Geological Quarterly, 2001, **45** (4): 373–386

The age of the oldest Scandinavian glaciations in mid-eastern Poland and southwestern Belarus

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Lindner L., Marciniak B., Sanko A. F. and Khursevich G. K. (2001) — The age of the oldest Scandinavian glaciations in mid-eastern Poland and southwestern Belarus. Geol. Quart., **45** (4): 373–386. Warszawa.

Analysis of type localities of Pleistocene deposits from mid-eastern Poland (Kozi Grzbiet, Łuków, Biała Podlaska and Wilczyn) and southwestern Belarus (Smolarka and Postolovo) has provided a new view on the age, limits and correlation of the oldest Scandinavian glaciations in the area. Integration of palaeontological data with determination of the Brunhes/Matuyama boundary (780 ka) at Kozi Grzbiet and Smolarka suggests that the first glaciation (Narevian) preceded this boundary and had a slightly smaller extent in SW Belarus than hitherto considered. The second glaciation (Nidanian) occurred slightly above or at this palaeomagnetic boundary. In Poland it is the first South Polish Glaciation, a till of which can be traced as far as the Holy Cross Mts. In SW Belarus it is represented by a till to the south of Brest and Bereza, and connected there with the oldest glaciation.

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Key words: Poland, Belarus, Early Pleistocene, Scandinavian glaciations, stratigraphic correlation.

INTRODUCTION

We provide an analisis of the age of the two oldest Scandinavian glaciations (Narevian and Nidanian?) in Poland and Belarus (Fig. 1). Halicki (1950) and Tsapenko and Makhnach (1959) identified the older of the two glaciations (Narevian) for the first time as being older than the Cracovian Glaciation (South Polish Glaciation, Elsterian and Mindelian). This glaciation was at that time referred to as older than the Bialostockian (*sensu* Różycki, 1961), Przasnysznian (*sensu* Różycki, 1967) and Korchevian Interglacial (*sensu* Voznyachuk, 1961). It was recognised as the first one of the four then distinguished Scandinavian glaciations (Różycki, 1961; Mojski and Nowicki, 1964) and finally termed the Narevian Glaciation (Voznyachuk, 1961; Voznyachuk *et al.*, 1977; Różycki, 1978).

The younger of the two glaciations (Nidanian) was identified on the basis of Scandinavian material present below the layer together with a fauna correlated with the Cromerian II (Westerhoven) in the Netherlands, discovered at the Kozi Grzbiet site near Kielce (Głazek *et al.*, 1976). This glaciation is also represented by one to two lowermost tills to the north of this site (Lindner, 1977). Palaeomagnetic data from Kozi Grzbiet indicates that the Nidanian Glaciation occurs around the Brunhes/Matuyama boundary (Lindner, 1978; Różycki, 1978). Later on it was recognised as the first of the three South Polish Glaciations (Lindner, 1988*a*). It has not yet been recognised in western Belarus (Lindner and Astapova, 2000).

The age and range of the Scandinavian ice sheets during these glaciations in Poland and Belarus are reconsidered on the basis of new palaeomagnetic data from the Smolarka (S3) section near Bereza in Belarus (Fig. 1). According to these data, the oldest till connected with the Narevian Glaciation is younger than the Brunhes/Matuyama boundary (Sanko and Moiseyev, 1996), determined recently at about 780 ka (Heller and Evans, 1995). Besides Kozi Grzbiet (Głazek *et al.*, 1977*a*), this boundary was also recognised in Poland at Witów near Kraków. It runs above preglacial gravels within silty-clayey deposits (Nawrocki and Wójcik, 1990) that underlie residual till of the Sanian 2 Glaciation (Lindner and Siennicka-Chmielewska, 1998). Palaeomagnetic data from overlying deposits suggest that the till considered as the equivalent of the Narevian Glaciation in the Kalejty section near Augustów might correspond to the Glacial A in the Netherlands (Ber, 1997).

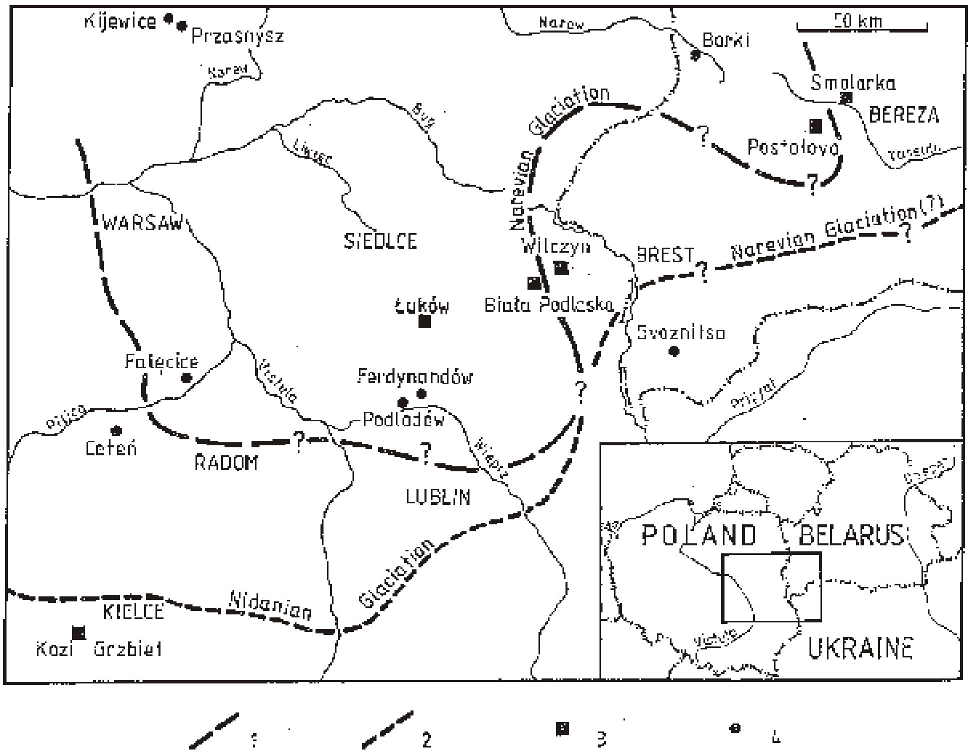

Fig. 1. Location sketch-map of mid-eastern Poland and southwestern Belarus

Ice sheet limits: 1 — older, 2 — younger; 3 — sites with lake deposits discussed in the paper; 4 — sites with interglacial deposits cited in the paper

GEOLOGICAL SETTING

Against a basis of recent correlations of glacial and interglacial units between Poland and Belarus (Nazarov, 1995; Velichkevich *et al.*, 1996, 1997; Lindner and Yelovicheva, 1998; Lindner, 1999; Lindner and Astapova, 2000), we have reanalysed the geological setting of the two main sites containing the Brunhes/Matuyama boundary, i.e. Kozi Grzbiet and Smolarka, while considering links with the other four sites (Łuków, Biała Podlaska, Wilczyn and Postolovo) containing the Older and Mid- Pleistocene interglacial lake deposits (Fig. 1). We aimed to throw some light on several problems: whether deposits of the Narevian Glaciation are isochronous in Poland and Belarus, whether the Narevian Glaciation is younger than the Brunhes/Matuyama boundary and, if so, whether its stratigraphic position is the same as that of the Nidanian Glaciation in Poland and in Belarus, and whether the ice limit of the Narevian Glaciation is smaller than supposed so far, especially in Belarus.

KOZI GRZBIET NEAR KIELCE (FIGS. 1–4)

The Kozi Grzbiet section, about 20 km to the west of Kielce, is represented by deposits in a cave within Devonian limestones (Głazek *et al.*, 1976, 1977*a*, *b*). These deposits (Fig. 2) are up to 9 m thick and in their lowermost part comprise grey-yellow clays with calcareous concretions representing a pre-Pleistocene (?) or even a Neogene limestone residuum. Cherry-red in colour, quartzose clayey and poorly sorted sands with intercalations and lenses of clays and limestone debris and calcareous concretions occur above. The sands are 3 m thick and are characterised by irregular bedding.

The sands contain up to 30% of clay, several percent of silt and 60–70% of fine sand. Their heavy minerals include abundant zircon, apatite, rutile and tourmaline, and smaller quantities of garnet, epidote, biotite, amphibole and pyroxene. Besides the dominant quartz, the light fraction contains small quantities of feldspar and siliceous rock fragments. The clays are composed mainly of kaolinite with small quantities of illite and smectite. The cherry-red colour is due to haematite. Considerable admixture of easily weatherable heavy minerals suggests a significant glacial component.

The sands are overlain by 1.5 m of “brecciated” cherry-red clay with calcareous concretions and grains of amphibole and pyroxene. The clay is composed mainly of kaolinite, haematite and vermiculite. Palaeomagnetic investigations have revealed the Brunhes/Matuyama boundary in its upper part (Figs. 2 and 3; Głazek *et al.*,1977*a*).

A *ca.* 1 m thick layer of sandy, brown-yellowish clays with bone fragments and snail shells (Kowalski, 1975; Młynarski, 1977; Stworzewicz, 1981; Szyndlar, 1981; Sanchiz and

Szyndlar, 1984), fragments of stalactites, calcareous tufa and fragments and blocks of limestone (Głazek *et al.*, 1977*b*) occurs above. The snails include *Helicigona banatica*, *Soosia diodonta*, *Isognomostoma personatum*, *Zenobiella vicina*, *Cochlodina laminata*, *C. orthostoma*, *Lacinaria cana*, *Ruthenica filograna*, *Clausilia cruciata*, *Iphigena latestriata*, *I. tumida* and *Acanthinula aculeata*, representing a warm and humid forest assemblage.

The amphibian and reptile bone fragments recognised are dominated by *Natrix* cf. *natrix* and *Triturus* cf. *cristatus*, forms typical of humid deciduous forests. The presence of such mammals as *Lemmus lemmus* and *Dicrostonyx simplicior* points to a rather cold climate, while *Castor fiber*, *Clethrionomys* cf. *glareolus*, *Sus scrofa*, *Alces* sp. and *Pliomys lenki* are typical of a humid forest. Among the numerous mammals there are *Ursus deningeri*, *Sus* cf. *scrofa*, *Alces* sp., *Beremendia fissidens*, *Citellus polonicus*, *Dicrostonyx simplicior*, *Lemmus lemmus*, *Pliomys lenki*, *Castor fiber*, *Mimomys savini*, *Clethrionomys* cf. *glareolus*, *Pliomys episcopalis*, *Pitymys gregaloides* and *Pitymys arvaloides*.

Fluvioglacial fine-grained sands with Scandinavian material (Fig. 2) cover the clays. This fact and the co-occurrence of *Pliomys lenki*, *Mimomys savini*, *Dicrostonyx simplicior*, *Ursus deningeri*, *Pliobatrachus Langhae* and *Bombina* cf. *bombina* in the clays, suggesting an Older Pleistocene (Late Biharian) faunal assemblage, are crucial to the age determination. The overlying sands are TL-dated to over 400 ka (Prószyński, pers. comm.) whereas FCI/P-age determinations of bones indicate 700–550 ka, making the cave deposits at Kozi Grzbiet correspond to the Cromerian II (Westerhoven) in the Netherlands. Analyses of collagen loss in bones suggest the coolest climate occurred during the deposition of the lowermost cave clays, followed by two warm episodes separated by a cool interval (Głazek *et al*., 1976, 1977*a*, *b*).

The cave deposits thus typify the climatic conditions of the Kozi Grzbiet Interglacial, correlated with the Jasionka section near Rzeszów (Dąbrowski, 1967; Laskowska-Wysoczańska, 1967), later named the Malopolanian Interglacial by Różycki (1978). Heavy minerals (amphibole and pyroxene) derived from weathered crystalline (Scandinavian) rocks, preserved at Kozi Grzbiet (definitely older than this interglacial), are considered to be the traces of the Nidanian Glaciation along with the oldest tills occurring north of this site (Fig. 4). The sands covering the cave clays within the site, as well as the younger tills occurring in the area, correspond to the Sanian Glaciation (Lindner, 1982), subdivided into the Sanian 1 and Sanian 2 (Fig. 4) and separated elsewhere by the Ferdynandovian Interglacial (Lindner, 1988*a*).

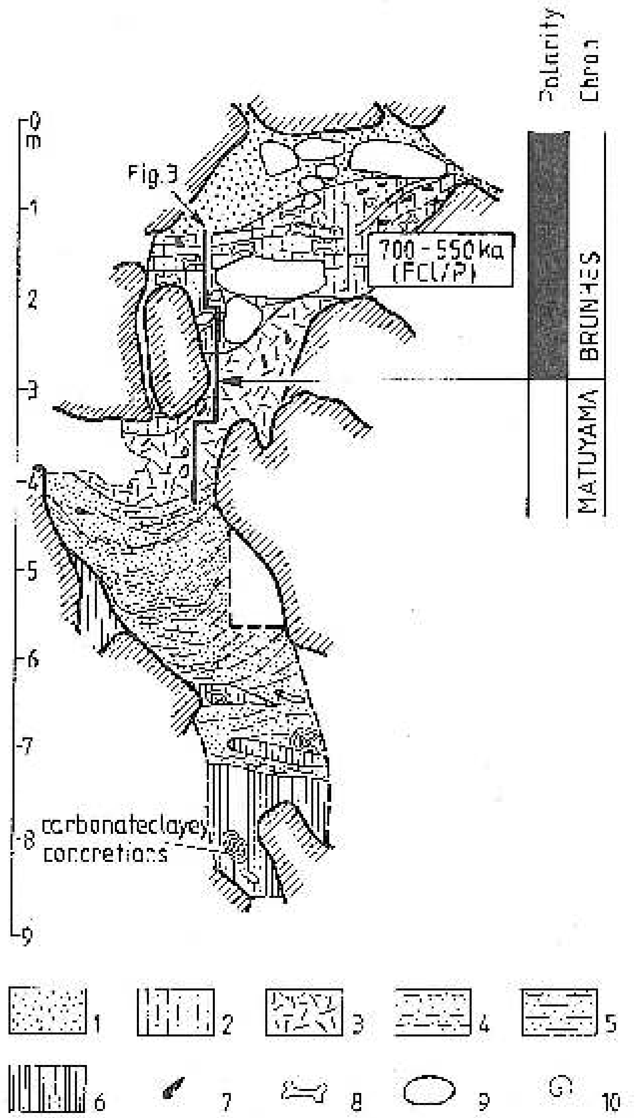

Fig. 2. Profile, FCI/P age and palaeomagnetic data of cave deposits from Kozi Grzbiet near Kielce (after Głazek *et al.*, 1977*a*)

Sanian 1 and Sanian 2 Glaciations: 1 — fine-grained sands with Scandinavian material, structureless in their upper part, laminated in their lower part, with fragments of stalactites and calc tufa as well as with limestone blocks and debris; **Malopolanian Interglacial**: 2 — brown-yellow sandy clays, with bone fragments and snail shells as well as fragments of stalactites, calc tufa and limestone blocks; **Nidanian Glaciation**: 3 — "brecciated" clay composed of pieces of laminated clay, cherry-red in colour, with carbonate concretions and grains of amphiboles and pyroxenes; **pre-Pleistocene** (?): 4 — cherry-red clayey sand, with debris of limestone and carbonate concretions, 5 — poorly sorted sand with clayey lenses and debris of limestone and carbonate concretions and with lenses of yellow to cherry-red clay, 6 — yellow-brown clay with carbonate concretions, 7 — limestone debris and small carbonate concretions, 8 — bone remains, 9 — larger limestone blocks in cave deposits, 10 — snail shells

ŁUKÓW CROSS-SECTION (FIG. 5)

The cross-section shown of the Quaternary deposits in Łuków (Fig. 5) constitutes the northeastern part of the cross-section of Rühle (1969). It is supplemented by the Ł-105 borehole, the organic deposits of which (peats and gyttja) were subjected to palynological analysis (Sobolewska, 1969) and are taken into account in the new stratigraphic interpretation.

The bedrock of the Quaternary deposits (that are 40–100 m thick) is composed of Pliocene clays, underlain by the Miocene sands with intercalations of silt and brown coal, underlain by

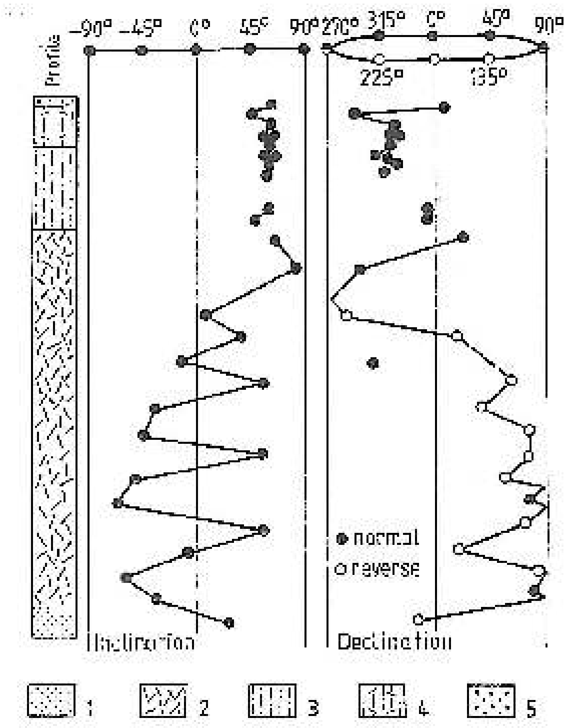

Fig. 3. Results of palaeomagnetic analyses of the younger cave deposits from Kozi Grzbiet near Kielce (after Głazek *et al.*, 1977*a*)

Pre-Pleistocene: 1 — poorly sorted sands with lenses of clay and debris of limestones and carbonate concretions; **Nidanian Glaciation**: 2 — "brecciated" clay composed of pieces of laminated clay, cherry-red in colour, with carbonate concretions and grains of amphibole and pyroxene; **Malopolanian Interglacial**: 3 — yellow-brown sandy clay, with numerous bone remains, 4 — yellow-brown sandy clay with bone remains and snail shells; **Sanian 1 and Sanian 2 Glaciations**, 5 — fine-grained sand with Scandinavian material

Oligocene sand with gravel, Eocene clay and silt with sand and Paleocene sandy marl and the lowermost Cretaceous marl and limestone. The oldest Quaternary is represented by the pre-Pleistocene (Pp) i.e. preglacial sands with gravel without Scandinavian material, and by poorly sorted, locally silty, sand.

The Pleistocene sequence begins with fluvioglacial sands with gravel containing Scandinavian material together with a thin till in and around a glacial-eroded depression. These deposits represent the oldest glacial horizon in the area, are 5–10 m thick and correspond to the Narevian Glaciation (N) (Fig. 5), formerly named the lower stadial of the South Polish Glaciation (Rühle, 1969), and later, the Podlasian Glaciation (Ruszczyńska-Szenajch, 1976). Sands with gravel, probably of fluvial origin, relate to the oldest interglacial named the Podlasian Interglacial (Po) or Augustovian (?), and lie above the till of this glaciation. The sands are 3–6 m thick and are covered by an almost continuous layer of a second till, 3–5 m thick. This second till probably represents the Nidanian Glaciation (Ni), and was formerly considered as the equivalent of the upper stadial of the South Polish Glaciation (Rühle, 1969) or as the older unit of glacial deposits of the Cracovian Glaciation (Ruszczyńska-Szenajch, 1976). The till corresponds to the Nidanian Glaciation of northeastern Poland (Kenig, 1998).

These deposits and also the Oligocene deposits in the borehole Ł-105 (Fig. 5), are overlain by up to 70 m of fine-grained silty sand with intercalations and lenses of gravel, clay and silt. Rühle (1969) and Ruszczyńska-Szenajch (1976) interpreted these a multi-cyclic fluvial succession of the Great Interglacial (Mazovian *sensu lato*). They are covered by a third till and younger sands as well as by peat and gyttja of the Ferdynandovian Interglacial (Cromerian? according to Sobolewska, 1969), and thus correlate with the older i.e. Małopolanian Interglacial (Ma) (Fig. 5). Therefore, the till younger than this interglacial cannot represent the Middle Polish Glaciation (glaciations) as hitherto considered (Rühle, 1969; Ruszczyńska-Szenajch, 1976), and corresponds rather to the Sanian 1 Glaciation (S1), as in the stratigraphic scheme of northeastern Poland (Kenig, 1998).

According to Sobolewska (1969) the peat and gyttja examined in borehole Ł-105, contain an interglacial forest flora from a climatic optimum, without any initial and terminal phases. She suggests that, during this interglacial, elevations were overgrown by oak-pine forests with abundant hazel in the undergrowth, while humid habitats within depressions comprised alder, elm and ash forests with maple, spruce and willow. This spectrum corresponds well with the fossil flora from Ferdynandów, at present considered to be the type locality of the Ferdynandovian Interglacial (F) (Janczyk-Kopikowa *et al.*, 1981; Rzechowski, 1996).

The younger Quaternary deposits near Łuków comprise two tills, the lower one of which probably represents the Sanian 2 Glaciation (S2) or Wilgian, while the upper corresponds to the Odranian Glaciation (Wartanian?) and is locally bipartite. The lower till is 2–15 m thick and is the best-developed glacial unit in the section. The younger till contains intercalations of gravel and sand, and is locally over 20 m thick. Fluvioglacial sands with gravel and/or fluvial gravels and sands of the Great Interglacial (Mazovian *sensu lato* — M) underlie it. Deposits of the Odranian (Wartanian?) Glaciation (O) or (W?) in Łuków are eroded and a palaeovalley is filled with gravel and fluvial sand of the Lubavian Interglacial (Lu). During the Wartanian (?) Glaciation (W?) the region occupied an extraglacial environment. Sandy-silty-gravely elluvial and alluvial sediments formed between the Eemian Interglacial and the Holocene (E+V+H) occur above these deposits and on the surrounding tills.

BIAŁA PODLASKA-WILCZYN CROSS-SECTION (FIG. 6)

The pre-Quaternary bedrock between Biała Podlaska and Wilczyn is represented by Oligocene sand and gravel with glauconite, clay and silt. The oldest Quaternary deposits include tills (subdivided mainly on the basis of geomorphology) in bedrock depressions. Tills are over 10 m thick and represent the oldest of the four glacial succession below organic deposits of the Mazovian Interglacial. They seem to correspond to the Narevian Glaciation (N) (Lindner, 1988*b*; Nitychoruk, 1994) and the Narevian interval in the stratigraphic scheme of northeastern Poland (Kenig, 1998). In the Biała Podlaska region a till is cut by an ancient river valley, over 15 m deep, infilled with gravel and sands of the Podlasian Interglacial (Po). The valley series is overlain with silt and locally bipartite till of the second glacial succession, connected with the Nidanian Glaciation (Ni). The till is 5–8 m thick, and occurs in depressions within the pre-Quaternary bedrock. It corresponds to the Nidanian intervals in the stratigraphic scheme of northeastern Poland (Kenig, 1998).

In the region of Biała Podlaska this till is cut by a younger ancient valley filled with gravel-sandy deposits, to 20 m thick and in many cases comprised of two subsequent gravel-sand-silty complexes. They represent alluvia of the Malopolanian Interglacial (Ma) of a palaeovalley running south-east. Fluvioglacial sands and a younger till of the third glacial complex spread widely across the whole (Fig. 6) valley. This till is 6–10 m thick, contains Scandinavian material along with a large admixture of fragments and pebbles of local Cretaceous marls and limestones. It is ascribed to the Sanian 1 Glaciation (S1). In the Biała Podlaska region the till is cut by a rather shallow (up to 5 m deep) ancient valley filled with fluvial gravel and sand up to 4 m thick, containing many boulders. Upwards, these deposits pass into an almost continuous horizon of sand, 5–10 m thick, representing the fourth glacial succession along with the overlying till. The till is locally up to 20 m thick and contains much Scandinavian material, and is considerably decalcified and plastic in the uppermost part. It was deposited by an ice sheet whose dynamics favoured the development of extensive and deep glaciotectonic deformation. This ice sheet was connected with the Sanian 2 Glaciation (S2), because its deposits are directly overlain by palaeontologically-dated (palynology, macrofauna and diatoms) lake deposits of the Mazovian Interglacial (M) in the sections Biała Podlaska 2/84 (Krupiński *et al.*, 1988; Marciniak and Lindner, 1995; Marciniak, 1998) and Wilczyn WL 1/92 (Bińka *et al.*, 1997).

The lowest palaeoflora at Biała Podlaska represents boreal forests, succeeded by mixed forest during the interglacial climatic optimum, with a slight cooling (PAZ–BP–F — *Pinus* — *Picea* — *Alnus*) in the older part of this optimum (Krupiński, 1988). The pre-optimal part of the interglacial was predominated by numerous periphytic diatoms within the macrophytes and on the lake bottom (*Fragilaria lapponica*, *Cymbella diluviana*, *Amphora pediculus* and *Navicula scutelloides*), followed by *Fragilaria* spp. and *Cyclotella* spp. (Marciniak, 1998). The optimum was marked by a dominance of the planktonic diatoms *Aulacoseira* (mainly *A. ambigua*) indicating a rise of water level and lake eutrophication, followed by periphytic, alkaliphilous diatoms (*Fragilaria construens* var. *venter* and *F. construens* var. *binodis*), typical of a littoral zone. The post-optimal part of the interglacial was characterised by the diatoms *Stauroneis*, *Pinnularia*, *Neidium* and *Navicula*, testifying to shallowing and overgrowing of the lake. Higher flora of the climatic optimum in Wilczyn is characterised by numerous exotics (*Parrotia type*, *Celtis*, *Buxus*, *Vitis*), with a climatic trend from oceanic to continental conditions (Bińka *et al.*, 1997).

Some of the former deep depressions in the Biała Podlaska region were later partly filled by sand from extraglacial rivers during the Liviecian Glaciation (L). The sands are 10 m thick and locally contain intercalations of soliflucted tills from nearby morainic plateaux (Fig. 6). At the foot of such an edge near Biała Podlaska a younger lake basin was formed, gradually filled with silts, most probably of the Zbójnian Interglacial (Z).

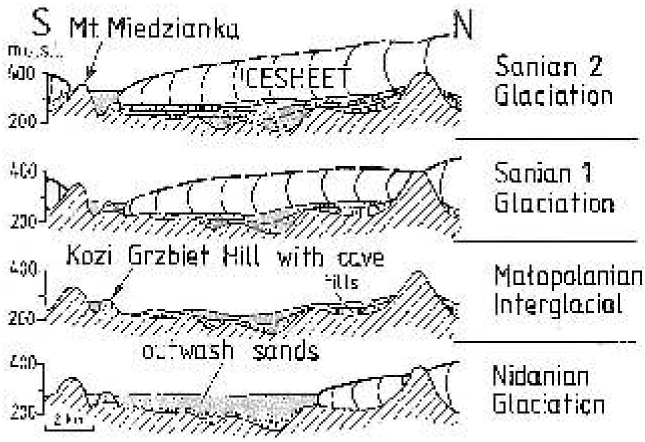

Fig. 4. Glacial and glaciofluvial accumulation in the western part of the Holy Cross Mts. (after Głazek *et al.*, 1977*a*)

In the Biała Podlaska region the interglacial valley, lake deposits and the ancient morainic plateau from the Sanian 2 Glaciation are covered by up to 15 m of glaciofluvial and ice-dammed deposits represented by sand, sand and silt, overlain by till of the Odranian (Wartanian?) Glaciation (O or W?). The till is rather thin (3–6 m), and it has been locally removed by energetic glaciofluvial flow during the ice sheet retreat. Vast sandur plains and valley sandurs formed at the ice sheet margin that stopped to the north in the vicinity of Konstantynów, Komarno and Klonowica (Lindner, 1996, 1997). Some valley or dead-ice depressions were later incorporated within the younger valley network, which influenced accumulation of sands, silts, peat and organic mud from the Lubavian Interglacial to the Holocene (Lu-H).

SMOLARKA PROFILE AND CROSS-SECTION (FIGS. 7 AND 8)

In the vicinity of Smolarka near Bereza the pre-Quaternary bedrock comprises Neogene (Ne) sandy deposits with intercalations of brown coal, overlain by clay with intercalations of sand or with Older Paleogene (Pa) sands on the Cretaceous (Cr) marls and limestones (Fig. 7).

The oldest Quaternary deposits include clays with admixtures or intercalations of sand up to 20 m thick, these representing the Varyazhskian cold (vr) (Sanko and Moiseyev, 1996). Palynological and macrofaunal investigations (Yakubovskaya and Rylova, 1992) showed three pollen phases, typical of a cooler forest devoid vegetation, part of the pre-Pleistocene (Eopleistocene of the Belarussian scientists). The lowermost pollen phase includes cold climatic flora with *Selaginella selaginoides*, *S. helvetica*, *Potamogeton vaginatus* and *Betula* cf. *humilis*. In the upper phases, the flora presents rather a warmer climate with *Azolla interglacialis*, *Scirpus kreczetoviczii* and *Stratiotes intermedius*. In the section Smolarka-3 (S-3 on Figs. 7 and 8) these deposits show reversed magnetic polarity, thus are located within the Matuyama epoch (Sanko and Moiseyev, 1996).

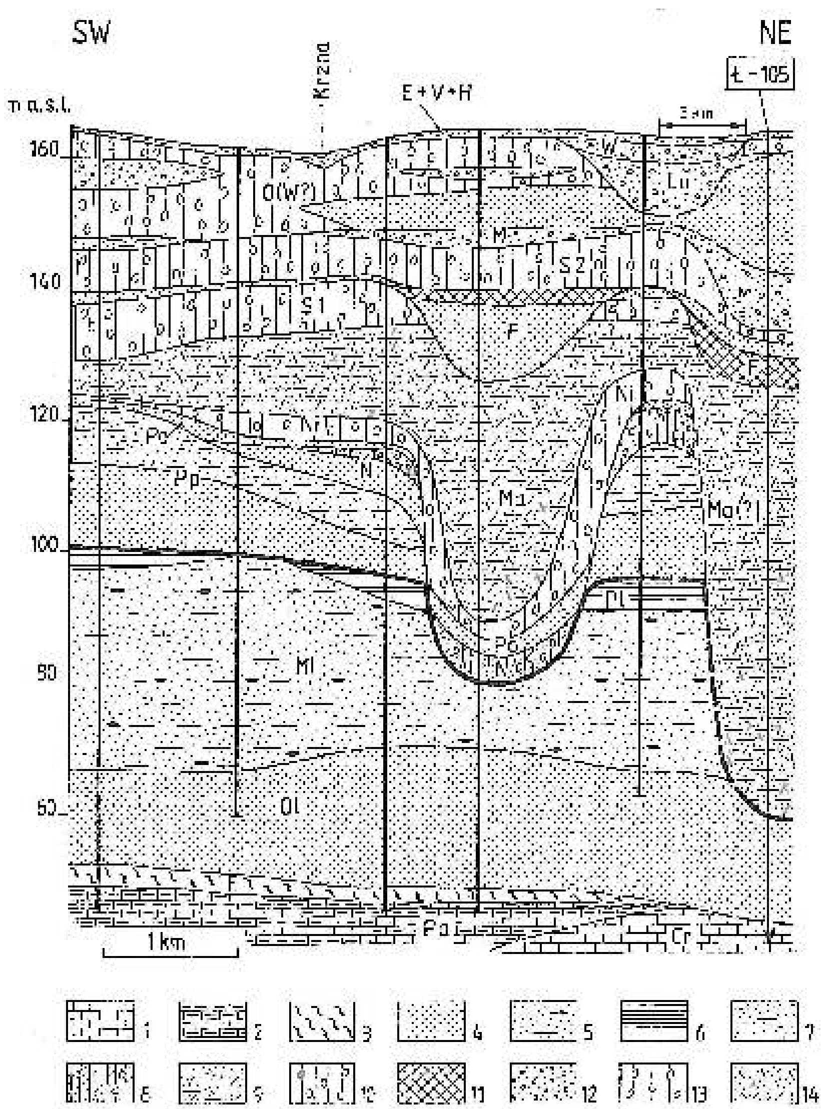

Fig. 5. Geological cross-section in the vicinity of Łuków, Siedlce Plateau (after Rühle, 1969), section Ł-105 with palynological data (after Sobolewska, 1969), age interpretation and stratigraphic symbols (after Lindner, 1992)

Cr — Cretaceous, Pa — Paleocene, E — Eocene, Ol — Oligocene, Mi — Miocene, Pl — Pliocene, Pp — pre-Pleistocene, N — Narevian Glaciation, Po — Podlasian Interglacial, Ni — Nidanian Glaciation, Ma — Malopolanian Interglacial, S1 — Sanian 1 Glaciation, F — Ferdynandovian Interglacial, S2 — Sanian 2 Glaciation, M — Mazovian Interglacial, O (W?) — Odranian (Wartanian?) Glaciation, Lu — Lubavian Interglacial, E+V+H — Eemian Interglacial + Vistulian Glaciation + Holocene; 1 — marl and limestone, 2 — sandy marl, 3 — clay and silt with sand, 4 — sand with gravel, 5 — sand with intercalations of silt and brown coal, 6 — clay, 7 — poorly sorted sand, partially silty sand, 8 — till with boulders and pebbles, 9 — fine-grained and silty sand with lenses of gravel, clay and silt, 10 — till with lenses of sands and gravel, 11 — peat and gyttja, 12 — gravel and sand, 13 — sandy tills with lenses of gravel and sand, 14 — fine- and medium-grained and poorly sorted sand

These deposits are covered by clay with sand intercalations and by sand with gravel and overlying blue-grey clay with positive polarity typical of the Brunhes epoch, therefore constraining the position of the Brunhes/Matuyama boundary (Sanko and Moiseyev, 1996). They are up to 6 m in thick (Fig. 7). According to Belarussian scientists they represent the Ruzhanskian warm (rz), despite the presence of varved clays (Velichkevich *et al.*, 1993), indicating deposition some distance from the ice sheet. Yakubovskaya and Nazarov (1993) connect these deposits with the Smorgonian cooling (sm?) that is the upper part of the Brest horizon of the Eopleistocene. According to Sanko and Moiseyev (1996) they are locally over 30 m thick and represent the anaglacial (preglacial) part of the Narevian Glaciation (Fig. 8). In the Smolarka-3 section they are covered by sands with gravel, and higher with sand and till of the Narevian Glaciation (nr). The till is from several to over 40 m thick and occurs at bottom of a glacial depression as well as covering ancient morainic plateaux, though locally it has been removed by younger erosion.

In the section Smolarka-3 the till is characterised by positive polarity, and is covered by clayey silts of the Korchevian Interglacial (kch) (Sanko and Moiseyev, 1996). The silts are overlain by a till of the Yaseldinian Glaciation (yas), likewise characterised by positive polarity, and up to 20 m thick. In the

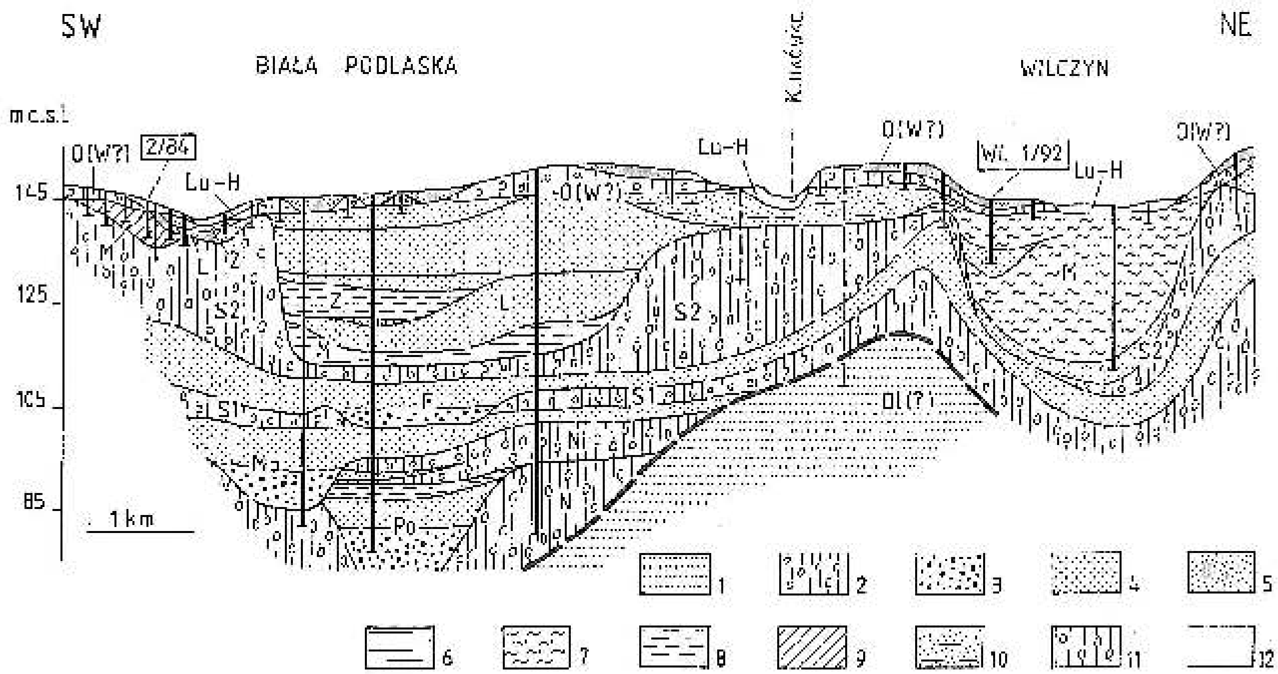

Fig. 6. Geological cross-section in the vicinity of Biała Podlaska (after Lindner and Marciniak, 1998), section 2/84 of the Mazovian Interglacial deposits with palynological data of Krupiński (Krupiński *et al.*, 1988) and diatom data of Marciniak (1998), section WL 1/92 of the Mazovian Interglacial deposits with palynological data of Bińka (Bińka *et al.*, 1996)

Ol (?) — Oligocene, N — Narevian Glaciation, Po — Podlasian Interglacial, Ni — Nidanian Glaciation, Ma — Malopolanian Interglacial, S1 — Sanian 1 Glaciation, F — Ferdynandovian Interglacial, S2 — Sanian 2 Glaciation, M — Mazovian Interglacial, L — Liviecian (?) Glaciation, Z — Zbójnian (?) Glaciation, O (W?) — Odranian (Wartanian?) Glaciation, Lu-H — Lubavian Interglacial-Holocene; 1 — sand and gravel with glauconite as well as clay and silt, 2 — tills (older), 3 — gravel and sand (fluvial), 4 — fluvial and glacifluvial sand, 5 — glacifluvial sand, gravel and silt, 6 — clays and silts, 7 — lake marl and gyttja, 8 — silts, 9 — bituminous silt and shale, 10 — sand and silt, 11 — till (younger), 12 — sand and silt, peat and organic mud

sections Smolarka-3 and Smolarka-13 there are gravels with sands and lake deposits up to 10 m thick. On the basis of palynologic data the lowermost part of the lacustrine deposits in the Smolarka section has been previously referred to the Korchevian Interglacial (Makhnach and Rylova, 1986; Velichkevich *et al*., 1993). In the light of new palaeobotanic data the following intervals have been distinguished in the Smolarka-3 section: Byelovezhian Interglacial *sensu lato*, at present subdivided into the Byelovezhian Interglacial *sensu stricto* (bl), a small Nizhinian Glaciation (nz) and the Mogilevian Interglacial (mh) (Sanko and Moiseyev, 1996; Velichkevich *et al*., 1997). These deposits are covered by a till of the Berezinian Glaciation (br) and by younger glaciofluvial sands (Figs. 7 and 8).

POSTOLOVO CROSS-SECTION (FIG. 9)

In the vicinity of Postolovo near Bereza (Fig. 1), the pre-Quaternary bedrock comprises Cretaceous (Cr) marls and limestones, covered locally by Palaeogene (Pa) clay, sand and sand with gravel, and Neogene (Ne) sand with gravel, sand and sandstone as well as clay and mud (Fig. 9).

The oldest Quaternary deposits include sand and silt with sand and overlying gyttja and peat with sand, up to 20 m thick. Flora from gyttja and peat contains Late Pliocene taxa (*Potamogeton perforatus, P. praemaackianus, P. pseudorutilus, P.* cf. *felixi, P.* cf. *parvulus, Caulinia palaeotenuissima, Scirpus atroviroides*), taxa linked with the beginning of the Pleistocene (*Eleocharis praemaximoviczii, Carex paucifloroides, Hypericum pleistocenicum*), as well as taxa of exotic flora, thus correlating the organic deposits to the Korchevian Interglacial (kch) (Velichkevich *et al.*, 1993).

The younger Quaternary deposits in the Postolovo region include three tills separated by sands (Fig. 9). They are to 50–60 m thick, and according to Velichkevich *et al.* (1993) represent the Lower Quaternary (gQ_1) with the Yaseldinian Glaciation (yas) included. The lower till, 10 m thick, fills a glacial depression. It lies directly on the Cretaceous rocks and is covered by sands 15 m thick. The middle till is also preserved within the same depression, as well as lying on the Neogene deposits in the northern part of the cross-section (Fig. 9). The covering sands are 40–80 m thick. On the northern slope of the depression, the uppermost till is underlain by clays 6 m thick. The till is up to 20 m thick and occurs in all boreholes of the cross-section (Fig. 9), most deeply within the depression and more shallowly in the northern part where it contains a clay xenolith.

Locally in the northern part of the depression there are silts with sands above the till, while in the remaining area the till is covered by up to 70 m of sand, in the region with a till to 18 m thick and reaching the surface (Fig. 9). The upper part of this

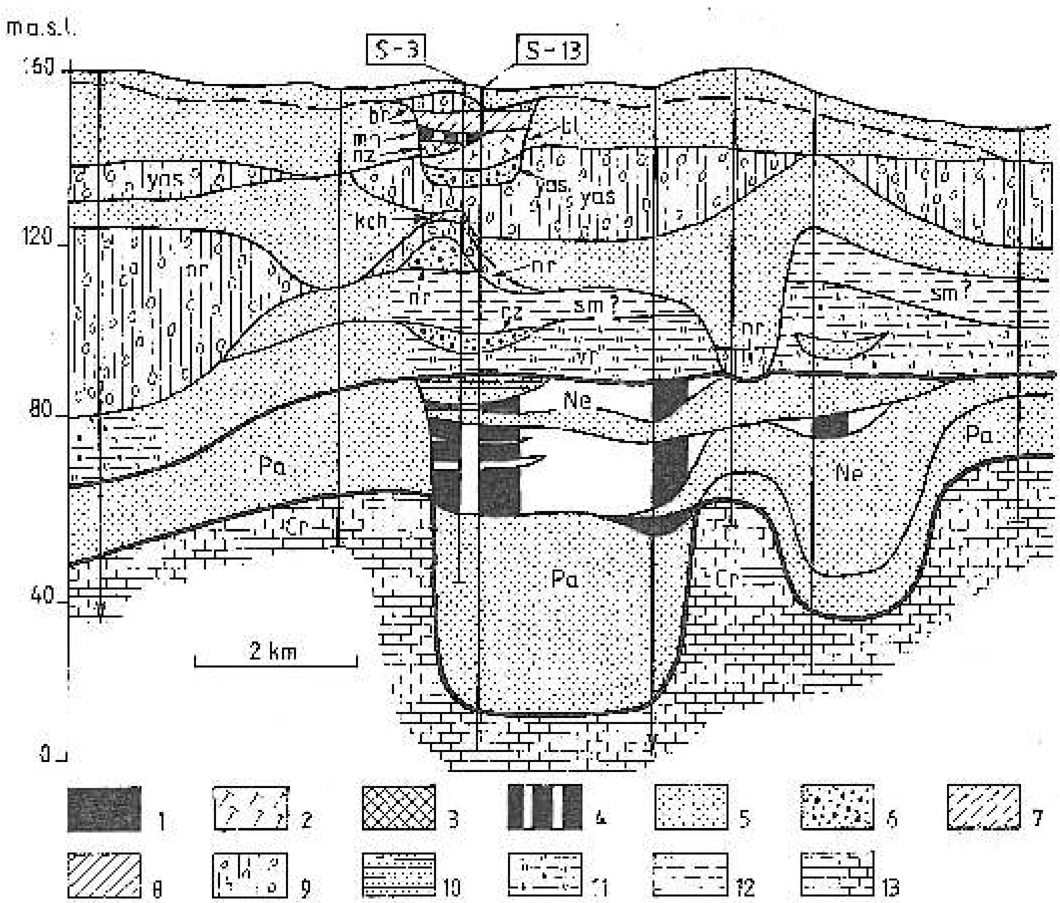

Fig. 7. Geological cross-section in the vicinity of Smolarka near Bereza (after Sanko and Moiseyev, 1996), supplemented by S-3 and S-13 sections with palaeobotanical data

Cr — Cretaceous, Pa — Paleogene, Ne — Neogene, vr — Varyazhskian cold, rz — Ruzhanskian warm, sm — Smorgonian cold (Narevian preglacial), nr — Narevian Glaciation, kch — Korchevian Interglacial, yas — Yaseldinian Glaciation, bl — Byelovezhian Interglacial, nz — Nizhinian cooling (Glaciation?), mh — Mogilevian Interglacial, br — Berezinian Glaciation; 1 — brown coal (Ne), 2 — peat, 3 — silty gyttja, 4 — peaty gyttja, 5 — fine-grained sand, 6 — poorly sorted sand with gravel, 7 — silt, 8 — clayey silt, 9 — till, 10 — clay with sandy intercalations, 11 — clay with sand, 12 — clay, 13 — marl and limestone

succession shows two lenses of lake marl and peat, 4–6 m thick, in the central and northern part of the cross-section. The organic deposits yield flora (i.e. *Picea, Larix, Pinus silvestris, Abies alba, Juniperus communis, Betula alba, B. humilis, Alnus* cf. *glutinosa, Carpinus* cf. *betulus, Sambucus racemosa*), which along with remains of exotic flora suggest correlation of these deposits to the Alexandrian Interglacial (al) (Velichkevich *et al.*, 1993). Therefore, the covering sands of the uppermost part of the series seem to represent fluvioglacial deposition of the following glaciation (Dnieperian?).

COMPARISON REMARKS

The data presented and recent correlation of the Pleistocene deposits in Poland and Belarus (Lindner and Yelovicheva, 1998; Lindner and Astapova, 2000) suggest biostratigraphical correlation of the lake deposits of the Mazovian and Alexandrian interglacials. In the area studied this is particularly the case for the closely spaced sites of Biała Podlaska and Gvoznitsa (Fig. 1), especially on the basis of palynological data (Krupiński, 1995).

Comparative diatom investigations of Poland carried out in sites with lake deposits from the Mazovian Interglacial (Marciniak, 1998) and the Alexandrian Interglacial of Belarus (Khursevich and Fedenya, 1998) revealed significant diversity, resulting from influence of climatic and ecological changes during this interglacial. All sites yield characteristic diatom taxa (i.e. *Cyclotella comta* var. *lichvinensis*, *C. vorticosa*) that are indicators of both the Mazovian and the Alexandrian interglacials. In both cases the lake deposits are younger than tills from the Sanian 2 (=Berezinian) Glaciation.

In the area analysed tills of this glaciation cover older, similarly correlable lake deposits of the Ferdynandovian and the Byelovezhian Interglacial (*sensu lato*). In mid-eastern Poland,

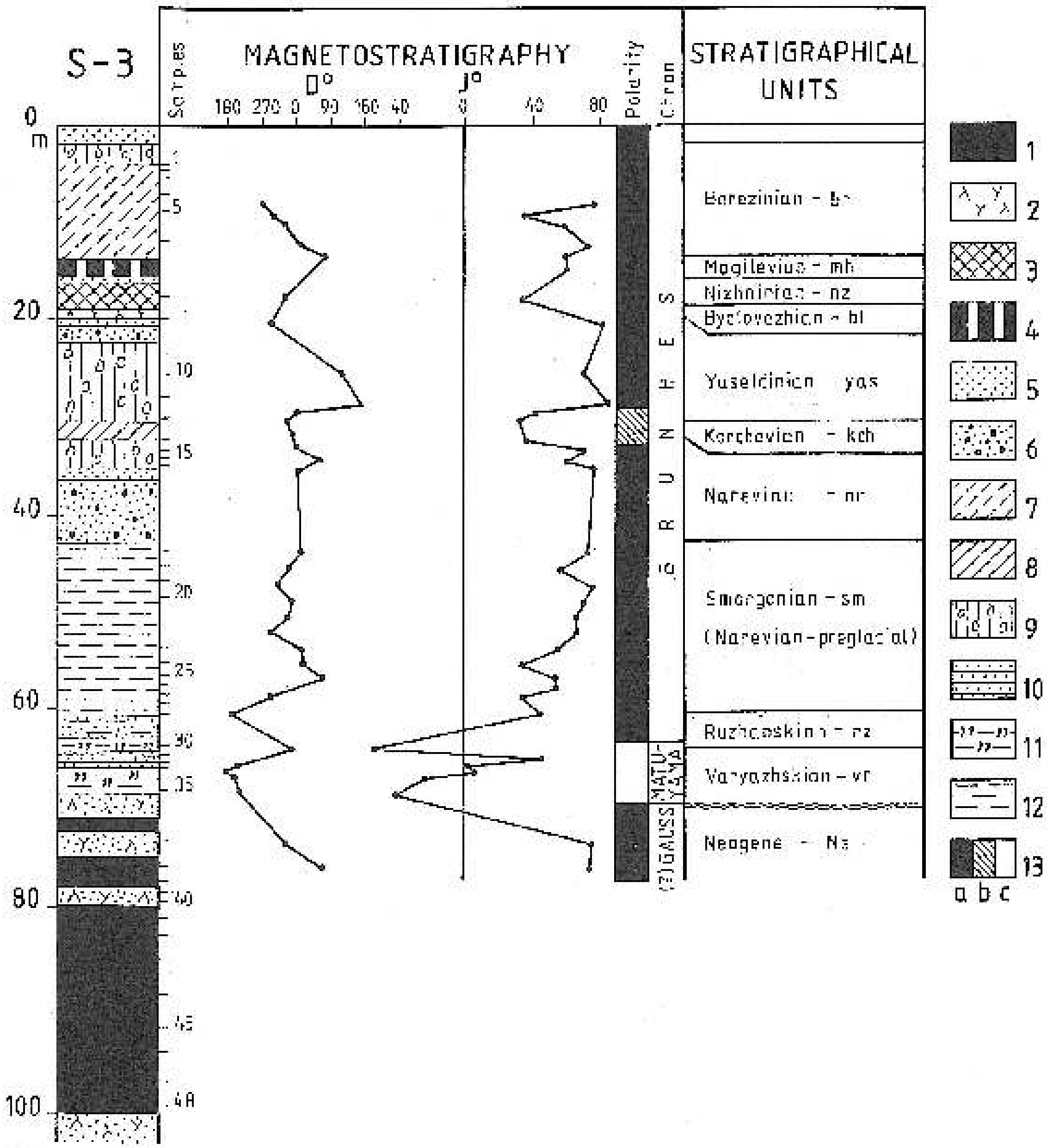

Fig. 8. Section S-3 and palaeomagnetic data at Smolarka near Bereza (after Sanko and Moiseyev, 1996)

D° — declination, I° — inclination; 1–12 explanation see Figure 7, 13 — magnetic polarity (a — normal, b — variable, c — reversed)

apart from section Ł-5 from the Łuków region (Figs. 1 and 5), deposits of the Ferdynandovian Interglacial have been described from Ferdynandów, Podlodów and Falęcice (Fig. 1). The pollen succession of the Ferdynandów Interglacial is characterised by small amounts of spruce. Oak and elm prevail at first during the optimum, followed by a domination of hazel, along with small quantities of linden, and sporadic occurrence of hornbeam and yew, while fir plays a crucial role. The second warming in the upper part of the type section at Ferdynandów resulted in the development of a deciduous forest with hornbeam (Janczyk-Kopikowa, 1963, 1991).

Diatom analysis from the type sections of the Ferdynandovian Interglacial from Ferdynandów and the Byelovezhian Interglacial from Krasnaya Dubrova (SE Belarus) carried out in tandem with the palynological subdivision indicated the presence of a rich diatom flora from the two climatic optima at Krasnaya Dubrova and a lack of diatoms in the upper, younger climatic optimum at Ferdynandów. The similar taxonomic composition of the dominant diatom species, the high content of shared taxa (*ca*. 80%) and occurrence of extinct taxa in both sections (i.e. *Cyclotella reczickiae*, *C. reczickiae* var. *diversa*, *Stephanodiscus peculiaris*, *S. niagarae* var. *insuetus*),

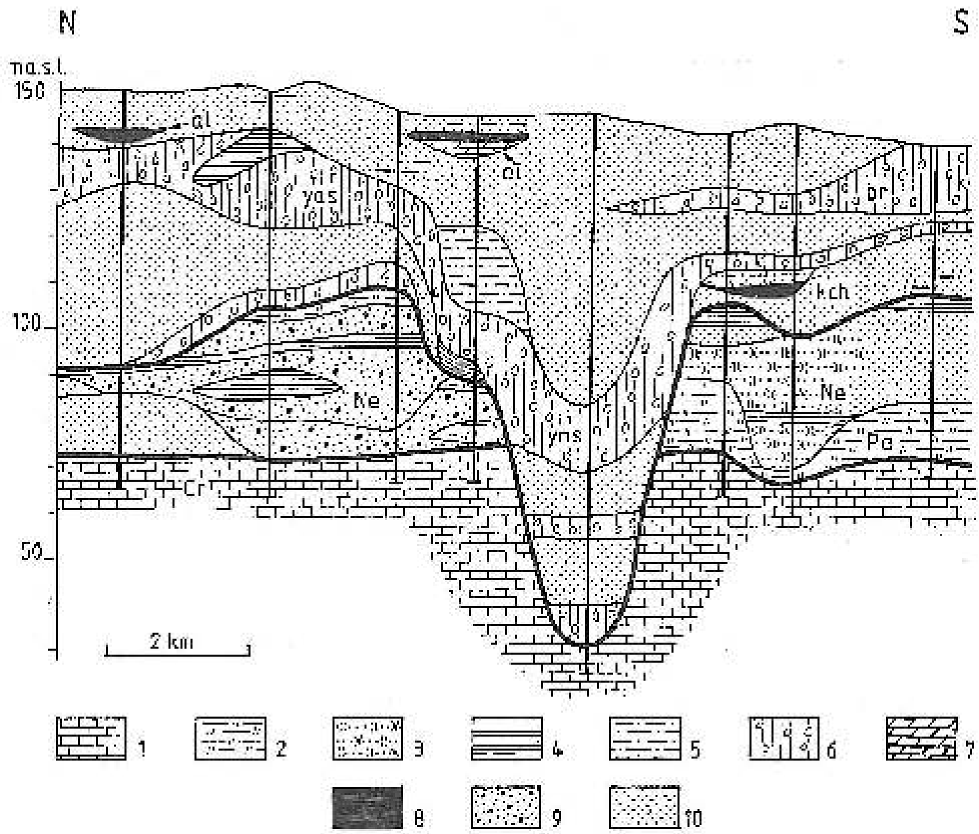

Fig. 9. Geological cross-section in the vicinity of Postolovo near Bereza (after Velichkevich *et al.*, 1993)

Cr — Cretaceous, Pa — Paleogene, Ne — Neogene, kch — Korchevian Interglacial, yas — Yaseldinian Glaciation, br — Berezinian Glaciation, al — Alexandrian Interglacial; 1 — marl and limestone, 2 — clay with sand, 3 — sand and sandstone, 4 — clay, 5 — silt with sand, 6 — till, 7 — lake marl, 8 — gyttja and peat, 9 — sand with gravel, 10 — sand

typical for the Byelovezhian and Ferdynandovian interglacials, indicate that the microflora are of the same age (Khursevich *et al.*, 1990). In lake deposits from Podlodów and Falęcice, diatoms have been similarly noted only in the lower, older climatic optimum of the Ferdynandovian Interglacial (Marciniak, 1991; Lindner *et al.*, 1991). Palynological and diatom studies at these sites suggest (Janczyk-Kopikowa, 1963, 1991; Khursevich *et al.*, 1990; Marciniak, 1991; Lindner *et al.*, 1991) that the lake deposits are of the same age as deposits of the Byelovezhian Interglacial *sensu lato* at Smolarka in western Belarus (Fig. 1) where diatoms are absent.

Palynological data from Borki (Fig. 1) suggest the lacustrine interglacial deposits there belong to the Byelovezhian Interglacial *sensu stricto* (Bogomolova *et al.*, 1985). Diatoms from Borki include *Cyclotella reczickiae* et var. *diversa*, *C. comta* (*C. radiosa*) var. *pliocaenica* et var. *lichvinensis* (Yakubovskaya *et al.*, 1991, Velichkievich *et al*., 1997), found also in the lower part of the section at Krasnaya Dubrova which corresponds to the Byelovezhian Interglacial.

From a biostratigraphical point of view, the three main parts of this interglacial (lower optimum, cooling and upper optimum) are referred in Belarus (Makhnach *et al.*, 1982; Nazarov, 1995; Velichkevich *et al.*, 1996; Velichkevich *et al.*, 1997) to the Byelovezhian Interglacial *sensu stricto*, the Nizhninian cooling (minor glaciation) and the Mogilevian Interglacial, respectively (Fig. 10). The lake deposits of the Ferdynandovian = Byelovezhian Interglacial *sensu lato*, are younger than tills of the Sanian 1 (=Yaseldinian) Glaciation.

Biostratigraphical correlation of the lake deposits of the Mazovian Interglacial in Poland with the lake deposits of the Alexandrian Interglacial in Belarus and correlation of deposits of the Ferdynandovian Interglacial in Poland with deposits of the Byelovezhian Interglacial *sensu lato* in Belarus suggest that the underlying glacial deposits are of the same age. Therefore, the two younger South Polish Glaciations (Sanian 2 and Sanian 1) should correspond in Belarus to the Berezinian Glaciations *sensu lato* (Berezinian *sensu stricto* and Yaseldinian respectively).

Determination of the stratigraphic position of the older interglacial and glacial deposits of the glacial Pleistocene in Poland and Belarus is more complicated. Thus, floral succession from lake deposits at Przasnysz (Fig. 1) may be regarded as similar to the succession in the Mazovian Interglacial or in Interglacial IV of the Cromerian complex in the Netherlands, while flora from Przasnysz in Poland and Korchevo in Belarus cannot indicate the same stratigraphic setting (Mamakowa, 1998). Based on these assumptions and on analyses from Kozi Grzbiet in Poland and Postolovo in Belarus, the Korchevian

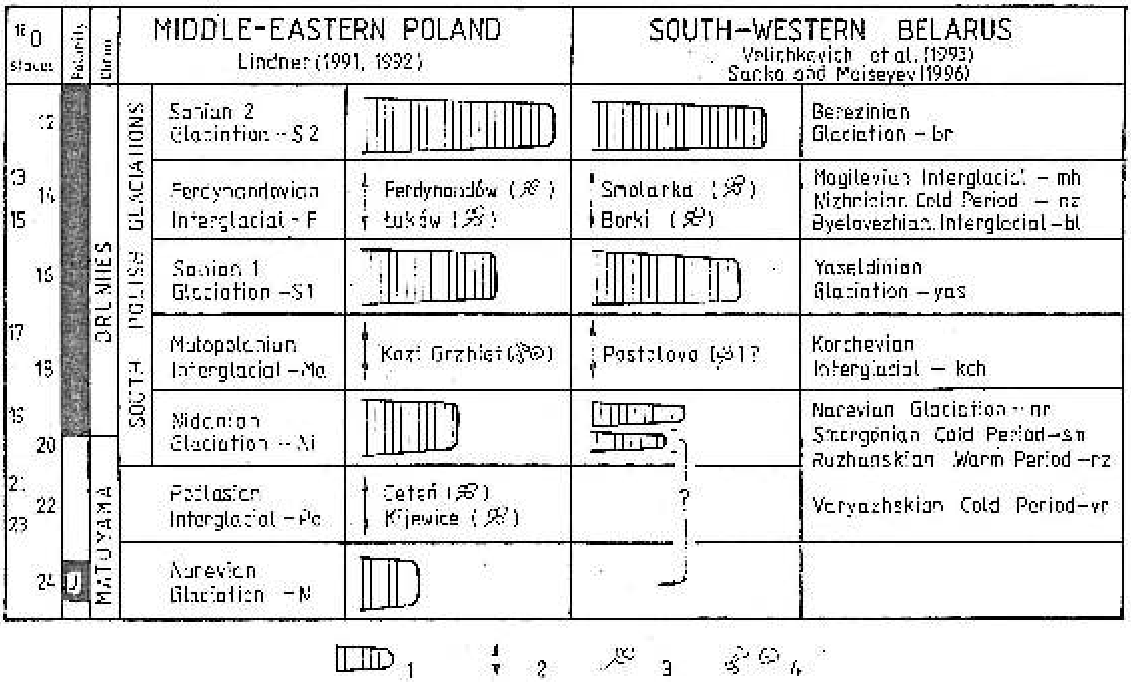

Fig. 10. Tentative correlation of glacial and interglacial units of the older Pleistocene in central-eastern Poland and southwestern Belarus

1 — till, 2 — sites with interglacial deposits, 3 — floral remains, 4 — faunal remains

Interglacial in Belarus should be regarded as an equivalent of the Malopolanian Interglacial in Poland. This interpretation is supported by similar faunal remains in deposits of the Korchevian Interglacial in Belarus (Motuzko, 1985) and the Malopolanian Interglacial in Poland, as pointed out by Nazarov (1995).

Older still is the Nidanian Glaciation in Poland, regarded as the first South Polish Glaciation, which is correlated on the basis of palaeomagnetic data with the Glacial A in the Netherlands (Lindner, 1991). In the Smolarka-3 section in Belarus (Fig. 7) silts of the Korchevian Interglacial (Sanko and Moiseyev, 1996) and in the Smolarka-13 section (Fig. 7) sand at depth 38.4–42.0 m are underlain by a till, palaeomagnetically younger than the Brunhes/Matuyama boundary. This may correlate with the Narevian Glaciation (Sanko and Moiseyev, 1996). In the nearby site of Postolovo, this till is bipartite and fills a glacial depression. Therefore, only the lower horizon of this till possibly represents the Narevian Glaciation, while the upper one corresponds to the till from Smolarka which, younger than the Brunhes/Matuyama boundary, may correlate with the Nidianian Glaciation in Poland.

In Poland the till of the Narevian (=Linge? or Menapian) Glaciation (Lindner and Siennicka-Chmielewska, 1998) is separated from the till of the Nidanian Glaciation by interglacial deposits from Kijewice near Przasnysz (Bałuk, 1991). Organic deposits from Ceteń (Fig. 1), occurring beyond the limit of the Narevian Glaciation, may be regarded as its equivalent, which, according to Lindner (1992), represents the Podlasian Interglacial (Fig. 10) along with the deposits from Kijewice. Organic deposits containing the recently discovered Augustovian floral succession (Janczyk-Kopikowa, 1996; Ber *et al.*, 1998) may also occupy the same stratigraphic position. The age of this succession corresponds either to the Bavelian Interglacial (Leerdam) or to the Cromerian II (Westerhoven) although such correlation is tentative (Ber, 2000; Marks, 2000). So far, this succession has not been noted in Belarus.

CONCLUSIONS

The data presented and issues discussed show that age determination of the oldest Scandinavian glaciations in mid-eastern Poland and western Belarus requires further biostratigraphic and palaeomagnetic investigations of the preglacial and Pleistocene deposits. Correlations have been established only for the two younger South Polish Glaciations (Sanian 2 = Berezinian *sensu stricto* and Sanian 1 = Yaseldinian) and the Ferdynandovian (=Byelovezhian) Interglacial which separates them. Dating of the older South Polish Glaciation (Nidanian), of the oldest glaciation (Narevian) and of the preceding interglacial requires further studies in the glaciated and the extraglacial area, including detailed palaeomagnetic research of thick Pleistocene deposits in NE Poland and NW Belarus in the former and of loess sections in SE Poland and NW Belarus in the latter.

Nevertheless, we consider that the Nidanian Glaciation was a distinct (first) South Polish Glaciation, and that it occurred slightly above or at the Brunhes/Matuyama boundary (780 ka), corresponding to Glacial A in the Netherlands. Therefore, the younger interglacial should correspond to the Cromerian II

(Westerhoven = Małopolanian = Korchevian), Cromerian III (Rosmalen = lower optimum of the Ferdynandovian = Byelovezhian *sensu stricto*) and Cromerian IV (Noordbergum = upper optimum of the Ferdynandovian = Mogilevian) of the Dutch researchers (Zagwijn, 1989, 1996). Furthermore, we do not exclude that the hitherto assumed range of the Scandinavian ice sheet during the oldest (Narevian) glaciation in western Belarus may be identified as the Nidanian Glaciation. The range of the oldest glaciation (Narevian) was smaller there, restricted practically to the present-day interfluve of Narew and Yaselda (Fig. 1). It should be separated from the South Polish glaciations by the Cromerian I (Wardenburg) Interglacial, deposits of which, along with the Bavelian complex, occur below the Brunhes/Matuyama boundary (Zagwijn, 1996) and display negative magnetic polarity. Another possibility suggests that during the oldest (Narevian) glaciation, the Scandinavian ice sheet advanced into mid-eastern Poland and southwestern Belarus in several distinct lobes, and so its range and sediments may be restricted to ancient glacial depressions, mainly of erosional origin. The analysis of several tens of cores and geologic cross-sections through the Pleistocene deposits in mid-eastern Poland and southwestern Belarus (Lindner and Astapova, 2000) reveals that tills of the Nidanian Glaciation typically represent the oldest glacial horizon outside these depressions i.e. on buried morphological elevations.

Acknowledgement. This work formed part of project BW-1484/6 “Stratigraphy of the Quaternary in mid-eastern Europe” (L. Lindner) and of the Polish-Belarussian Intergovernmental Project “Bio- and lithostratigraphy of Quaternary deposits of central and eastern Poland and western Belarus” (B. Marciniak, G. K. Khursevich and A. F. Sanko).

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