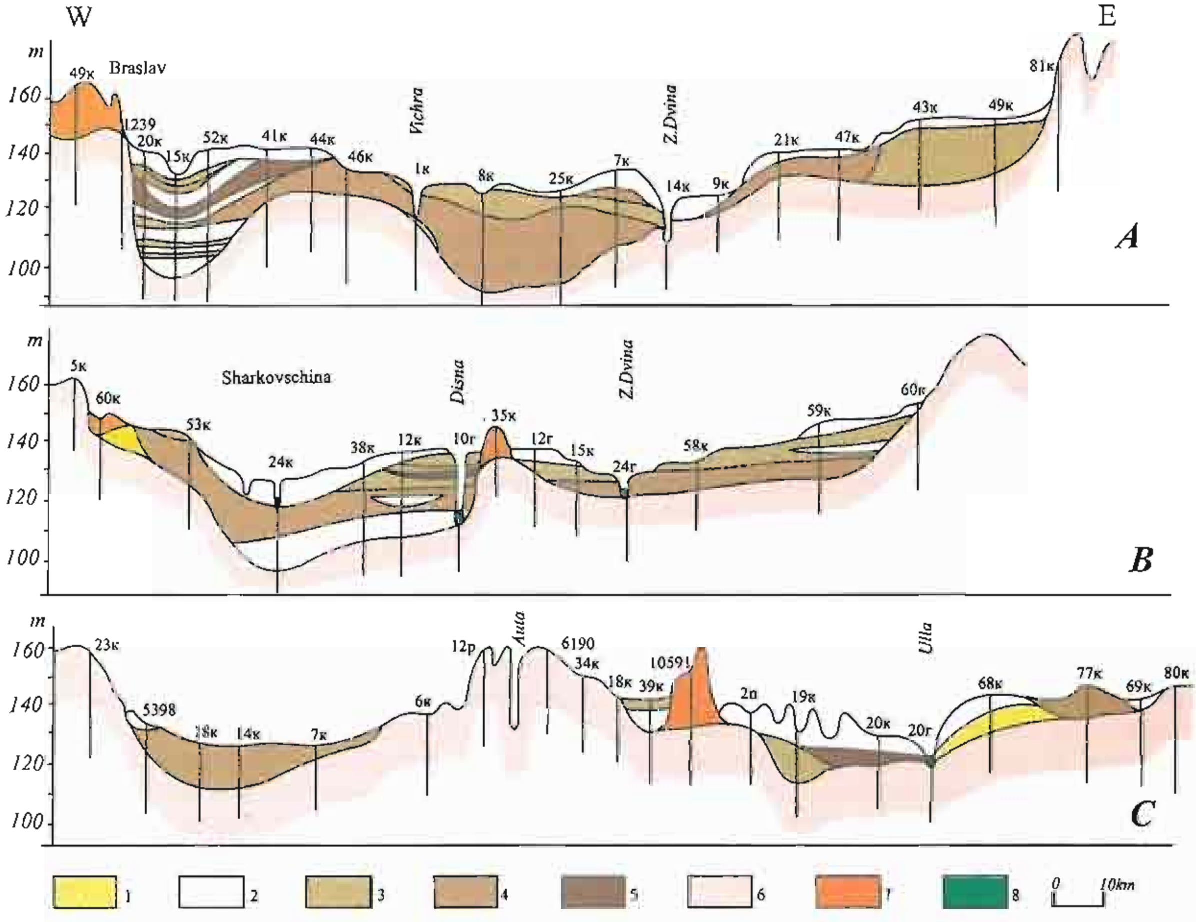

Fig. 3. Geological cross-sections of the proximal *(a)*, intermediate *(b)* and distal *(c)* glaciolacustrine sequences

1 — beach gravel and sand, 2 — fine-grained sand, 3 — silt, 4 — varved clay, 5 — massive clay, 6 — till, 7 — kame deposits, 8 — alluvium

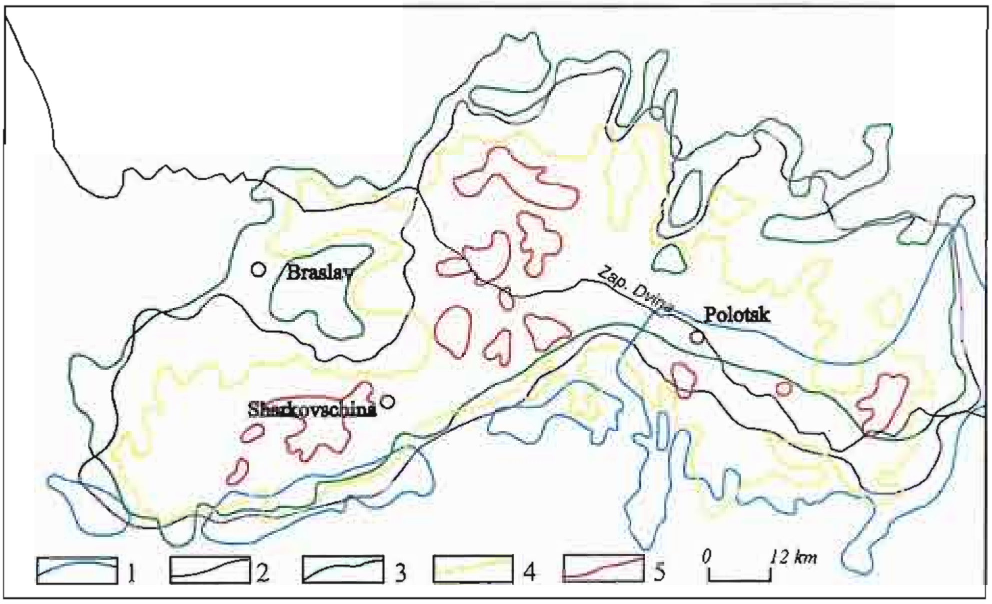

Fig. 4. Phases of the Polotsk lake

1 — local lakes of the Obol oscillation; reconstructed shorelines of the Polotsk lake during: 2 — Braslav Stage, 3 — maximum proximal displacement, 4 — phase of stabilization; 5 — Late Glacial residual lakes

Lithology and sedimentary structures have been described previously (N. Zaitseva, 1969; I. Pavlovskaya, 1994*a*).

The glaciolacustrine series infilling the Polotsk basin can be divided into two distinct associations based on thickness, structure and their position in the section (Fig. 3). The proximal sequence (1) is the interbedding glaciolacustrine unit, 37 m thick (Fig. 3*a*). It contains layers of varved clays, massive clays with coarse debris and lenses of flow till, silts, and sands. The rhythmic interbedded structure of the proximal sequence and the presence of layers of massive clays can be related to the sedimentation pulses due to readvances of ice sheet margin during the Braslav Stage. The coarseness of deposits and dropstones in glaciolacustrine layers indicate that sedimentation took place near the ice margin.

Generally, the proximal sequence is a typical sedimentary succession that was deposited as an effect of successive diminution of the area and depth of a glacial lake. It has a regressive type of bedding: glaciolacustrine sands and silts are recovering varved clays. All sites with coastal deposits are exposed and they are located at strong morphologic shorelines.

Distal sequence (2) reflects calmer conditions of the glaciolacustrine environment. Its structure is less complicated, and thickness is relatively small (Fig. 3*c*). The lowermost part of the distal series comprises thick glaciolacustrine clays, overlaid by thin (no more than 2.8 m) diamicton and gravel associations. These sediments were found southwards from the buried ice marginal formations which were related to the Obol oscillation (I. Pavlovskaya, 1994*a*). Therefore, the above-mentioned series was deposited most probably in isolated lakes, existing during the initial phase of the basin infilling before the Polotsk lake forming. The buried coastal deposits occur in a distal part (see Fig. 3*c*). The presence of buried shore formations has outmost importance, because they are overlaid by littoral fine-grained sands. It may record a significant rise of water level.

Deposits of the lake distal part represent a transgressive sequence. Unfortunately, the age of the overlaying sandy and silty sediments is unknown exactly, because no localities with biogenic material were found in glaciolacustrine accumulations. However, the upper series of fine-grained deposits have very similar altitude, thickness and structure in both proximal and distal parts. The distal upper silty-sandy series and the proximal ones appear to be the same unit, having the same lithologic characteristics and position within the sediment body. Their deposition corresponded to the period when the northwestern drainage channel was formed. Occurrence of the series indicates the most probable local transgression on the distal shore.

Comparison of the proximal and distal sequences shows environmental differences between them. The first one represents gradual drops of a water level, the second one may be deposited as a result of significant increase of the lake depth. It is difficult to explain such differences of proximal and distal sequences only in view of successive drop of lake water levels, because the proximal part of the basin was much deeper than the distal one. Underlying glacial sediments in the northern part of the lake occur at about 90–100 m a.s.l. In the southern part, the bed of glaciolacustrine deposits is located at 120–130 m a.s.l., and the depth of the reservoir should be smaller there. Therefore, geometry of the sediment body indicates that a distal part should have been drained first of all during a drop of the water level and transgressive sequence should not be formed. But the transgressive series occurs just in the distal part. Hence, there is an evidence of a local transgression that can be explained taking into account a possible displacement of a water body due to glacioisostatic shifting.

LATE POOZERIE EVENTS

Reconstruction of the Late Poozerie events was based on correlation to nearby areas where succession of events has been already known (G. Eberhards, 1972; V. Vonsavicus *et al.*, 1986; I. Pavlovskaya, 1994*a*). Besides, pollen data were used from the Late Glacial lake and bog sediments that overlay series of the Polotsk lake. It is obvious that sedimentological interruption between these accumulations could occur. Nevertheless, it seems unreasonable to suggest that such interruption could be continuous, taking into consideration peculiarities of lake and bog sedimentation on dried surfaces. Therefore, the age of the upper part of glaciolacustrine deposits should be slightly older than the age of the overlaying organic sediments. It has also been taken into account that the most rapid rebound was recorded at some distance from the ice margin, and the maximum uplift occurred during relatively short time as it is confirmed in areas where glacioisostatic rebound was significant (S. Björck, 1989; H. Moriwaki, 1990; J.-C. Dionne, 1990).

Peculiarities of spatial distribution of shorelines and structure of glaciolacustrine deposits have led to the following reconstruction of events. During the Braslav Stage, when the upper proximal shorelines were formed, a probable zone of glacioisostatic uplift was situated close to the marginal zone of the Sventiany Phase of the Poozerie Glaciation. When the ice sheet started retreating from the Braslav Stage limits, the southern part of the Polotsk basin was isostatically uplifted. The southern passages were blocked by glacioisostatic uplift. Distal part of the basin was isostatically submerged. The southern shoreline was situated northward in comparison with shorelines of the younger phases of lake development (Fig. 4).

Where ice receded, the lake flooded north of the Braslav end moraines. Then, the large abrasive terraces were formed. Since rapid glacioisostatic rebound caused displacement of a water body, there was not any significant glaciolacustrine sedimentation on terrace surfaces. It is very likely, that rebound was accomplished along the Braslav end moraines according to Goldthwaits hinge-line model modified by C. E. Larsen (1987). When the ice margin retreated further, the uplift displaced towards the northwest-north. Therefore, some displacement of the water basin in the southeastern direction might take place according to the glacioisostatic tilt. A water body displaced southwards and major zone of glaciolacustrine deposition was placed on a distal part of the basin. The transgressive series of a distal part of the Polotsk lake has been formed. The fact that sites with buried coastal deposits and forms are situated only in a southern part of the basin can serve as evidence for the isostatic transgression.

The isostatic transgression was changed by stabilization phase as it is recorded in both the morphological and geological data. In contrast to higher levels, the shoreline at 140 m a.s.l. surrounds the basin. The shoreline is associated morphologically with various beach forms such as cliffs and beach ridges. It indicates a long-term stagnation of a water level. The distal terrace as well as the proximal one at this level represent the accumulative features with relatively thick glaciolacustrine cover, from 3 m (proximal part) to 7–10 m (distal part). Such peculiarities suggest that the shoreline at 140 m a.s.l. is the evidence of stabilization and indicates the end of isostatic displacement of a water body. According to the age of bog and lake sediments overlying the glaciolacustrine deposits (I. Pavlovskaya, V. Zernitskaya, 1995), the stabilization took place during the Bölling. Indirect data from surrounding areas confirm also this stabilization time (G. Eberhards, 1972). It was a final phase of glacioisostatic rebound in the studied area. The main line of shifting was displaced northwards.

The stabilization was interrupted by opening of the northwestern outlet towards the Latvian glacial lakes. This outflow was a rapid and catastrophic process, which resulted in development of a narrow valley, 35 m deep (the Druya Gate). The lake level dropped to 132–135 m a.s.l. and the Polotsk lake had disintegrated into several residual lakes, drained by the Zapadnaya Dvina during the Alleröd or the Preboreal times. It is questionable, whether glacioisostatic subsidence within the territory of southern Latvia might provoque opening of this outlet. The solution of this problem will be available through detailed studies of morphology and structure of the Latvian glacial lakes.

CONCLUSIONS

A comparison of irregularities in the terrace spectrum and glaciolacustrine sequences, with special consideration of spatial differences between them, allowed to distinguish influence of glacioisostatic movements on morphological and sedimentological processes in a glacial lake. The glacioisostatic rebound caused the terraee inversion, coupled with the transgressive sedimentary sequence on the distal part of the Polotsk lake basin.

Divergence of terraces shows that the amplitude of glacioisostatic movements was about 40 m. It would be possible to confirm that glacioisostatic tilting occurred during a period of about 3000 years. The high enough amplitude and the short time of rebound could be due to two main reasons: (1) relatively long ice loading due to stagnation and readvances of an ice sheet in the northwestern part of the Polotsk basin during the Braslav Stage; (2) intensive reaction of the substratum to pressing, determined by prevalence of resilient clay deposits in the Quaternary thickness of the Polotsk lake area.

Studies of other lakes in northeastern Belarus have been carried out. However, there were not found any evidence similar to the one obtained for the Polotsk lake (I. Pavlovskaya, 1994*b*). It is very likely that glacioisostatic rebound had different and discordant eharacter within the ice marginal zone, with relatively small thickness of ice. Without doubt, it depended on dimension of the area, and on time of downloading. Most probably, it was linked to hinge-line mechanism of isostatic tilting. The same mechanism of glacioisostatic uplift is recorded in other areas covered by the last ice sheet (J. Donner, 1987; A. Hequette, 1989; T. Jantunen, 1990). It also might depend on resilient properties of sediments.

An analysis of morphology is, together with a study of glaciolacustrine sequences, an effective tool to receive correct information about evolution of glacial lakes. The altitude analysis of shorelines, without studies of their spatial distribution as well as glaciolacustrine sequences, can lead to erroneous conclusions regarding a glacioisostatic rebound, especially in marginal areas of the last glaciation.

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REFERENCES

BASALYKAS A. (1967) — Proglacial lakes in the southern Peribaltic (in Russian). In: Istoriya ozer severo-zapada SSSR: 17–33. Nauka. Leningrad.

BJÖRCK S. (1989) — The geodynamic and geologic value of a regional network of shore displacement curves: examples from southern Sweden. Geol. Fören. Stockholm Förhand., **111** (3): 292–295.

BYLINSKI E. (1985) — Glacioisostatic evidence of the platform areas in Pleistocene (in Russian). Geomorphologiya, **1**: 22–36.

DIONNE J.-C. (1990) — Observations sur le niveau marin relatif á l'Holocene, á riviére-du-loop, éstuaire du Sent-Laurent, Québec (in French with English and German summary). Geogr. Phys. Quatern., 44 (1): 43–63.

DONNER J. (1987) — Some aspects of the nature of the Late Weichselian and Holocene uplift in Finland. Geol. Surv. Finland, Spec. Paper, 2: 9–12.

DVARECKAS V., EBERHARDS G. (1978) — Structure and peculiarities of forming of alluvium in the south and middle Peribaltic valleys (in Russian). In: Problemy morphogeneza i paleogeographii Latvii: 3–19. Zinatne. Riga.

EBERHARDS G. (1972) — Structure and development of the valleys of the Daugava river basin (in Russian). Zinatne. Riga.

GUDELIS V. (1973) — Relief and Quaternary deposits in the Peribaltic area (in Russian). Mintis. Vilnius.

HEQUETTE A. (1989) — Une transgression marine holocene au Spitsberg nord-occidental (Svalbard): une origine eustatique ou glacio-isostatique? (in French with English summary). Norois, **36** (142): 199–204.

ILYIN E. (1967) — Ice-dammed lakes in the northern Belarus (in Russian). In: Istoriya ozer severo-zapada SSSR: 71–84. Nauka. Leningrad.

JANTUNEN T. (1990) — Maankohoamisen saranalinjoista Suomen kallioperässä: tutkimuskohteena Pikkalan-Lahden murroslaakso (in Finnish with English summary). Terra (Finl.), **102** (3): 158–163.

LARSEN C. E. (1987) — Geological history of glacial Lake Algonquin and the Upper Great Lakes. U.S. Geol. Surv. Bull., **1801**.

LEVKOV E., KARABANOV A. (1988) — Feature of glacioisostatic movements within the marginal zone of the last glaciation of Belarus (in Russian). In: Litol., geochem. i stratigr. kontinent. otlozeniy Belarussi: 203–208. Nauka i Tekhnika. Minsk.

MARKS L. (1988) — Relation of substrate to the Quaternary paleorelief and sediments, western Mazury and Warmia (northern Poland). Zesz. Nauk. AGH, 1165, Geol. Kwart., **14** (1).

MORIWAKI H. (1990) — Late- and postglacial shoreline displacement and glaciation in and around the Skagi peninsula, Northern Iceland. Geogr. Reports Tokyo Metrop. Univ., 25: 81–97.

PAVLOVSKAYA I. (1994*a*) — The Polotsk glaciolacustrine basin: structure, relief and history (in Russian). Nauka i Tekhnika. Minsk.

PAVLOVSKAYA I. (1994*b*) — Peculiarities of glacioisostatie movements of the Belarussian Lake District (in Russian with English summary). Lithosphere, **1**: 91–93 .

PAVLOVSKAYA I., ZERNITSKAYA V. (1995) — Late Pleistocene and Holocene palaeogeography of the Zapadnaya Dvina drainage basin (in Russian with English summary). Lithosphere, **2**: 67–74.

PUZANOV L. (1967) — Disna proglacial lake (in Russian). In: Istoriya ozer severo-zapada SSSR: 135–139. Nauka. Leningrad.

STRAUME J. (1978) — Glaciolacustrine plains and main Late Glacial reservoirs in Latvia (in Russian). In: Problemy morphogeneza i paleogeographii Latvii: 45–66. Zinatne. Riga.

VIGDORCHIK M. (1973) — Dynamic systems of terrace forming in the area of the last glaciation (in Russian). In: Khronologiya pleistocena i klimat. Stratigraphiya: 98–120. Nauka. Leningrad.

VONSAVICUS V., DICEVICENE L., MIKALAUSKAS A., PETRAITENE D. (1986) — Quaternary eover structure within southeastern lateral valley of Lithuania (in Russian). In: Issledovaniye lednikovykh obrazovaniy Pribaltiki: 60–64. Mintis. Vilnius.

ZAITSEVA N. (1969) — Varved clays in Belarus (in Russian). Nauka i Tekhnika. Minsk.

PÓŹNOGLACJALNA GLACIIZOSTAZJA PÓŁNOCNEJ BIAŁORUSI: DOWODY I FAKTY

Streszczenie

Przedstawiono niektóre wyniki badań geologicznych i geomorfologicznych z obszaru największego basenu zastoiskowego Białorusi (fig. 1), tj. zbiornika połockiego położonego na obszarze ostatniego zlodowacenia pomiędzy strefami marginalnymi fazy święciańskiej (frankfurckiej) i stadium brasławskiego (pomorskiego) zlodowacenia poozierskiego (wisły). Celem opracowania było prześledzenie linii brzegowych zbiornika i zmienności w osadach zastoiskowych, zmierzające do wyjaśnienia ewentualnego wpływu ruchów glaciizostatycznych na procesy sedymentacji glacilimnicznej i kształtowania rzeźby w strefie marginalnej lądolodu.

Na podstawie analizy położenia dawnych linii brzegowych zbiornika połockiego stwierdzono zróżnicowane rozprzestrzenienie i genezę tarasów glacilimnicznych (fig. 2). W części proksymalnej obszaru zastoiska wyróżniono regresywne następstwo poziomów, w którym tarasy abrazyjne położone są wyżej niż tarasy akumulacyjne. Na brzegu dystalnym występuje inwersja form brzegowych i starsze poziomy przykryte są młodszymi osadami tarasu akumulacyjnego. Zaznacza się również zróżnicowanie sekwencji proksymalnej i dystalnej osadów glacilimnicznych (fig. 3). Występują serie regresywne w proksymalnej części zastoiska i seria transgresywna w części dystalnej. Wymienione cechy budowy geologicznej i formy rzeźby zbiornika połockiego wskazują, że kształtowały się one pod wpływem obniżeń i wypiętrzeń związanych z glaciizostazją. Amplituda ruchów glaciizostatycznych sięgała 40 m, a reakcja na obciążenie przez lądolód ujawniała się podczas istnienia zbiornika, co spowodowało migrację wód jeziora w kierunku dystalnym, zmiany położenia linii brzegowych i depozycję transgresywnej sekwencji osadów (fig. 4).