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The age and geological setting of Pleistocene glacigenic beds around the border between Poland and Belarus

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Pleistocene glacigenic sediments around the Polish-Belarussian border are correlated. Tills of the Narevian Glaciation are present in both countries, are those in Poland possibly being order. Within the older South Polish Glaciations (Elsterian) there is no definite evidence of deposits of the Nidanian Glaciation in Belarus, though the younger of these glaciations (Sanian 1 and 2), seem to correspond to the Berezinian Glaciation *sensu lato* (Yaseldinian and Berezinian *sensu stricto*). During the older Middle Polish Glaciations (Saalian), comprising two glaciations (Liviccian, Krznanian), the Scandinavian ice sheets occupied Polish territory only. Till of the Odranian + Wartanian Glaciation in Poland is correlated with till of the Dnieperian Glaciation in Belarus. There are similar deposits of the Vistulian Glaciation (Poozerian) in both countries.

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Key words: Poland, Belarus, Pleistocene, tills, stratigraphic correlation.

INTRODUCTION

This paper discusses the age, location and correlation of the Pleistocene glacial sediments (mainly tills) around the border between Poland and Belarus, considered in the context of interglacial deposits in this region.

Studies of the Pleistocene in both countries have hitherto used different methodological approaches as regards lithological description and biostratigraphical analyses, interpretation and conclusions. This paper attempts to overcome some of these differences. Four schematic geological cross-sections of the Pleistocene deposits in this area are given (Figs. 1–5). The different density of boreholes in each cross-section necessitated a varying horizontal scale. Two sections run meridionally: one cuts northeastern Poland from Augustów in the north to Biała Podlaska in the south (A–B at Figs. 1 and 2) and the other cuts western Belarus from Gozha in the north to Gvoznitsa in the south (G–H at Figs. 1 and 5). These sections are joined by two which run west-east, one from Białystok to Grodno (C–D at Figs. 1 and 3), the other from Biała Podlaska to Malorita (E–F at Figs. 1 and 4). All sections were constructed on the same basis as previously published north-south and west-east geological sections of the Quaternary sediments in Poland (*cf.* Lindner *et al.*, 1995).

The presented sections are based on a single exposure and 99 boreholes, most reaching pre-Quaternary strata. Some boreholes, particularly the very deep ones around Białystok and Sokółka, were drilled more than 30 years ago and hence their lithological description was often oversimplified. The Pleistocene sediments in this area range from about 280 m thick near Grodno and 220–240 m near Sokółka, to about 80 m near Biała Podlaska and 30–40 m near Malorita. Commonly they contain interglacial organic deposits.

The pattern of interbedding of tills and glaciofluvial deposits comprised the basis to identify and date the main glacigenic beds in this area. The stratigraphy of these beds in Poland involved the subdivision of the Pleistocene into 8 main glaciations separated by 7 interglacials (Lindner, 1988*a*, *b*, 1991; Baraniecka, 1990; Lindner and Marks, 1994, 1999; Lisicki, 1997; Lindner and Marciniak, 1998). The glacigenic deposits in Belarus were meanwhile assigned to 5 glaciations separated by 4 interglacials (Astapova, 1983, 1993; Astapova and Monkevich, 1990; Velichkevich *et al.*, 1996, 1997). Here we show that the Berezinian Glaciation *sensu lato* in Belarus equates with three South Polish Glaciations (Nidanian, Sanian

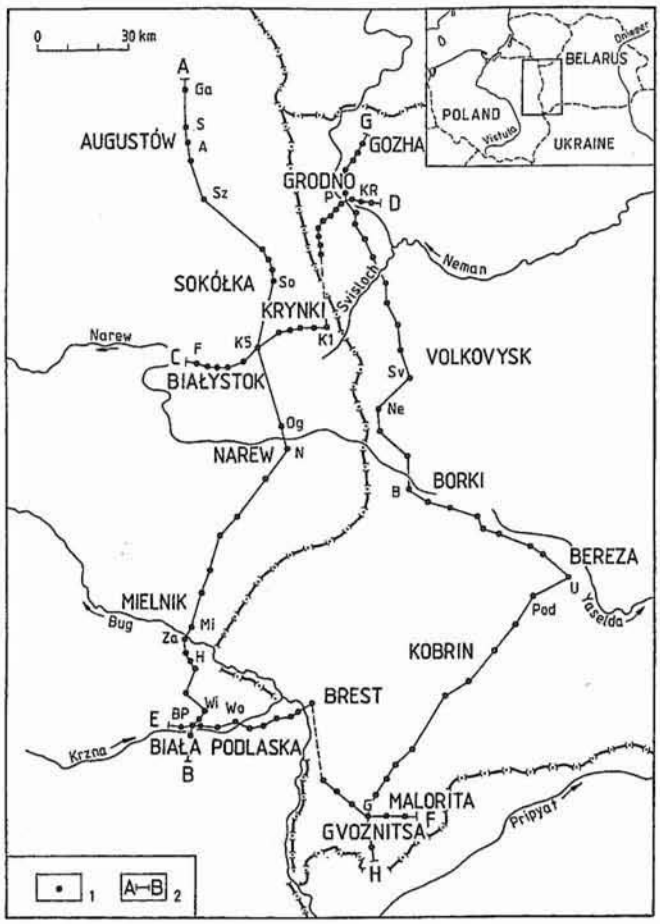


Fig. 1. Area studied in around the Poland–Belarus border

1 — boreholes and exposures: Ga — Gawrych-Ruda, S — Szczebra, A — Augustów, Sz — Sztabin, So — Sokółka, K5 — Kruszyniany 5, Og — Ogrodniki, N — Narew, Mi — Mielnik, Za — Zarzecze, H — Horoszki, Wi — Wilczyn, F — Fasty, K1 — Kruszyniany 1, KR — Kolodezhny Rov, BP — Biała Podlaska, Wo — Woskrzenice, G — Gvoznitsa, P — Princmanskaya, Sv — Svisloch, Ne — Nevbovichi, B — Borki, U — Uglany, Pod — Podosye; 2 — schematic geological sections (Figs. 2–5)

1, Sanian 2) and that the Scandinavian ice sheets did not reach Belarus during the older Middle Polish Glaciations (Liviecian, Krznanian).

GEOLOGICAL SETTING

GEOLOGICAL CROSS-SECTION AUGUSTÓW–BIAŁA PODLASKA

This cross-section contains the most identified glacigenic units. The oldest is a till assigned to the Narevian Glaciation — Na (= nr). It occurs in several boreholes at depth of 150–160 m in the vicinity of Augustów (Ber, 1996), is up to 20 m thick and is underlain by Tertiary (Paleogene?) sands and marls. This till is overlain by later Narevian silts and sands at Szczebra (S at Figs. 1 and 2) and/or by interglacial organic sediments showing two climatic optima, assigned to the Augustovian Interglacial (Janczyk-Kopikowa, 1996; Ber *et al.*, 1998), which correlates with the Podlasian Interglacial in earlier schemes (Lindner and Yelovicheva, 1998).

Tills of the Narevian Glaciation — Na (= nr) contain more carbonate clasts than crystalline ones, and include abundant dolomites and local rocks (to 32.2%), with petrographic coefficients: K/W = 0.86, O/K = 1.23, A/B = 1.2 and Dp/Wp = 0.46 at Szczebra (Ber, 1996) and K/W = 1.27, O/K = 0.94 and A/B = 0.76 at Krzyżewo in which O are sedimentary rocks, K — crystalline rocks and quartz, W — carbonate rocks, A — rocks non-resistant to weathering, and B — resistant to weathering (Kenig, 1998), to the west of the cross-section. Among heavy minerals there are abundant garnets and amphiboles (Ber *et al.*, 1998).

Around Sokółka this till forms the basal part of the Pleistocene succession and occurs at a depth 200–220 m (So at Fig. 2). It is 5–10 m thick and underlain by Tertiary sands. At Kruszyniany 5 (K5) it fills a glacigenic depression, resting on Cretaceous deposits (Fig. 2). Further to the south it occurs at a depth of 60–80 m and forms isolated patches, either on buried elevations (between Narew and Mielnik) or within glacigenic depressions (near Biała Podlaska). This till has generally been assigned to the older stadial of the South Polish Glaciation (Nowicki, 1965, 1969; Ber, 1970), and only Różycki (1961, 1967), followed by Nowak (1971), correlated it with the Podlasian Glaciation (= Narevian).

A younger glacigenic unit in this area, correlated with the Nidanian Glaciation — Ni (the first South Polish Glaciation), is best recognised near Augustów (A at Fig. 2), where it occurs at a depth of 120–140 m (Ber, 1996) and is represented by a till underlain by glaciofluvial sands with gravel. This till, underlain by sediments of the Podlasian Interglacial — Po (= Augustovian — A), contains more crystalline rock fragments than carbonate ones, with a content of local rocks of to 4.9–5.8% (Ber, 1996). At Szczebra, petrographic coefficients of this till are: O/K = 1.70, K/W = 0.61 and A/B = 1.58 (Kenig, 1998). Among heavy minerals there are slightly more garnets and less amphiboles than in the older till but no biotite occurs (Ber *et al.*, 1998).

Further to the south there is a relatively continuous bed of this till. At Kruszyniany 5 it is at its deepest, thus resting on buried alluvium of the Podlasian Interglacial — Po (= Augustovian — A) and it is preserved in a similar setting near Biała Podlaska (Fig. 2). In both these regions it has been treated previously as a representative of a stadial of the South Polish Glaciation (Nowicki, 1969; Nowak, 1971), latterly assigned to the Nidanian Glaciation, particularly in papers on the geology of Biała Podlaska (Lindner, 1988*b*; Nitychoruk, 1994).

Tills of the younger South Polish Glaciations (Sanian 1 — S1, Sanian 2 — S2 = Wilgian), previously assigned to stadials of the South Polish Glaciation (Nowicki, 1965, 1969; Ber, 1970; Nowak, 1971), are preserved at Sokółka at a depth of 150–170 m, in the Narew–Mielnik and Mielnik–Biała Podlaska regions at a depth of 30–40 m (Fig. 2). Near Biała Podlaska petrographic coefficients of the lower till are equal to: O/K = 1.54, K/W = 0.76 and A/B = 1.09 (Kenig, 1998). These tills and the accompanying glaciofluvial sands and gravels, and particularly the younger till, are covered by silty glaciolacustrine deposits, widespread in northeastern Poland and northwestern

Belarus (Marks and Pavlovskaya, 1998). At Gawrych-Ruda (Ga) near Augustów and at Wilczyn (Wi) near Biała Podlaska, these silts and sands are overlain by organic sediments of the Mazovian Interglacial — M (= Alexandrian — al) with its characteristic floristic succession (Janczyk-Kopikowa in: Ber, 1996; Bińka *et al.*, 1997).

The younger glacigenic unit in this cross-section comprises deposits of the Liviecian Glaciation — L (Fig. 2) which, according to Lindner and Marks (1999), is the first of the three Middle Polish Glaciations. Near Augustów a till of this glaciation is up to 12 m thick and is preserved at depths of 80–120 m, overlain by silts (Ber, 1996). Petrographic coefficients of this till are: K/W = 1.27, O/K = 0.83, A/B = 1.18 and Dp/Wp = 0.33, and it contains up to12.8% of local Paleogene rocks (other local rocks: 2.3%). At Gawrych-Ruda it is overlain by organic sediments, presumably of the Zbójnian Interglacial — Z. Near Sokółka, a till of the Liviecian Glaciation — L forms a buried elevation and seems to occur as far as the Narew river valley (Fig. 2), therefore indicating a limit of the Scandinavian ice sheet during this glaciation.

A till of the Krznanian Glaciation — Krz (Fig. 2) is, according to Lindner and Marks (1999), an equivalent of the second Middle Polish Glaciation. This till is preserved at depths of 80–100 m near Augustów where it is a dozen metres thick, and at depths of 20–80 m between Sokółka and Biała Podlaska. At its southernmost limit the till does not cross the Lower Krzna river valley, indicating the maximum extent of the Scandinavian ice sheet. Previously this till was connected with the older (pre-maximum or maximum) stadial of the Middle Polish Glaciation (Nowicki, 1965, 1969; Ber, 1970; Nowak, 1971). At Narew (N at Fig. 2) this till is overlain by sands containing organic material, presumably of the Lubavian? Interglacial — Lu? (Kupryjanowicz *et al.*, 1999).

The third Middle Polish Glaciation, at present treated as the Wartanian Glaciation with its maximum, the Odranian Stadial (Lindner and Marks, 1999), is represented in this area by a locally bipartite till (O + W = dn at Fig. 2). At Szczebra near Augustów this is the youngest till, with the petrographic coefficients K/W = 1.47, O/K = 0.82, A/B = 1.36 and Dp/Wp = 0.28, indicating a predominance of crystalline over carbonate rocks (Ber, 1996). At Krzyżewo to the west of Augustów, petrographic coefficients of this till are O/K = 1.96, K/W = 0.54 and A/B = 1.89 (Kenig, 1998). In the middle part of the section there are distinctly less garnets, accompanied by more amphiboles, while biotite is absent (Ber *et al.*, 1998). According to Ber (1996), this till represents the Odranian Glaciation, and it occurs at depths of 12–30 m.

The bipartite nature of this till near Mielnik and Sokółka (Fig. 2), and its occurrence at surface outcrop between Sztabin (Sz) in the north to Biała Podlaska in the south, suggests oscillations during ice sheet retreat, expressed in this part of Poland by at least two or three distinct stadial advances. Thick glaciofluvial sediments beneath this till at Kruszyniany 5 (Fig. 2) and Zarzecze (Za at Fig. 2) indicate meltwater erosion, leading to the development of deep glacigenic channel-like depressions.

The youngest glacigenic bed is relates to the Vistulian Glaciation — V (= Poozerian — pz) and is preserved in the vicinity of Augustów only (Fig. 2) where it delimits a maximum extent of the Scandinavian ice sheet. A till, several metres thick, represents it together with underlying and overlying glaciofluvial sediments. At Żubrynek near Gawrych-Ruda to the north-west of Augustów (outside the cross-section shown), petrographic coefficients of this till are O/K = 2.14, K/W = 0.53 and A/B = 1.87 (Kenig, 1998).

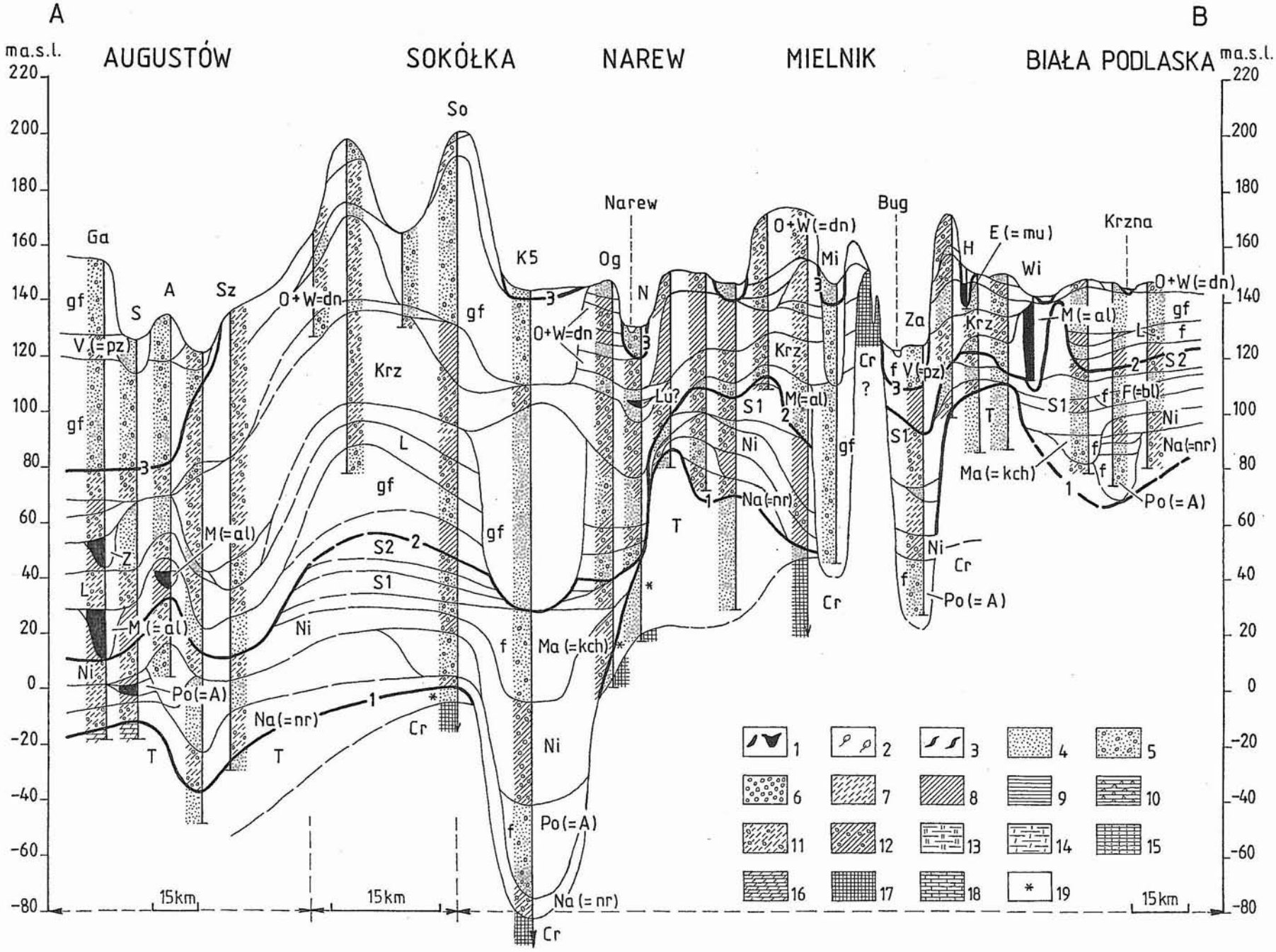
GEOLOGICAL CROSS-SECTION BIAŁYSTOK–GRODNO

A till of the Narevian Glaciation — Na (= nr), noted near Białystok at depths of 170–220 m is the oldest glacigenic bed in this cross-section (Fig. 3). It is up to 10 m thick and fills the bottoms of deep glacigenic depressions eroded in the Tertiary sands or in Cretaceous rocks. This till has been generally correlated with the older stadial of the South Polish Glaciation (Nowicki, 1969), named the Podlasian (Różycki, 1961) and then the Narevian Glaciation (Różycki, 1978). Only Tsapenko and Makhnach (1959) assigned it to the older glaciation. At Kruszyniany 5 (Figs. 1 and 3), this till is overlain by alluvium of the Podlasian Interglacial — Po (= Augustovian — A).

A till of the Narevian Glaciation — nr (= Na) was noted also in the vicinity of Grodno. Together with the accompanying glaciofluvial sands and gravels it occurs at depths of 115–220 m (Fig. 3). This till is up to 90 m thick and overlies Jurassic limestones in a deep glacial depression and Cretaceous rocks in a shallower depression eroded by meltwaters (possibly a subglacial tunnel valley). The depressions are fragments of two systems (Sopotskinskovo and Losenskovo), formed during the earliest ice sheet advances. Lineaments on satellitary photos (Azhgirevich *et al.*, 1990) indicate that the former depression runs NE–SW (from Vilnius to Druskeninkai) and the other NW–SE (from Grodno to Mosty).

In the vicinity of Grodno a till of the Narevian Glaciation — nr (= Na) contains a characteristic set of heavy minerals, contents of hornblende, garnets, ilmenite, glauconite, epidote, zircon, leucoxene, pyrite, tourmaline each exceeding 10% (Astapova, 1989). The coefficient of Scandinavian rocks is < 1, calculated as the ratio of Scandinavian minerals (hornblende, biotite, pyroxene) to local minerals (glauconite, siderite, pyrite, dolomite, phosphates) in the fraction 0.25–0.1 mm. The heavy mineral composition of this till can be denoted by the symbol HEGIP (hornblende, epidote, garnet, ilmenite and pyrite). The coefficient of crystalline rocks content is equal to 0.3–0.5, based on examination of the 3–5, 5–7 and 7–10 mm fractions. This coefficient is a ratio of the total of crystalline rock fragments (granite, *etc.*) to the total of sedimentary rock fragments (sandstones, dolomites, limestones and others).

In the vicinity of Białystok these deposits are overlain by 3 younger glacigenic units, corresponding to the South Polish Glaciations (Nidanian — Ni, Sanian 1 — S1, Sanian 2 — S2). Each is represented by a single bed, commonly separated from the others by sands with gravels or by silts (Fig. 3). Only at


A
B
m a.s.l.
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Kruszyniany 5 are there buried alluvial deposits of the Malopolanian Interglacial — Ma (= Korchevian — kch) separating the glacial deposits Nidanian — Ni and Sanian 1— S1. In total, the three glacigenic units of the South Polish Glaciations (Berezinian *sensu lato*) are about 100 m thick and occur at depths of 50–140 m. All units in this complex were correlated previously with stadials of the South Polish Glaciation (Nowicki, 1965, 1969).

In the vicinity of Grodno there is a similar glacigenic complex of the Berezinian Glaciation *sensu lato* — br *s.l.* (= Sanian 1 + Sanian 2 — S1 + S2). It is composed of 3–4(?) largely amalgamated tills, accompanied by sands and gravels (Fig. 3). These deposits are also to about 100 m thick and occur at depths of 50–140 m. At Kruszyniany 1 (K1) there is also a buried alluvial unit, set in the upper part of the Berezinian complex, and representing a palaeovalley of the Ferdynandovian Interglacial — F (= Byelovezhian — bl).

Deposits of the Berezinian Glaciation *sensu lato* — br *s.l.* (= Sanian 1 + Sanian 2 — S1 + S2) near Grodno contain abundant amphiboles (17–25%), hornblende, actinolite and tremolite, and also pyroxenes (2–3%). Among local minerals (31.6%) in tills there are: glauconite, dolomite, pyrite, phosphates and siderite. From a mineralogical-petrographical point of view these tills are similar to the till of the Narevian Glaciation — nr (= Na). The Belarussian authors denoted them with the symbol HGIE (hornblende, garnet, ilmenite and epidotes) and HGIF (hornblende, garnet, ilmenite and phosphate). The coefficient of Scandinavian rocks in these tills is equal to 1. In the Grodno area these tills contain commonly clasts of Silurian limestones with brachiopods, and also traces of numerous glaciodynamic and glaciotectonic deformations. The age of these tills was determined by reference to the overlying organic deposits of the Alexandrian Interglacial — al (= Mazovian — M) for example in the Kolodezhny Rov exposure (Figs. 1 and 3) (Yakubovskaya, 1976).

The youngest bed in the vicinity of Białystok and Grodno is represented by a till at the land surface accompanied by sands and gravels of the Odranian + Wartanian Glaciation — O + W (= Dnieperian Glaciation — dn). This till is 5–40 m thick (Fig. 3). In the Grodno area it contains some local material (to 10%), and the coefficient of crystalline rock content is over 2. Heavy minerals are predominantly hornblende, garnets and ilmenite (in total 60–90%). Boulders in end moraines of the Dnieperian Glaciation — dn (= Odranian + Wartanian — O + W) in this area are dominated by material from central Scandinavia, particularly from northern and central Sweden, the Åland Islands and the bottom of the Baltic Sea (Astapova, 1981).

GEOLOGICAL CROSS-SECTION BIAŁA PODLASKA–MALORITA

In the vicinity of Biała Podlaska a till of the Narevian Glaciation — nr (= Na) represents the oldest glacigenic bed. It occurs at depths of 75–> 82 m (Fig. 4). Tertiary (Oligocene) sands in a glacial depression underlie the till. This till is dissected by a buried river valley of the Podlasian Interglacial — Po (= Augustovian — A) and overlain by a glacigenic bed of the Nidanian Glaciation — Ni comprising sands, silts and till. The till occurs at depths of 50–60 m, is 4–16 m thick and locally directly underlain by Tertiary sands.

In this area the overlying glacigenic bed is represented by a till of the Sanian 1 Glaciation — S1, to 8 m thick and occurring at depths of 40–50 m (Fig. 4). This till is locally dissected by buried valleys of the Ferdynandovian Interglacial — F (= Byelovezhian — bl) and overlain by the succeeding glacigenic unit, of the Sanian 2 Glaciation — S2 (= Berezinian *sensu stricto* — br *s.s.*). This unit is dominated by a till, several to 30 m thick. Near Biała Podlaska the top of this till occurs at depths from several to over 30 m. Its stratigraphical setting is constrained by organic deposits of the Mazovian Interglacial — M (= Alexandrian — al), with palynological (Krupiński *et al.*, 1988) and diatomological (Marciniak and Lindner, 1995; Marciniak, 1998) analyses at Biała Podlaska (BP at Figs. 1 and 4), and detailed palaeobotanical analyses at Woskrzenice (Wo at Figs. 1 and 4; Bińka and Nitychoruk, 1995).

The youngest glacigenic bed in the vicinity of Biała Podlaska corresponds to the Odranian + Wartanian Glaciation — O + W (= Dnieperian — dn). It is represented by a relatively thin (to 3–4 m) discontinuous till and by accompanied silts and sands and glaciofluvial sands with gravels (Fig. 4; Lindner, 1996). In the Bug river valley these deposits are dissected to the Tertiary and the incision is filled with Late Pleistocene and Holocene alluvium.

Around Malorita there are two Pleistocene glacigenic beds only (Fig. 4). The older is represented by a till of the Berezinian Glaciation *sensu stricto* — br *s.s.* (= Sanian 2 — S2). This till, in spite of its mosaic preservation, is to 25 m thick and occurs at depths of 30–50 m, directly on Cretaceous rocks (Fig. 4). During this glaciation (glaciations?) a deep and narrow glacigenic

Fig. 2. Schematic geological cross-section A–B of the Quaternary sediments and their substrate from Augustów to Biała Podlaska; by L. Lindner based on data of Rühle and Zwierz (1961), Nowicki (1969), Ber (1970, 1996), Nowak (1971), Lindner (1988*b*, 1996), Nitychoruk (1994), Ber *et al.* (1997), Bińka *et al.* (1997) and Kupryjanowicz *et al.* (1999)

Lithology: 1 — organic deposits, 2 — plant detritus, 3 — humus, 4 — sands, 5 — sands with gravels, 6 — gravel and boulders, 7 — sandy silt, 8 – claycy silt, 9 — silt, 10 — diatomaceous silt, 11 — sandy till, 12 — till, 13 — clay, 14 — claystones, 15 — sandstones, 16 — marl, 17 — chalk, 18 — limestone, 19 — glauconite; **origin of sands and gravels**: f — fluvial, gf — glaciofluvial; **age**: Cr — Cretaceous, T — Tertiary, Na (= nr) — Narevian Glaciation, Po (= A) — Podlasian Interglacial (= Augustovian), Ni — Nidanian Glaciation, Ma (= kch) — Malopolanian Interglacial (= Korchevian), S1 — Sanian 1 Glaciation, F (= bl) — Ferdynandovian Interglacial (= Byelovezhian), S2 — Sanian 2 Glaciation, M (= al) — Mazovian Interglacial (= Alexandrian), L — Livieeian Glaciation, Z — Zbójnian Interglacial, Krz — Krznanian Glaciation, Lu? — Lubavian Interglacial?, O + W (= dn) Odranian + Wartanian Glaciation (= Dnieperian), E (= mu) — Eemian Interglacial (= Muravian), V (= pz) — Vistulian Glaciation (= Poozerian); **top of**: **1** — Tertiary, **2** — South Polish Glaciations (Berezinian *sensu lato*), **3** — Middle Polish Glaciations (Dnieperian); explanations of borehole symbols see Fig. 1

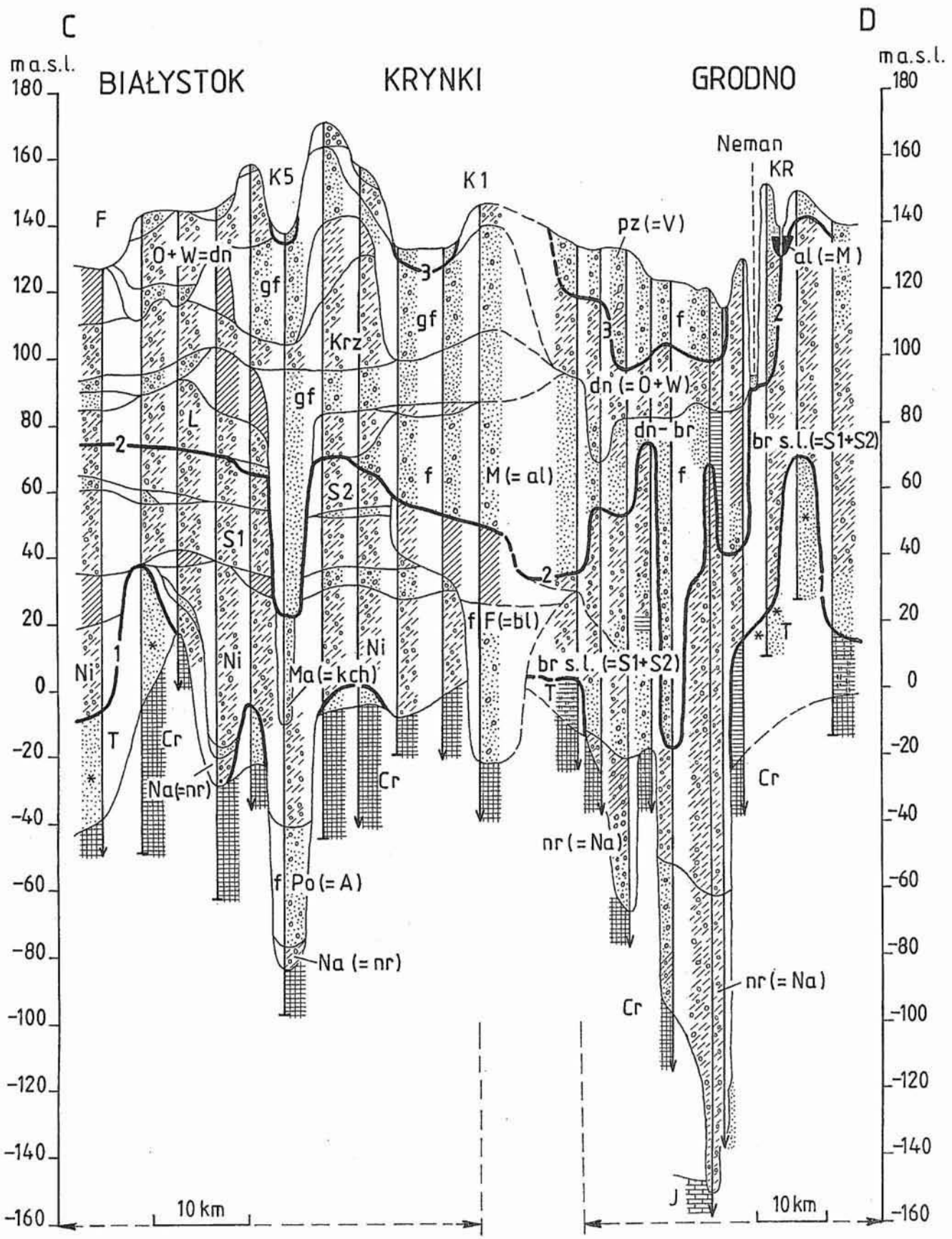

Fig. 3. Schematic geological cross-section C–D of the Quaternary sediments and their substrate from Białystok to Grodno; by L. Lindner for Poland, based on data of Nowicki (1969), and by S. D. Astapova for Belarus

J — Jurassic, nr (= Na) — Narevian Glaciation, br *s.l.* (= S1 + S2) — Berezinian Glaciation *sensu lato* (= Sanian 1 + Sanian 2), br-dn — Berezinian *sensu lato*-Dnieperian Glaciations, al (= M) — Alexandrian Interglacial (= Mazovian), dn (= O + W) — Dnieperian Glaciation (= Odranian + Wartanian), pz (= V) — Poozerian Glaciation (= Vistulian); for other explanations see Figs. 1 and 2

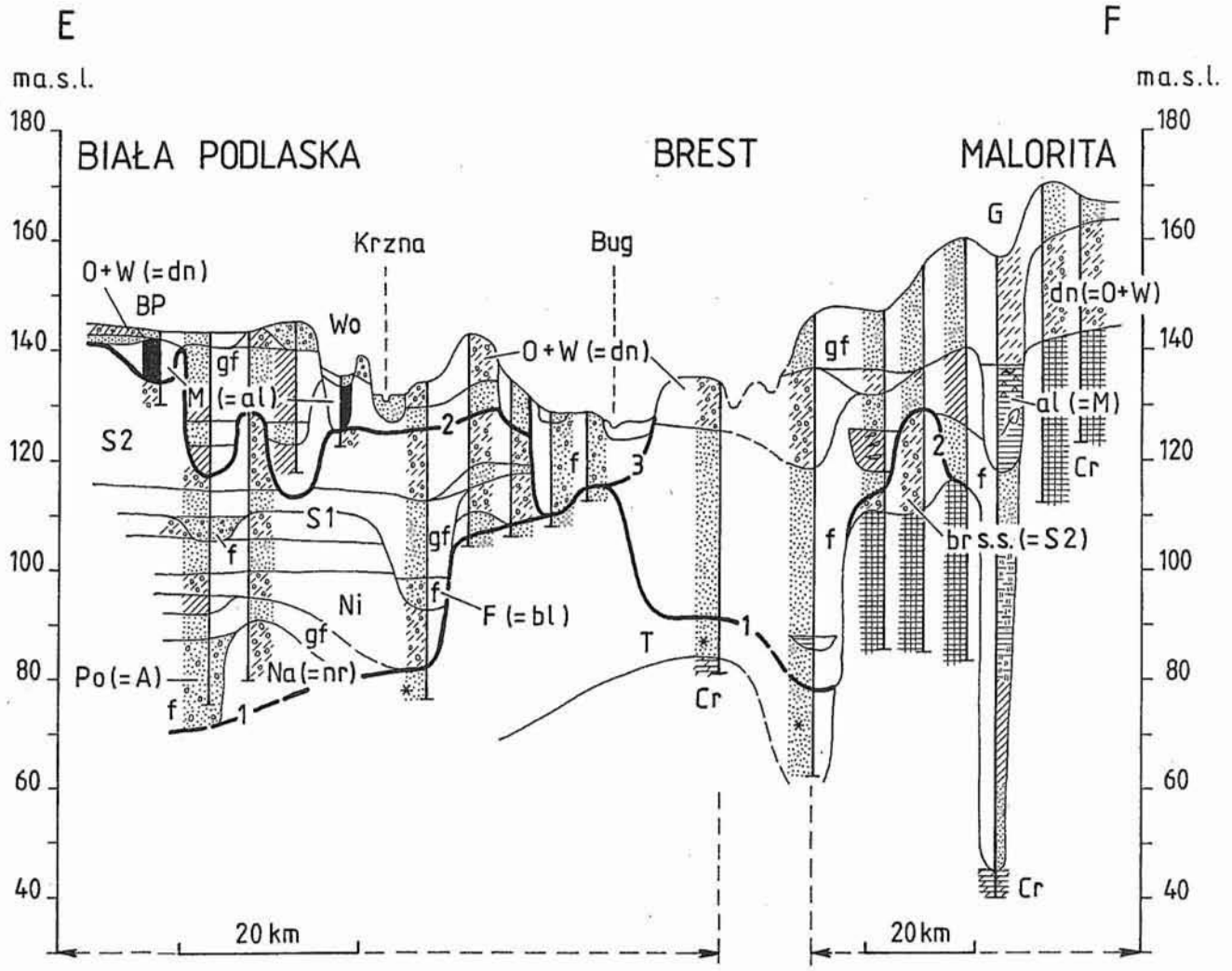

Fig. 4. Schematic geological cross-section E–F of the Quaternary sediments and their substrate from Biała Podlaska to Malorita; by L. Lindner for Poland, based on data of Rühle (1952), Nowak (1971), Lindner (1988*b*, 1996), Nitychoruk (1994), Bińka and Nitychoruk (1995), Lindner and Marciniak (1997, 1998), and by S. D. Astapova for Belarus

br *s.s.* (= S2) — Berezinian Glaciation *sensu stricto* (= Sanian 2); for other explanations see Figs. 1–3

tunnel-like depression was formed, noted at Gvoznitsa (G at Figs. 1 and 4) and filled with sands, silts and clays. It was occupied by a lake, with the deposition of diatomaceous silts which contain a typical floristic succession of the Alexandrian Interglacial — al (= Mazovian — M) (Gruzman *et al.*, 1975). A deep palaeovalley near Brest, incised in to Tertiary (Oligocene?) sands, is presumably of the same age.

This valley and the interglacial lake sediments are overlain by the youngest glacigenic bed of the Dnieperian Glaciation — dn (= Odrian + Wartanian — O + W), represented by a till, locally at the land surface and up to 25 m thick, and by ice-dammed silts and glaciofluvial sands. The deposits in end moraines the Dnieperian Glaciation and erratics on a land surface near Malorita, contain abundant flint, phosphorites and organic limestones in addition to crystalline material (Astapova, 1987). They were deposited by an ice sheet which advanced mainly from northwestern Finland, the Åland Islands and the Baltic Basin and to a smaller degree (to 13% of the material), from northern and central Sweden.

GEOLOGICAL CROSS-SECTION GOZHA–GVOZNITSA

Near Gozha (to the north of Grodno) the oldest glacigenic bed is represented by patches of till of the Narevian — nr (= Na) Glaciation, up to 30 m thick and occurring at depths of 180–210 m on the southern slope of a glacial depression (Fig. 5). The latter reaches Grodno and is part of a more general depression of the base of the Quaternary, running NW–SE from Grodno to Mosty (Azhgirevich *et al.*, 1990). The base of this depression is incised through Tertiary sands in to Cretaceous rocks.

Further to the south, a glacigenic unit of the Narevian Glaciation — nr (= Na) is preserved between the Svisloch river valley and Borki (B at Figs. 1 and 5), where it is represented by silts and sands with gravel and by a till. These deposits are preserved mainly on a glacigenic elevation, composed of Tertiary sands underlain by the Cretaceous rocks. The till is 12–25 m thick and occurs at depths of 80–160 m (Fig. 5). Near Borki this till and the locally underlying silts are up to 40 m thick and occur at

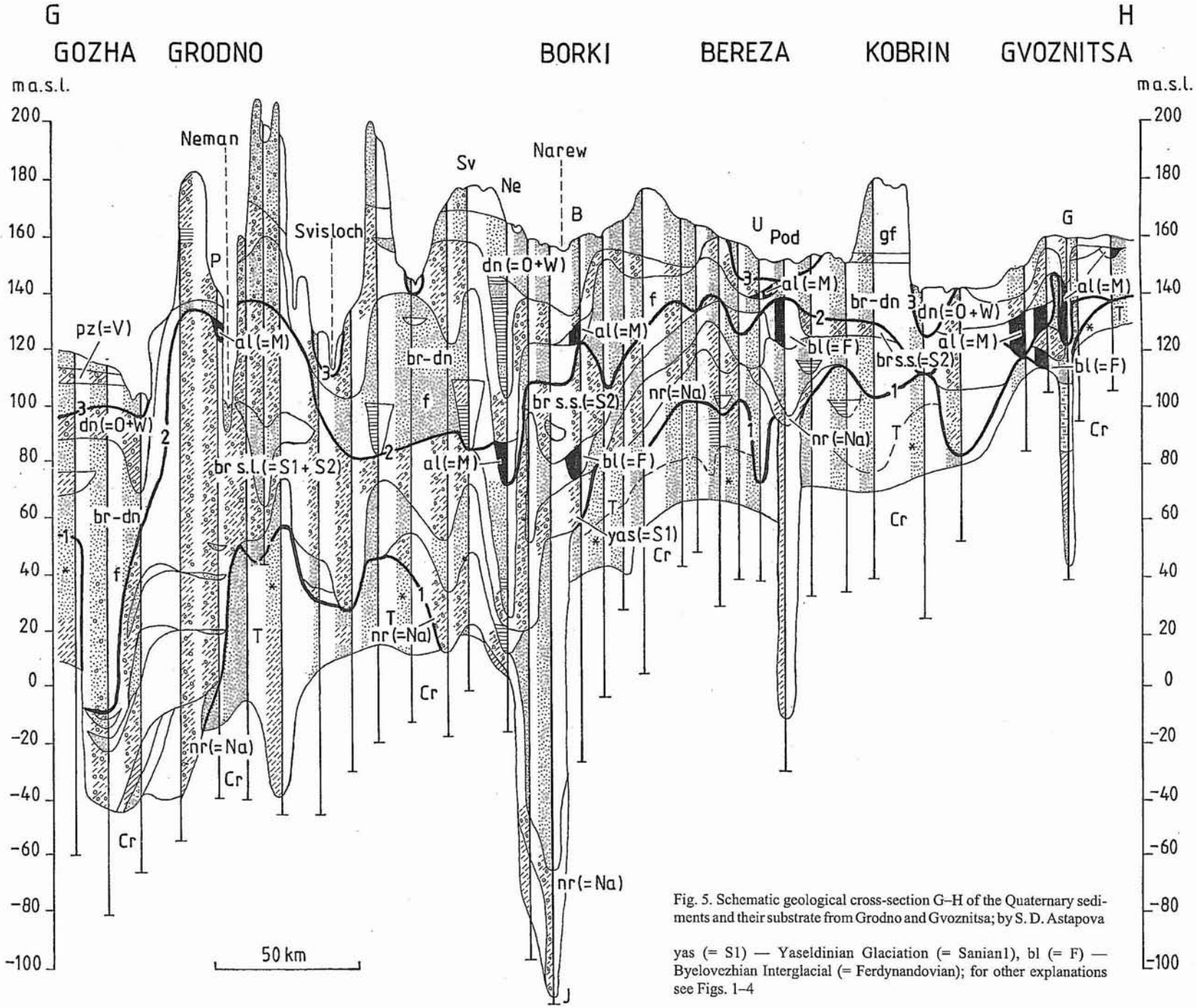

Fig. 5. Schematic geological cross-section G–H of the Quaternary sediments and their substrate from Grodno and Gvoznitsa; by S. D. Astapova

yas (= S1) — Yaseldinian Glaciation (= Sanian1), bl (= F) — Byelovezhian Interglacial (= Ferdynandovian); for other explanations see Figs. 1–4

depths of 140–210 m. They fill a glacigenic depression, generally corresponding to the present valley of the Upper Narew river.

Further to the south a glacigenic unit of the Narevian Glaciation — nr (= Na) is composed of sands and silts overlain by till. Between Borki and Bereza these deposits are 20–40 m thick and occur at depths of 30–90 m. Only at Podosye (Pod at Figs. 1 and 5) silts (about 100 m thick) underlie these deposits, presumably inside a deep and narrow meltwater depression, the base of which occurs at depths of about 150 m. In the same section this glacigenic unit is overlain by organic deposits of the Byelovezhian Interglacial — bl (= Ferdynandovian — F).

Borehole data indicate that the Scandinavian ice sheet of the Narevian Glaciation advanced to the Kobryin area (Figs. 1 and 5). In the Narew and Yaselda waterfluve the coefficient of the Scandinavian rocks in the till is < 1 and there is a significant content of pyrite, dolomite and siderite. The mineralogy is denoted by the symbol GRIS (garnet, rutile, ilmenite and siderite).

A younger glacigenic unit is composed of deposits of the Berezinian Glaciation *sensu lato* — br *s.l.* (= Sanian 1 + Sanian 2 — S1 + S2). In the northernmost part of the section near Gozha they are 30–90 m thick and occur at depths of 50–150 m, filling a glacigenic depression with glacial rafts of Cretaceous rocks. Near Grodno a till is 40–130 m thick, with traces of bi- or tripartity due to the presence of intertill sands and clays which may total 20 m or more. Organic deposits of the Alexandrian Interglacial — al (= Mazovian — M) at the top of the youngest till at Prinemanskaya (P at Figs. 1 and 5), determine the age of the underlying tills.

Further to the south a till of the Berezinian Glaciation *sensu lato* — br *s.l.* (= Sanian 1 + Sanian 2 — S1 + S2) is considerably thinner (to about 10 m) at Nevbovichi (Ne at Figs. 1 and 5), thickening near Borki. At Borki (Figs. 1 and 5) the till is divided by organic deposits of the Byelovezhian Interglacial — bl (= Ferdynandovian — F). Therefore, the older part of this glaciation can be distinguished as a separate Yaseldinian Glaciation — yas, correlated with the Nidanian — Ni or Sanian 1 Glaciation — S1 (Nazarov, 1995). Further to the south, deposits of the Byelovezhian Interglacial underlie the younger till of the Berezinian Glaciation *sensu stricto* — br *s.s.*, both near Bereza at Podosye (Pod at Figs. 1 and 5) and near Gvoznitsa.

The succeeding glacigenic unit in western Belarus is composed of 1–2 tills, in total 5–40 m thick, of the Dnieperian Glaciation — dn (= Odrian + Wartanian — O + W), in the northern and central part of the section. Between Grodno in the north and Gvoznitsa in the south, these tills are mostly exposed at the land surface or covered by thick (20–30 m) glaciofluvial sands and gravels. The age setting of these tills is constrained by the underlying organic deposits of the Alexandrian Interglacial — al (= Mazovian — M), noted at Nevbovichi (Ne at Figs. 1 and 5), Borki (B at Figs. 1 and 5), Uglany (U at Figs. 1 and 5) and Gvoznitsa (G at Figs. 1 and 5). In many places these deposits are accompanied by interglacial alluvium, composed of sands with subordinate silts and clays, which also underline tills of the Dnieperian Glaciation — dn in western Belarus.

The youngest glacigenic unit in this section is represented by deposits of the Poozerian Glaciation — pz (= Vistulian — V). They outcrop in the north near Gozha, where they form a separate till, 2–7 m thick, overlain by sands and underlain by

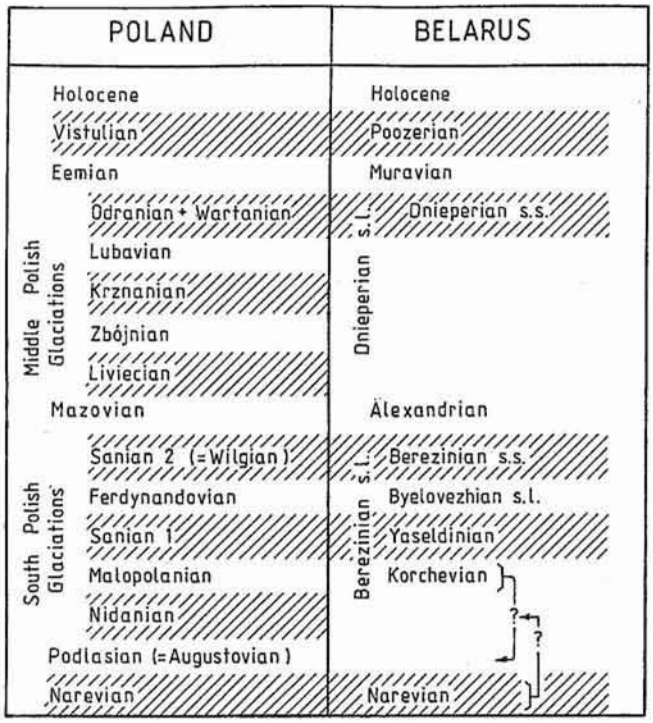

Fig. 6. Attempted correlation of Pleistocene glacigenic beds (hatched) around the border between Poland and Belarus

glaciofluvial sands (Fig. 5). These deposits are up to 20 m thick. The till contains much calcite and dolomites in the gravel fraction and also hornblende, pyroxene and biotite.

FINAL REMARKS

This paper attempts an initial spatial correlation of the Pleistocene deposits around the border between Poland and Belarus. The setting and age of the two youngest glacigenic units, assigned to the Vistulian (= Poozerian) and Odranian + Wartanian (= Dnieperian) glaciations, was most easily determined (Fig. 6). These deposits occur at outcrop in Poland and Belarus, and their geology and geomorphology has been studied for many years. The age and correlation of the deeper glacigenic beds, accessible mostly in the boreholes only, was more difficult to ascertain.

Starting from the top, in western Belarus there are no deposits that could correspond to the glacigenic deposits of the Krznanian and Liviecian glaciations, as well as to the Lubavian and Zbójnian interglacials in Poland. The Scandinavian ice sheets during these glaciations presumably only reached Poland and land to the north of Belarus. Such a conclusion is supported by recent studies in Lithuania (Baltrūnas, 1995; Kondratienė, 1996; Ber *et al.*, 1997; Lisicki, 1998) and Russia (Bolikhovskaya and Sudakova, 1996).

The glacigenic deposits correlated in Poland with the South Polish Glaciations (Nidanian, Sanian 1, Sanian 2 = Wilgian) seem to have their equivalents in two glaciations i.e. Berezinian *sensu lato* (= Sanian 2) and Yaseldinian (= Sanian 1). The ice

sheet of the Nidanian Glaciation therefore either did not reach Belarus or its deposits have not been identified there yet. This problem is related to that of the mutual age relations of the three oldest interglacials in Poland and Belarus (Korchevian, Podlasian = Augustovian, Malopolanian). Assuming that in Belarus the oldest of these is the Korchevian Interglacial and in Poland the Podlasian Interglacial (= Augustovian), we conclude that the oldest of Pleistocene glacigenic unit in both countries seems referable to the Narevian Glaciation. But, it is also possible that the Narevian Glaciation in Belarus corresponds to the Nidanian Glaciation in Poland (Lindner and Yelovicheva, 1998).

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