The Pleistocene stratigraphy of the south-eastern sector of the Scandinavian glaciation (Belarus and Lithuania): a review

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Abstract

The paper summarises geological and palaeobotanical investigation data on Pleistocene of recent decades in Lithuania and Belarus. The main problems in Pleistocene stratigraphy and correlation of sections are discussed. As a result, the chronostratigraphical correlation chart of Pleistocene deposits is presented and some changes in local stratigraphic schemes are proposed. The main stratigraphical units are comparable and correlate well; however some unsolved stratigraphical problems still exist. The lack of the absolute chronology dates of the Pleistocene deposits of Belarus and the controversial dating results of some sections in Lithuania is still the main problem.

Keywords • Pleistocene • stratigraphy • palaeobotany • correlation

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INTRODUCTION

The areas of Lithuania and Belarus belong to the zone of the continental glaciations and have similar geology of the Quaternary cover varying from 10–30 m up to 300 m. Quaternary stratigraphy has been one of the high priority research objects in Lithuania and Belarus for many years. Pleistocene stratigraphic subdivision elaborated in the mid-nineties was mainly based on lithostratigraphy (petrography and mineralogy) and biostratigraphy (pollen, plant macroremains, diatoms, mammal and mollusc) data (Gaigalas, Satkūnas 1994; Baltrūnas 1995; Kondratienė 1996; Velichkevich et al. 1996, 1997). In 2004, the improvements proposed to the Quaternary stratigraphic subdivision of Lithuania (Guobytė, Satkūnas 2011), have not been accepted by the Lithuanian Stratigraphic Commission due to the controversial opinions. The new stratigraphical charts for the Precambrian and Phanerozoic of Belarus were accepted in 2010 (Kruchek 2010) except for the Quaternary because of the disagreements between the researchers.

MATERIAL AND METHODS

Within the last decades, when the drilling became rather limited, the possibilities to get new cross-sections have decreased. Therefore much attention was paid to use new methods, in particular for chronology dating. The promising results were obtained from various methods: U/Th datings (Satkūnas et al. 2003; Arslanov et al. 2005; Gaigalas et al. 2005; Baltrūnas et al. 2013); OSL (Molodkov et al. 2010; Satkūnas, Grigienė 2012); ESR (Gaigalas, Molodkov 2002) and palaeomagnetic investigations (Sanko, Moiseev 1996; Baltrūnas et al. 2013, 2014).

The stratigraphical subdivision presently used for the Quaternary of Lithuania and Belarus is based mostly on climatostratigraphy (Kondratienė 1996; Rylko 2006; Rylko, Savchenko 2006, 2011).
According to the Lithuanian Stratigraphic Guide (Grigelys et al. 2002), in order to determine a rank of a unit, the amplitude of climate fluctuations and time duration are used. Following this rule the boundaries between the stratigraphic units are drawn by applying a climatostratigraphic criterion that is valid for interglacial periods. In opposite, for glacial periods the application of the climatostratigraphic criterion is limited, therefore a lithostratigraphical criterion is used. The naming of stratigraphic units for interglacials is based on section stratotypes, the areal stratotypes are used for the glaciations (tills). In Belarus, the stratigraphical subdivision is based on the Russian Stratigraphic Code (Zhamoida 2006), where the basic lithostratigraphic unit is named horizon (highlighted with asterisk* in Fig. 1).

Thus, the stratigraphical description of the Pleistocene presented in this paper, worked out within the bilateral project between Lithuania and Belarus, makes an attempt to review the existed data and to compile a new lithostratigraphic correlation chart. Principal lithostratigraphic unit-terms used below are: Formation, Subformation, Member, Bed(s) (Grigelys et al. 2002) (Fig. 1).

**RESULTS AND DISCUSSION**

**Lower Pleistocene**

The Lower Pleistocene has limited distribution, floral and faunal remnants are absent or very poor, high amount of re-deposited material is observed. The lower boundary of Pleistocene in Belarus is designated at 1.8 Ma (Kruchek 2010). Having in mind that International Commission of Stratigraphy redefined its position by placing at the base of Gelasian Stage, i.e. c. 2.558 Ma (Gibbard, Head 2010), the Dvorets Formation is placed in the Lower Pleistocene (see Fig. 1). The holostratotype section (the outcrop on Dnieper River and borehole No. 7; Fig. 2) of this formation correlates with the Tiglian sections in the Netherlands (Stuchlik 1994). In the western part of Belarus the Dvorets Formation is divided to Novogrudok and Olkhovka Members. According to the pollen composition, the Novogrudok Member has the same typical features as the Dvorets Formation occurring in the eastern part of the country. The older Olkhovka Member contains plant macrofossils typical for periglacial environments and pollen of tundra plants. Thus, the...
Olkhovka Member may correlate with the Praetiglian deposits in Western Europe (Kruchek 2010). The Dvorets Formation overlies the Kholmech Formation which denotes the top of the Neogene system.

In Lithuania, the lowermost Lower Pleistocene is presented by the Anykščiai Formation likely analogous to the Dvorets Formation in Belarus. The lower boundary of the Anykščiai Formation holds in the pure quartz sand sequence gradually changing to Neogene according to palaeobotany data (Kondratienė 1996). The upper boundary of this formation could be stated by the presence of hornblende and black ilmenite, high contents of feldspars and garnets (Klimašauskas, Prakapaitė 1971).

The Dvorets Formation is overlain by the Brest Formation mainly occurring in western and southern Belarus. The formation is composed of lacustrine, lacustrine-alluvial and alluvial deposits, reaching the thickness of 20–35 m. A lithological composition is rather similar to that of the Neogene (high content of quartz and low content of feldspars). However, the higher content of feldspars and carbonates in the upper part of the formation allows to attribute it to the Pleistocene ones. In the stratigraphic chart of Belarus (Kruchek 2010), the Brest Formation is subdivided into two subformations and four members. Nevertheless, present investigations do not provide evidences for such subdivision. Therefore the authors leave the presence of single Brest Formation, as it was described previously (Golubtsov 1983). The Brest Formation could be correlated with the Daumantai Formation in Lithuania.

The Daumantai Formation is distributed in the eastern Lithuania, Anykščiai and Vilnius regions, where they overlie the pre-Quaternary sedimentary rocks. The formation is represented by 10–20 m thick lacustrine sandy-silt sediments. The recent palaeomagnetic studies have detected a Brunhes/Matuyama boundary in the two outcrops: Daumantai-1 and Daumantai-3. Additionally, a Jaramillo subchron was detected in the Daumantai-3 and Šlavė-2 outcrops (Baltrūnas et al. 2013; 2014). These findings enabled to justify the stratigraphical position of the deposits studied.

The Brunhes/Matuyama boundary was fixed in the Brest Formation as well, in the section Smoliarka-3 in south-western Brest region (Sanko, Moiseev 1996). An inversion was obtained in the layers of grey sandy loam, black clay and dark grey sandy loam with mollusc shells. This sequence lies on the Miocene deposits (sandy coal).

Palaeobotanical investigations of the Brest and Daumantai formations point out similar characteristics implying their simultaneous sedimentation environments. Pollen and plant macrofossils composition reflects the cold, but ice free climatic conditions (Yakubovskaya, Rylova 1992; Kondratienė 1996).
Rhythmic vegetation changes stated from the pollen diagrams indicate climate changes representative for stadial and interstadial climatic periods. Frequent sedimentation breaks are apparent in the sections. The numerous ancient extinct pollen species are decreasing upwards, toward the younger time period.

**Middle Pleistocene**

The oldest glacial deposits of the Middle Pleistocene in Belarus are those of the Narev Glacial. The Narev ice sheet covered the greater part of Belarus, however deposits of this glaciation have been mostly eroded and disturbed during the subsequent ice advances. As a result, today the Narev tills are not exposed anywhere and are found mainly in palaeoincisions or depressions. The thickness of the Narev till varies from 0.2–0.5 m up to 40–70 m. The limit of the maximum ice advance is debatable (Matveyev 2002). The distinctive feature of the glacial deposits of this formation is a very high content of clayey particles as compared with the younger formations and low contents of crystalline rocks. The tills are composed of sandy loam, clay loam or clay of high density and contain a great admixture of gravel and pebbles (Yarcev et al. 2002). In the stratigraphic chart (Kruchek, 2010) the Narev Formation is subdivided into three subformations: Novogrudok, Korchevo and Yaselda.

The Narev glaciation was interrupted by the warm Korchevo interglacial. Recent geological and palaeobotanical data from numerous sections allow to conclude that the Korchevo Subformation occurred in the intertill interval of the Narev/Berezina glaciations. They are supposed to be formed during the Belovezhian period (Yarcev et al. 2002; Rylova 2006; Mamakova, Rylova 2007; Karabanov et al. 2011).

In general, the Narev Formation can be correlated with the Dzūkija Formation in Lithuania. The Dzūkija glacial deposits are widespread within their representative site in the south-eastern Lithuania. An average thickness is 7–10 m. The Dzūkija Formation is composed by sandy loam and loam, glaciofluvial sand, sandy gravel, glaciolacustrine sand, silt and clay. The Dzūkija till is of a grey, greenish grey and greyish brown colour and is predominated by gravel and pebbles of crystalline rocks presumably transported from southern Sweden (Gaigalas 1979). The high content of SiO₂, TiO₂, Ti, Zr and Yb as compared with other tills of the Middle and Upper Pleistocene and the low content of CO₂, MgO and FeO are characteristic for the Dzūkija till (Guobytė, Satkūnas 2011).

However, the Dzūkija Formation does not represent the oldest Middle Pleistocene glacial deposits discovered in Lithuania. One likely older till formation is described near Anykščiai, in several outcrops on the Šventoji River (Gaigalas 1987). The similar till was found in 11 boreholes of the Kalviai locality near Vilnius, and named as Kalviai Formation (Satkūnas 1993; Gaigalas, Satkūnas 1994). The till thickness reaches 2–3 m and it is a greenish grey loamy sand with pebbles (3–8%). The Kalviai till is carbonate-free and contains small amounts of dolostone and marl gravel. These features separate it from the younger tills. No analogous glacial deposits were discovered in Belarus so far.

The Kalviai Formation is overlain by the Vindžūnai interglacial deposits (Kondratienė 1996; Guobytė, Satkūnas 2011) that have been discovered in the same Kalviai representative site and encountered in five sections (see Fig. 2). The pollen composition from the Vindžūnai interglacial sections indicates that the vegetation does not represent a complete warm (interglacial) climatic cycle but the fragmented sequence can be attributed to the first part of an interglacial period (Kondratienė 1996). The vegetation is represented by mixed coniferous deciduous forests with a high presence of *Quercus* (up to 34%) and some admixture of pollen of broad-leaved trees (*Quercus, Tilia, Alnus*). Single grains of exotic taxa such as *Tsuga, Pterocarya* and *Pinus haploxyylon* are also present. According to O. Kondratienė (1996), these remains are most probably re-deposited. However, the absence of full vegetation successions and a specific character of vegetation composition, i.e. high number of herbs (up to 30–40%), domination of Poaceae, *Artemisia*, Cyperaceae, overall presence of Caryophyllaceae, Apiaceae, Ranunculaceae (including *Thalictrum*) and of spores *Botrychium, Selaginella selaginoides*, makes difficult the interpretation of these sediments as deposited during the interglacial as well as their correlation.

The Narev Formation in Belarus is overlain by the Belovezhian Formation that is composed of two Borky and Mogilev interglacial subformations separated by the periglacial Nizhynsky Subformation with presence of Arctic-boreal fauna and flora. The Belovezhian Formation is represented by lacustrine, bog and alluvial formations and reaches up to 10–15 m in the Poozerey region, 15–25 m in the Central Belarus Highland and up to 36 m in the Dnieper and Pripyat River basins.

The Borky Subformation is widely spread in southern and eastern parts of Belarus. The complete pollen investigations enabled to distinguish eight pollen zones (Rylova 1998; Rylova, Savchenko 2006). The characteristic features of vegetation development are maximal distribution of *Larix* during the beginning of interglacial as compared with the rest of it; the spread of broad-leaved trees in the subsequent order, i.e. *Quercus* and *Ulmus* the first and *Tilia* and *Corylus* the second; predominance of *Quercus* and *Ulmus* during the climatic optimum; and wide presence of *Ulmus* and absence of *Carpinus*.
The data of pollen diagrams of the Borky Subformation could be correlated with the diagrams of the Muchkap Interglacial of Russian Lowland (Pisareva 1997), the lower warm interval of the Zidini Interglacial in Latvia (Kondratienė et al. 1985) and the Ferdinando Interglacial in Poland (Janczyk-Kopikowa et al. 1981; Pidek 2003). They are also similar to the Hunteburg Interglacial in Germany (Hahne 1996) and the Westerhoven section in the Netherlands (Cromer II; Zagwijn 1996). No sections analogous to the Borky Subformation were found in Lithuania. The most similar vegetation succession to that of the Borky Interglacial is present in the Kintai-19 section located in western Lithuania (see Fig. 2; Kondratienė et al. 2003).

The Nizhninsky Subformation is presented by a succession of periglacial deposits of greenish-grey sandy loam and loam with admixture of sand and gravel and loamy clay with peat and gyttja interlayers. The thickness of the deposits reaches up to 3.5 m. As to palaeogeography, the Nizhninsky time could be interpreted as a Little Glacial but not reaching northern Belarus where the periglacial deposits predominated (Vaznyachuk 1985; Kondratienė, Sanko 1985; Makhnach, Rylova 1986; Velichkevich et al. 1996).

The Mogilev Formation is mainly distributed in southern and eastern Belarus (see Fig. 2). The thickness reaches up to 1.8–5.0 m. The Mogilev Interglacial could be correlated with the Turgeliai Interglacial in Lithuania. Five vegetation development phases were distinguished during this period (Rylova, Savchenko 2011). The main characteristic features of the vegetation development are wide spread of *Picea* and *Alnus* during the beginning of the interglacial; dominance of coniferous trees during all the interglacial; the simultaneous spread of broad-leaved trees; the later and simultaneous spread of *Abies* and *Carpinus*; insignificant role of broad-leaved trees during the climate optimum; considerable presence of *Corylus*; presence of exotic species during all the interglacial (*Taxus baccata, Pterocarya, Fagus, Buxus, Vitis, Ligustrum* etc.).

The vegetation development during the Alexandrian Interglacial can be correlated with those of the Butēnai Interglacial in Lithuania, the Likhvin in Russia (Gričuk 1989; Pisareva 1997), the Mazovian in Poland (Krupiński 1995; Pidek 2003), the Holsteinian in Latvia (Kahnía 2001) and Germany (Erd 1978) and with the Marine Isotope Stage (MIS) 11 covering a time interval of 405–305 ka BP (Berger 1989; Loutre 2003).

Lacustrine sediments of the Butēnai Interglacial are well established and correlated palynologically. They occur throughout Lithuania except the central part of the country and are established in more than 40 sections. Most of the sections have been examined in the north-eastern Utina region regarded as a stratotypical area. The seven local pollen zones were distinguished (Kondratienė 1996). The vegetation development is...
comparable with the described for the Alexandrian Interglacial in Belarus: coniferous forests flourished with the predominance of Abies alba and Picea; broad-leaved trees were not widely spread and Quercus with Carpinus dominated among them. It seems likely that there was no permanent snow cover in winter times. Climatic conditions were favourable for such ther-mophilous plants as Abies alba, Taxus baccata, Picea omorica, Buxus sempervirens, Ilex aquifolium, Hedera helix, Pterocarya, Vitis, Osmunda cinnamomea and O. claytoniana (Kondratienė 1996).

The Alexandrian Formation is covered by the Pripiatian Formation that deposits are widespread in all the Belarus. In the Belarusian Poozerye they form the land surface. Sediment thickness varies from several up to 100 m. The Pripiatian Formation is subdivid-ed into Dnieper and Sozh subformations, representing two large glacial stages. The areal stratotype of the Pripiatian Formation is designated in the Pripyat River valley. This formation is subdivided into the Dnieper and Sozh subformations but the interglacial sediments are absent in between these two bodies.

A Pripiatian glacial ice sheet stretches southwards from the Belarus border and reaches the northern Ukraine. The Dnieper Formation is represented by till, glaciofluvial, glaciolacustrine and periglacial deposits. The Dnieper till occurs on the surface and forms marginal ridges in the southern Belarus. The average thickness is 10–18 m in the south and 2–10 m in the east, varying in the central part from 30–40 m up to 80–92 m. The Dnieper Formation could be correlated with the Žemaitija Formation in Lithuania.

The Žemaitija Formation is deposited by the Mid-dle Pleistocene glaciation. The Žemaitija till is in average about 23 m thick, but reaches over 100 m in some deeply incised sections. It is represented by loam and sandy loam with high value of Fe₂O₃, MgO, Ca, Cr, Co and Ni. The maximum value of a SiO₂/Al₂O₃ ratio is recorded comparing with the other tills (Satkūnas, Bitinas 1995). The gravel component consists mostly of crystalline rocks (derived from southern Finland), dolostones and limestones. The dark brown colour and high hardness are the characteristic properties of the Žemaitija till. The stratotype areal of this unit is recognised in the north-eastern Lithuania.

The Sozh till is present in a considerable part of Belarus, but irregularly distributed. Deposits of the Sozh Subformation are in average 10–25 m thick, reaching 135 m in the highland areas. In the north-ern part of Belarus, it has been almost completely eroded. Some patches of the original till cover have been preserved within the largest glacial basin, i.e. the Polotsk glacial depression. During this time the highlands (Grodnenskaya, Volkovyskaya, Slonimskaya, Novogrudskaya, Minskaya) and ridges (Osh-mianskaya and Kopylskaya) have been formed. The Sozh Subformation could be correlated with the Medininkai Formation in Lithuania.

The Medininkai till is represented by loam and sandy loam and texturally and structurally is quite similar to that of the Žemaitija. It is of yellowish brown colour and of smaller average thickness (~ 15 m). The gravel component consists mostly of crystalline rocks derived from northern Sweden and contains large amounts of dolostones as compared with the Žemaitija till (Gaigalas 1979). The areal stra-totype of the Medininkai Formation is the Medininkai Heights in the Nalšia (Ašmena) Upland, the south-eastern Lithuania.

The Žemaitija and Medininkai formations in Lithuania are separated by the Snaigupėlė interglacial sediments that are discovered in the eastern part of Lithuania (see Fig. 2). They are subdivided into seven pollen zones (Kondratienė 1996). The succession of flora is most similar to that of the Merkinė Intergla-cial and differs from the latter by some distinctive features: Alnus appeared and spread simultaneously with broad-leaved trees much earlier than Corylus; the maximum spread of Tilia occurred before Corylus and was less prominent; Quercus culminated twice, i.e. at the beginning of the climate optimum and at the beginning of Carpinus expansion.

No analogous interglacial sediments to the Snaigupėlė Formation were observed in Belarus, Latvia and Estonia. Their correlation with similar sediments in other European countries is still under discussion (Kondratienė 1996; Gaigalas et al. 2005). Recently, the discussion points out that the two sections attributed to the Snaigupėlė Interglacial are of different age: Snaigupėlė section should be correlated with the MIS 9 and Buivydižiai section with the MIS 7 (Kondratienė 2011).

**Upper Pleistocene**

The Upper Pleistocene base marker formations are the Merkinė Interglacial in Lithuania and the Muravi Interglacial in Belarus unquestionably corresponding with the Eemian Interglacial in Poland (Makowka 1989; Granoszewski et al. 2003), Germany (Behre 1989), Latvia (Kalnina 2001) and Estonia (Livre 1991) and the Mikulinski Interglacial in Russia (Grichuk 1989). These interglacial sediments are covered by the Nemunas Formation in Lithuania and Poozerian Formation in Belarus.

The Merkinė Formation is mainly distributed in the eastern part of Lithuania and reaches up to 10 m in thickness. Five phases of the vegetation suc-cesion have been identified during this interglacial (Kondratienė 1996). Broad-leaved trees dominated (up to 80%) during the thermal optimum, firstly ap-peared and spread Quercus and Ulmus, later Tilia. In
the southern Lithuania, *Tilia* was probably dominating and constituted ca. 70% of vegetation. *Carpinus* appeared only in the second part of the interglacial. The maximum spread of *Corylus* occurred in between the *Quercus* and *Tilia* culminations.

The Muravian Formation is widely spread in Belarus and reaches from several metres up to 20 m. The palynological studies of more than 300 sections allow to subdivide the vegetation succession into nine regional zones (Rylova et al. 2008). The Muravian Interglacial is overlain by the Poozerian Formation which is subdivided into four subformations: Kulakovsky, Lovatsky, Dvinsky and Narochansky (Kruček 2010). The stratotype area of this formation is chosen in the Belarusian Poozero where its thickness varies from 20–30 m up to 60–70 m. The Poozerian Formation is composed by till, glaciofluvial, glaciolacustrine and diluvial-solifluction deposits. The till is represented by sandy loam with boulders and clayey loam of reddish brown colour with interlayers of various sands with gravel, and is in average 10–15 m thick (Geology of Belarus 2001). The Early Poozerian contains an alternation of stadal and interstadal deposits (Rylova et al. 2008). The Poozerian Formation correlates with the Nemunas Formation in Lithuania.

The investigations point to the presence of non-glacial palaeoenvironments since the end of the Merkinė Interglacial, during the Early and Middle Nemunas. The alternation of stadal and interstadal climate conditions is characteristic for this time and it is rather well studied (Satkūnas, Grigienė 2012; Satkūnas et al. 1998; 2003; 2009). Most likely, the major part of the eastern Baltic area was not covered with ice until the Late Nemunas (Poozerian) Substage (Lunkka et al. 2004; Kalm 2006; Satkūnas et al. 2009).

The Middle Nemunas is still problematic from the point of view of stratigraphy and palaeogeography. The latest data suggest that a “part of the south–western margin of the Eurasian ice sheet could have been situated in the Lithuanian coastal region or in the whole western Lithuania during the Weichselian early pleniglacial maximum” (Molodkov et al. 2010). Possible presence of the early Middle Weichselian glaciation is suggested in Poland (Marks 2004), Latvia (Zelčs, Markots 2004) and Estonia (Kalm 2006).

The Upper Nemunas Formation is subdivided into two stratigraphical units: the Grūda and Baltija Subformations corresponding to stadials. No interstadal sediments of this period were determined in Lithuania (Satkūnas, Hütt 1999).

CONCLUSIONS

The complex data of the geological and palaeobotanical investigations enabled to compare the pairs of the Pleistocene stratigraphical subdivision in Lithuania and Belarus as follows: Lower Pleistocene: Daumantai vs. Brest; Middle Pleistocene: Dzūkija vs. Narev; Turgeliai vs. Mogilev; Dainava vs. Berezina; Butėnai vs. Alexandrian; Žemaitija vs. Dnieper; Medininkai vs. Sozh; Upper Pleistocene: Merkinė vs. Muravian, and Nemunas vs. Poozerian.

A set of stratigraphical problems has to be solved during the future detail investigations. More studies are required for the correlation of the Dvorets Formation with some parts of the Anykščiai Formation. The recently available data are insufficient to subdivide the Narev Formation into subformations and to distinguish the Korchev Interglacial. Further investigations are needed for an establishment of the Vindžiūnai Interglacial.

The reliable data have to be collected for the correlation of the Nizhninsky and Belovezhian Formations in Belarus with the appropriate sections in Lithuania. The analogous sections of the Snaigupėlė Interglacial should be defined or the correction of the stratigraphical position of this interglacial should be provided.

Some improvements of the stratigraphical chart of Belarus are proposed: to attribute the Dvorets and Brest Formations to the Lower Pleistocene; to place the Neogene/Pleistocene boundary between the Kholmech (Pliocene) and Dvorets Formations; to define the boundary between the Lower and Middle Pleistocene at the base of the Narev till; to exclude the Korchev Formation from the Narev Formation.

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