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Evolution of Early and Middle Pleistocene river valley systems in Polish-Ukraine-Belarus cross-border areas based on geological and malacological proxies

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The geological setting of the Bug–Pripyat interfluve and the close proximity of the source of the Pripyat River to the well-developed Middle Bug River valley suggest that these rivers may have been connected in the past. Analysis of geological cross-sections around the Polish-Ukraine-Belarus cross-border areas together with study of associated Pleistocene palaeoflora shows that buried alluvial deposits of the proto-Bug and proto-Pripyat clearly represent the Preglacial (MIS 103-23), Podlasian/Turskian-Donian/Brest Interglacial (Cromerian I-II; MIS 21-17) and the Mazovian/Likhvinian/Alexandrian Interglacial (Holsteinian; MIS 11c). Their elevated position in mid-eastern Poland suggests the possibility of accumulation by proto-Bug waters flowing eastwards, which determined the formation and development of the lower-lying proto-Pripyat valley system in northwestern Ukraine at those times. The occurrence of the Ponto-Caspian species *Lithoglyphus naticoides* (C. Pfeiffer, 1828), *Borysthenia naticina* (Menke, 1845) and *Corbicula fluminalis* (O.F. Müller, 1774) in the mollusc assemblages of the Mazovian/Likhvinian/Alexandrian Interglacial implies that the main watershed between the Baltic Sea and the Black Sea drainage basins might have been situated in the northern part of the area studied. Presumably its main part was drained by the waters of the proto-Bug catchment connected with the proto-Pripyat and flowing farther to the east towards the Dnieper River entering the Black Sea.

Key words: Early and Middle Pleistocene, buried river valleys, Bug–Pripyat interfluve, Polish-Ukraine-Belarus cross-border areas, molluscs.

INTRODUCTION

Because the near-surface occurrence of interglacial fluvial deposits is extremely rare (e.g., Terpiłowski et al., 2014; Zieliński et al., 2016), palaeogeographic analysis of the main river valleys in the Early and Middle Pleistocene has been mostly based on research boreholes and regional geological cross-sections. There has been much focus on the Mazovian river network. The drainage systems of the proto-Warta/Odra, proto-Noteć, proto-Vistula and proto-Neman were associated with deglaciation following the Sanian 2/Okian/Berezinian Glaciation (Elsterian; MIS 12) and changes in the level of the Holsteinian Sea in the Baltic Basin, resembling (especially in central Poland) the present river pattern (e.g., Straszewska, 1968; Baraniecka et al., 1978; Lindner et al., 1982; Karabanov, 1987; Pavlovskaya, 1998; Marks and Pavlovskaya, 2003; Marks, 2005). Some substantial differences in Mazovian runoff have been postulated for mid-eastern Poland and western Belarus, where flow to the south-west and west has been suggested (e.g., Mander, 1973; Pavlovskaya, 1998; Marks and Pavlovskaya, 2003; Marks, 2005). Moreover, Marks and Pavlovskaya (2003) showed the westward position of the watershed between the Baltic and the Black See drainage basins compared to the present one. However, this reconstruction did not encompass the Polesie region.

Our studies on the Quaternary of the Polish-Ukraine-Belarus cross-border areas were initiated in the 1980s and 1990s. Fruitful cooperation with colleagues from Ukrainian, Belarusian and Lublin scientific centres has resulted in many publications, which were mostly devoted to Pleistocene stratigraphy and Scandinavian glacial limits (e.g., Szołkoplyas et al., 1985; Lindner, 1988; Lindner et al., 1985, 1991b, 1998; Lindner and Yelovicheva, 1998). It was also a time when the first views emerged of the possibility of palaeogeographic reconstruction of this region in the Early and Middle Pleistocene, the development and course of the interglacial river and glacial tunnel valleys (Boguckij et al., 2002) as well as the runoff of proglacial and extraglacial waters (Lindner et al., 2004). These research directions have continued in the last decade (e.g., Gozhik et al., 2012; Lindner, 2009, 2016).

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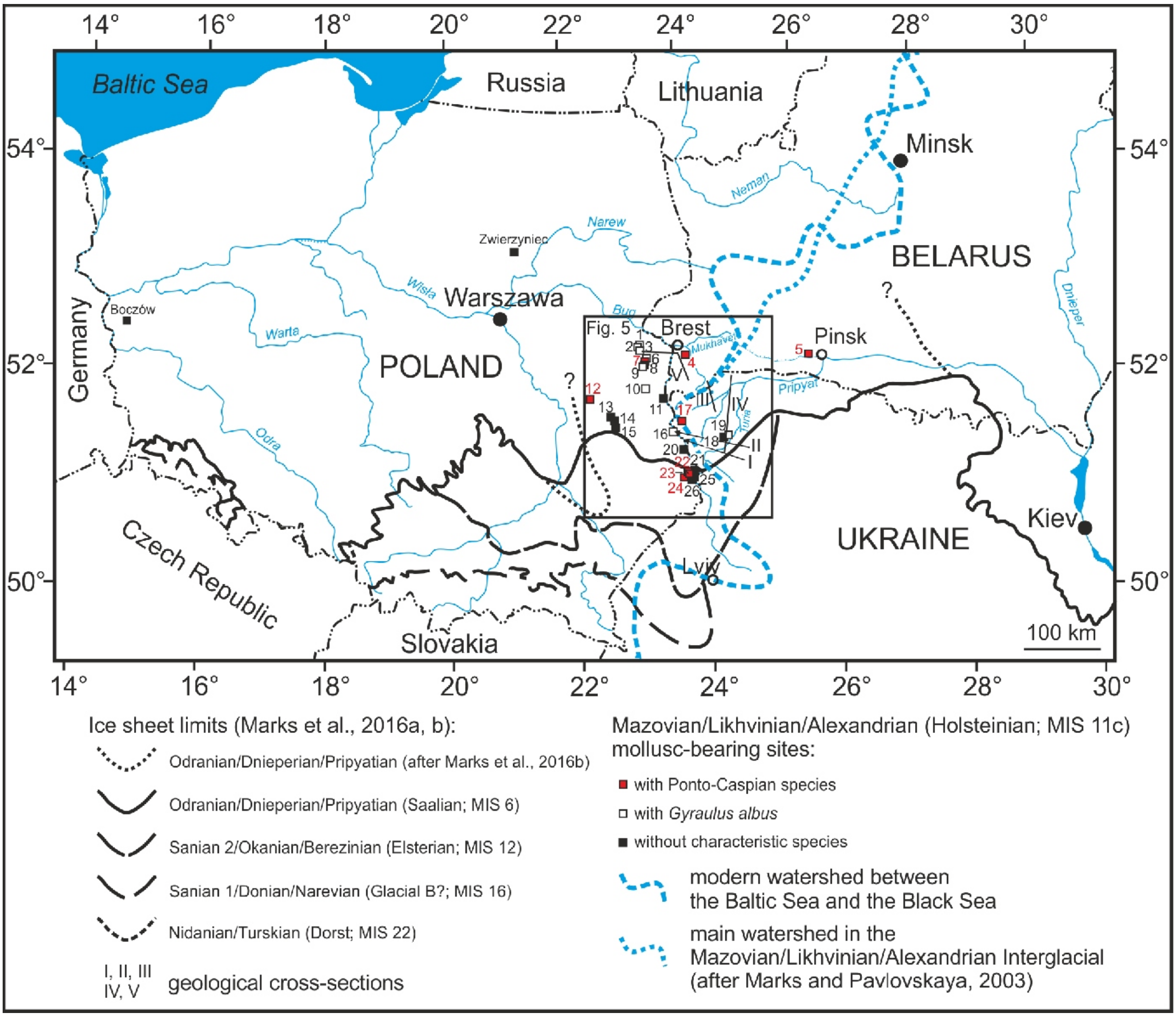

Fig. 1. Location sketch of studied area, surface ice sheet limits of Early and Middle Pleistocene glaciations and Mazovian/Likhvinian/Alexandrian mollusc-bearing sites in the Polish-Ukraine-Belarus cross-border areas

1 – Ossówka, 2 – Hrud, 3 – Roskosz, 4 – Malyya Radvanichi, 5 – Izin, 6 – Ortel Królewski, 7 – Szymanowo, 8 – Szelest, 9 – Rossosz, 10 – Opole 5, 11 – Suszno, 12 – Krępa, 13 – Syrniki, 14 – Czerniejów, 15 – Charlęż, 16 – Ruda 5, 17 – Rohovi Somliary, 18 – Stari Koshary, 19 – Kalinovka, 20 – Dubienka, 21 – Strzyżów, 22 – Hrubieszów, 23 – Tatarska Góra, 24 – Michałówka, 25 – Czumów, 26 – Ślipcze; geological cross-sections: I – Turka–Berezhtsi, II – Ruda–Hniszów, III – Upper Pripyat and Tur Lake, IV – Upper Pripyat and Lower Turia, V – Biała Podlaska–Maloryta

The geological setting of the interfluve of the Bug and Pripyat rivers and the proximity (ca. 10 km) of the Pripyat source to the well-developed Middle Bug River valley imply that both rivers may have been connected in the past. One of the first reports in this regard occurred in a note about Pleistocene deposits in the Bug valley near Uhrusk (Wojtanowicz, 1993). This issue is continued in the present paper. Its main goal was to answer if indeed and when the Bug and Pripyat may have connected. It also suggests a possible position of the main watershed of the Baltic and Black Sea in the area studied during the Middle Pleistocene.

REGIONAL SETTING

The study area is located in eastern Poland, southwestern Belarus and northwestern Ukraine (Fig. 1) and belongs to four macro-regions, namely the South Podlasie Lowland, Western Polesie, Volhynian Polesie and the Volhynian Upland (Kondracki, 2002). This area is mostly flat (only in its southernmost part is there more distinct topographic relief), covered with marshes, meadows, some farmland and sparse forests. It was formed by the several advances of the Early and Middle Pleistocene Scandinavian ice sheets as well as by fluvial, glaciofluvial and aeolian processes. The area was covered or partly covered by the ice sheets of five glacial periods corresponding to the Nidanian/Turskian (Dorst; MIS 22), Sanian 1/Donian/Narevian (Glacial B?; MIS 16), Sanian 2/Okian/Berezinian (Elsterian; MIS 12), Krznanian/Dnieperian 1 (MIS 8) and Odranian/Dnieperian 2/Pripyatian (Saalian; MIS 6; Table 1). At the surface, tills and glaciofluvial sands of the Sanian 2/Okian/Berezinian and Odranian/Dnieperian 2/Pripyatian glaciations predominate. The present river valleys are infilled with sands and gravels, peaty and sandy muds, and peats.

Table 1

Quaternary stratigraphy in Western Europe, Poland, Ukraine and Belarus
(after Gozhik et al., 2012; Lindner et al., 2013; Marks et al., 2016a, b)

AGE [ka]	MIS	Stratigraphy	WESTERN EUROPE	POLAND	UKRAINE	BELARUS
11.7	1	**Holocene**	Holocene	Holocene	Holocene	Holocene
	2-5d	**Upper Pleistocene**	Weichselian	Vistulian	Valday	Poozierian
130	5e		Eemian	Eemian	Mikulinian	Muravian
	6	**Middle Pleistocene**	Saalian	Odranian	Dnieperian 2	Pripyatian
	7		Schöningen	Lublinian		
	8			Krznanian	Dnieperian 1	
	9		Wacken	Zbójnian		
	10		Fuhne	Liwiecian		
420	11		Holsteinian	Mazovian	Likhvinian	Alexandrian
	12		Elsterian	Sanian 2	Okian	Berezinian
	13		Cromerian IV	Ferdynandovian		Belovezhian
	14		Glacial C			
	15		Cromerian III			
	16		Glacial B	Sanian 1	Donian	Narevian
	17		Cromerian II	Podlasian		Brest
780	18		Glacial A			
	19	**Lower Pleistocene**	Cromerian I			
	20					
	21					
	22		Dorst	Nidanian	Turskian	
	23-103		Leerdam	Preglacial (Krasnystaw and Kozienice series)		
			Linge			
			Bavelian s.s.			
			Menapian			
			Waalian			
			Eburonian			
			Tiglian			
2588			Praetiglian			

In grey are cold periods; MIS – marine isotope stages

Vistulian/Valday/Poozierian (Weichselian; MIS 5d-2) loess and aeolian sands also occur in the region studied (Krasnov et al., 1975; Lindner et al., 2007; Marks and Karabanov, 2016).

MATERIAL AND METHODS

Five geological cross-sections (Figs. 2 and 3) in the Polish, Ukraine and Belarus cross-border areas were analysed. The first one was made through the Bug River valley between Turka and Berezhtsi (Szwajgier, 1998; Fig. 2A), and the second – based on Wojtanowicz (1993, 1995) – between Ruda and Hniszów (Fig. 3). The third geological cross-section shows Quaternary deposits in the Upper Pripyat River valley in the vicinity of Tur Lake (Lindner et al., 2007; Fig. 2B), while the fourth is in the Upper Pripyat and Lower Turia river valleys (Zaleski and Gozhik, 2005; Fig. 2C). The fifth cross-section, created between Biała Podlaska and Maloryta, crosses the Bug River valley in the vicinity of Terespol and Brest (Lindner and Astapova, 2000; Fig. 2D). The stratigraphic position of the deposits is constrained by palaeobotanical and faunal evidence (e.g., Janczyk-Kopikowa, 1991; Skompski, 1996) and supported by TL dates cited in the source publications (Wojtanowicz, 1993, 1995; Szwajgier, 1998).

Interpretation of regional cross-sections was supplemented by analysis of 26 mollusc assemblages of Mazovian/Likhvinian/Alexandrian age (MIS 11c) in the area studied (Fig. 1) with key sections at Malyya Radvanichi (Karaszewski, 1972), Izin (Sanko, 1999), Szymanowo (Szymanek, 2014), Krępa (Jesionkiewicz, 1982), Hrubieszów (Jahn, 1956), Tatarska Góra (Prószyński, 1952), Michałówka (Mojski, 1956, 1965) and Rohovi Smoliary (Prószyński, 1952; Table 2). Mollusc analysis was qualitative, focusing on the zoogeographical distribution of the mollusc species, with a crucial role played by Ponto-Caspian taxa, which may be indicative of the Black Sea drainage basin. Initially these taxa were endemic to the regions between the Black, Azov and Caspian seas and then expanded to the north. In addition the occurrence of *Gyraulus albus* (O.F. Müller, 1774) was highlighted, as in Belarus this snail was listed among characteristic species of the Black Sea drainage region (Sanko, 1999; Sanko et al., 2011).

RESULTS

GEOLOGICAL DATA

The oldest fluvial deposits in the area studied, assigned to the Preglacial (MIS 103-23) and Podlasian/Turskian-Donian

Interglacial (MIS 21-17) (Szwajgier, 1998), were drilled in the upper part of the Bug River valley between Turka and Berezhtsi (Fig. 2A). They are composed of fine- and coarse-grained sands, completely devoid of Scandinavian material, lying on Upper Cretaceous marls (Harasimiuk et al., 1989), and a succession of silts and fine- and medium-grained sands dated by TL at 720 ka (Szwajgier, 1998). The base of the alluvial succession was determined at 148–142 m a.s.l. and its top at ~158 m a.s.l., being situated slightly to the east of the contemporary Bug River valley (Fig. 2A). In the vicinity of Berezhtsi it is overlain by glaciolacustrine silts (TL = 193 ka) of the Odranian (Krznanian?)/Dnieperian 2 (1?) Glaciation [MIS 6 (8?)] and alluvia of overflood (II) and floodplain (I) terraces of the Bug River situated at 170 m a.s.l. In the western part of this geological cross-section the Early Pleistocene alluvia are overlain by silts assigned to the Sanian 1/Donian Glaciation (MIS 16) (Szwajgier, 1998; Fig. 2A).

Farther to the north, in the Ruda–Hniszów cross-section, Preglacial and Podlasian buried river deposits occur within the Bug valley westwards to its contemporary river bed (Fig. 3). They are represented by thick sands and gravels free of Scandinavian material occurring at an altitude of 124–117 m a.s.l. and underlain by Cretaceous marls. They are overlain by two units of till (the upper dated by TL at 438 ± 66 ka) separated by a sandy-gravel succession. Both till units appear to represent the Sanian 1 (?) Glaciation (or San according to Wojtanowicz, 1995), whereas sandy silts which lie above represent the Ferdynandovian/Donian-Okian/Beloviezhian Interglacial (Cromerian III-IV; MIS 15-13; Fig. 3).

Above those deposits there is a younger succession of fluvial sands and gravels (TL = 348 ± 52 ka). This succession is overlain by 15 m of gyttja with plant and mollusc remains assigned to the Mazovian Interglacial (Janczyk-Kopikowa, 1991; Skompski, 1996) and deposited in part of the proto-Bug valley of that age. According to Wojtanowicz (1995), the overlying sands and silts (TL = 230 ± 34 ka and 197 ± 29 ka) represent the Odranian Glaciation (MIS 6) and in our opinion the deposits of the higher terrace (II) belong to the Vistulian Glaciation (MIS 5d-2; Fig. 3). A further part of this interglacial valley was sampled by two boreholes in nearby Hniszów, these deposits being represented by sands preserved above a boulder clay formed presumably on the till of the Sanian 2 Glaciation (MIS 12). The fluvial deposits are overlain by clay with mollusc remains that are as yet unstudied. Based on TL dates, these clays (TL = 114 ± 17 ka to 90 ±15 ka) and underlying till (TL = 225 ± 36 ka) were ascribed to the Eemian/Mikulinian/Muravian Interglacial (MIS 5e) and the Odranian Glaciation, respectively (Wojtanowicz,

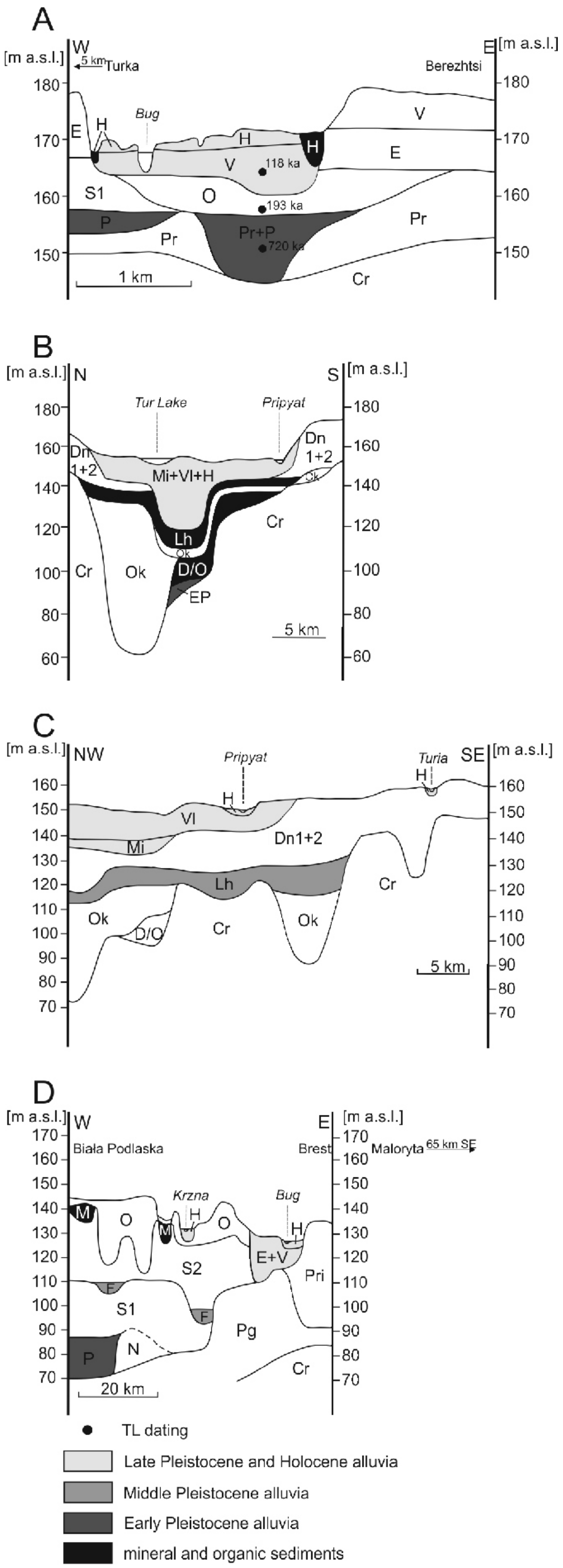

Fig. 2. Schematic geological cross-sections of the Bug–Pripyat interfluve

A – fragment of the Bug River valley near Turka and Berezhtsi (after Szwajgier, 1998, modified); **B** – Quaternary deposits in the Upper Pripyat River valley in the vicinity of Tur Lake (after Lindner et al., 2007, modified); **C** – Quaternary deposits in the Upper Pripyat and Lower Turia river valleys (after Zaleski and Gozhik, 2005, modified); **D** – the Bug River valley in the vicinity of Terespol and Brest (Lindner and Astapova, 2000, modified); stratigraphy: Cr – Cretaceous, Pg – Paleogene, EP – Early Pleistocene, Pr – Preglacial, N – Nidanian Glaciation, P – Podlasian Interglacial, S1 – Sanian 1 Glaciation, S2 – Sanian 2 Glaciation, M – Mazovian Interglacial, O – Odranian Glaciation, E – Eemian Interglacial, V – Vistulian Glaciation; D/O – Donian-Okian Interglacial, Ok – Okian Glaciation, Lh – Likhvinian Interglacial, Dn1+2 – Dnieperian 1+2 Glaciation, Pri – Pripyatian Glaciation, Mi – Mikulinian Interglacial, Vl – Valday Glaciation; H – Holocene; position of the cross-sections is presented on Figure 1

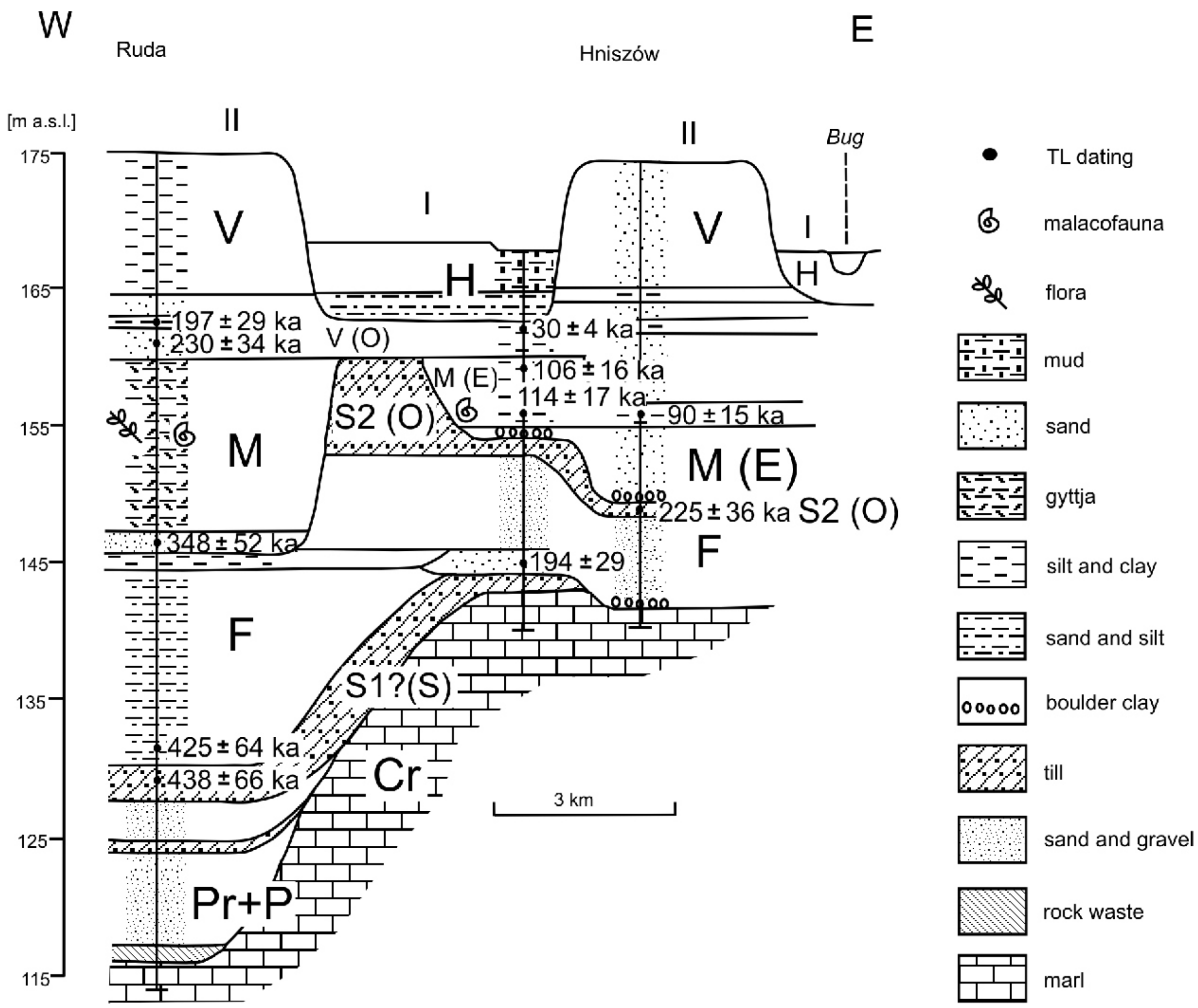

Fig. 3. Geological cross-section through Quaternary deposits in the Bug River valley between Ruda and Hniszów (after Wojtanowicz, 1993, 1995, modified)

In brackets stratigraphy after J. Wojtanowicz; Cr – Cretaceous, Pr+P – Preglacial + Podlasian Interglacial, S1 – Sanian 1 Glaciation, S – Sanian Glaciation, F – Ferdynandovian Interglacial, S2 – Sanian 2 Glaciation, M – Mazovian Interglacial, O – Odranian Glaciation, E – Eemian Interglacial, V – Vistulian Glaciation, H – Holocene; I – floodplain terrace, II – overflood terrace; position of the cross-section is presented on Figure 1

1993). Above, there are silts and sands of the Vistulian Glaciation (TL = 30 ± 4 ka) and a Holocene terrace (I) of the Bug River (Fig. 3).

In Ukraine, to the east of the modern Bug River valley, Early Pleistocene fluvial deposits were noted in the geological cross-section through the Pripyat valley system made in the vicinity of Tur Lake (Zalesski and Mielniczuk, 1975). The buried alluvia are composed of sands with clasts of local rocks (mostly Cretaceous marls), devoid of Scandinavian material and preserved at an altitude of 95–82 m a.s.l. (Fig. 2B). They are up to 10 m thick, lie on Cretaceous marls and are overlain by silts, clayey silts, sands and peats of the Donian-Okian Interglacial (MIS 15-13) (Lindner et al., 2007).

Above the deposits of the Donian-Okian Interglacial, a till of the Okian Glaciation (MIS 12) occurs, being underlain by a thick sandy-gravel succession filling the buried glacial tunnel valley of that age (Fig. 2B). This till is overlain by silts, sands and peats of the Likhvinian Interglacial (MIS 11c). To the south of the Pripyat they are overlain by a till of the Dnieperian 1 and Dnieperian 2 glaciations (MIS 8 and 6, respectively). The axial part of the Pripyat valley is filled by fluvial sands that accumulated from the Mikulinian Interglacial (MIS 5e), through the Valday Glaciation (MIS 5d-2) to the Holocene (Fig. 2B).

Farther to the east, the part of the Pripyat–Turia valley system studied lacks unequivocal evidence of the Early Pleistocene alluvial succession (Fig. 2C). However, a well-developed buried tunnel valleys of the Okian Glaciation filled with sands with gravels and boulders occur. Locally they are underlain by deposits of the Donian-Okian Interglacial or lie directly on Cretaceous marls. Above the deposits of Okian Glaciation, at an altitude of 125–115 m a.s.l., 5 to 13 m thick fluvial sands with plant remains of the Likhvinian Interglacial have been recorded (Fig. 2C). In the interfluve of Pripyat and Turia these are partly overlain by a till of the Dnieperian 1 and Dnieperian 2 glaciations, glaciofluvial sands of those ages lying above as well as younger valley deposits belonging to the Mikulinian Interglacial, the Valday Glaciation and the Holocene (Zaleski and Gozhik, 2005; Lindner et al., 2007).

In the area of Brest and Terespol, fluvial deposits comprise a 5 to 20 m thick sandy-gravel Eemian/Muravian (MIS 5e) succession, with the base approximately at 110 m a.s.l., i.e. ~20–15 m beneath the bottom of the contemporary Bug River

Table 2

An occurrence of *Gyraulus albus* and Ponto-Caspian species in the Mazovian/Likhvinian/Alexandrian Interglacial in eastern Poland, southwestern Belarus and northwestern Ukraine

Sites	Characteristic species				References
	Lithoglyphus naticoides (Pfeiffer)	*Borysthenia naticina* (Menke)	*Gyraulus albus* (Müller)	*Corbicula fluminalis* (Müller)	
1. Ossówka			+		Szymanek (2011)
2. Hrud			+		Lindner et al. (1991a) Szymanek (2012)
3. Roskosz			+		Szymanek (2013)
4. Malyya Radvanichi		+			Karaszewski (1972)
5. Izin				+	Sanko (1999)
6. Ortel Królewski			+		Albrycht et al. (1995) Szymanek (2011)
7. Szymanowo		+	+		Albrycht et al. (1995) Szymanek (2014)
8. Szelest			+		Albrycht et al. (1995)
9. Rossosz			+		Albrycht et al. (1995)
10. Opole 5			+		Skompski (1989)
11. Suszno					Mojski and Trembaczowski (1975)
12. Krępa	+				Jesionkiewicz (1982)
13. Syrniki					Prószyński and Karaszewski (1952)
14. Czerniejów					Jahn (1956)
15. Charlęż					Jahn (1956)
16. Ruda 5			+		Skompski (1996)
17. Rohovi Somliary				+	Prószyński (1952)
18. Stari Koshary					Karaszewski and Rühle (1976)
19. Kalinovka			+		Dmitruk and Yatsyshyn (2005)
20. Dubienka					Prószyński (1952)
21. Strzyżów					Dolecki (1977)
22. Hrubieszów	+	+			Jahn (1956)
23. Tatarska Góra	+				Prószyński (1952)
24. Michałówka	+				Mojski (1956, 1965)
25. Czumów					Mojski (1956)
26. Ślipcze					Mojski (1956)
Environment	F	F, S	S, F	F	

In grey are key sites mentioned in the text; F – flowing waters, S – stagnant waters

valley (Lindner and Astapova, 2000; Nitychoruk et al., 2007). These deposits are overlain by silts and sands, up to 15 m thick, representing overflood (II) and floodplain (I) terraces of the Bug. Near Terespol, the latter lies at ~130 m a.s.l. (Fig. 2D).

MALACOLOGICAL RECORD

In the Mazovian shell-bearing successions of the upper part of the Bug River valley and adjacent areas, Ponto-Caspian species are represented by the gastropods *Lithoglyphus naticoides* and *Borysthenia naticina*, and the bivalve *Corbicula fluminalis*. These were noted in 8 from 26 sites, whereas 9 sites lack any indicative taxa (Fig. 1 and Table 2). *L. naticoides* occurred in the alluvial succession in eastern Poland at Krępa near Kock (Jesionkiewicz, 1982) and in the vicinity of Hrubieszów (Hrubieszów, Tatarska Góra, Michałówka; Prószyński, 1952; Jahn, 1956; Mojski, 1956, 1965). *B. naticina* was noted at Malyya Radvanichi in southwestern Belarus (described as *Valvata naticina* Menke, 1845; Karaszewski, 1972), Hrubieszów (Jahn, 1956), and in the lake deposits at Szymanowo (eastern Poland; Albrycht et al., 1995; Szymanek, 2014), whereas *C. fluminalis* was present at Izin (southern Belarus; Sanko, 1999) and Rohovi Smoliary (northwestern Ukraine; Prószyński, 1952). *G. albus* occurred at ten lacustrine sites (Fig. 1 and Table 2).

Wider faunal comparisons were hindered by variable malacological data available from the sites studied, including mentions of only single species, e.g. Syrniki (Prószyński and Karaszewski, 1952), Tatarska Góra (Prószyński, 1952), Michałówka (Mojski, 1956, 1965); lists of species, e.g. Opole (Skompski, 1989), Ruda (Skompski, 1996), Kalinovka (Dmytruk and Yatsyshyn, 2005); or comprehensively described successions with abundant molluscs, e.g. Hrud (Lindner et al., 1991a; Szymanek, 2012), Ortel Królewski (Albrycht et al., 1995; Szymanek, 2011), Roskosz (Szymanek, 2013) and Szymanowo (Szymanek, 2014).

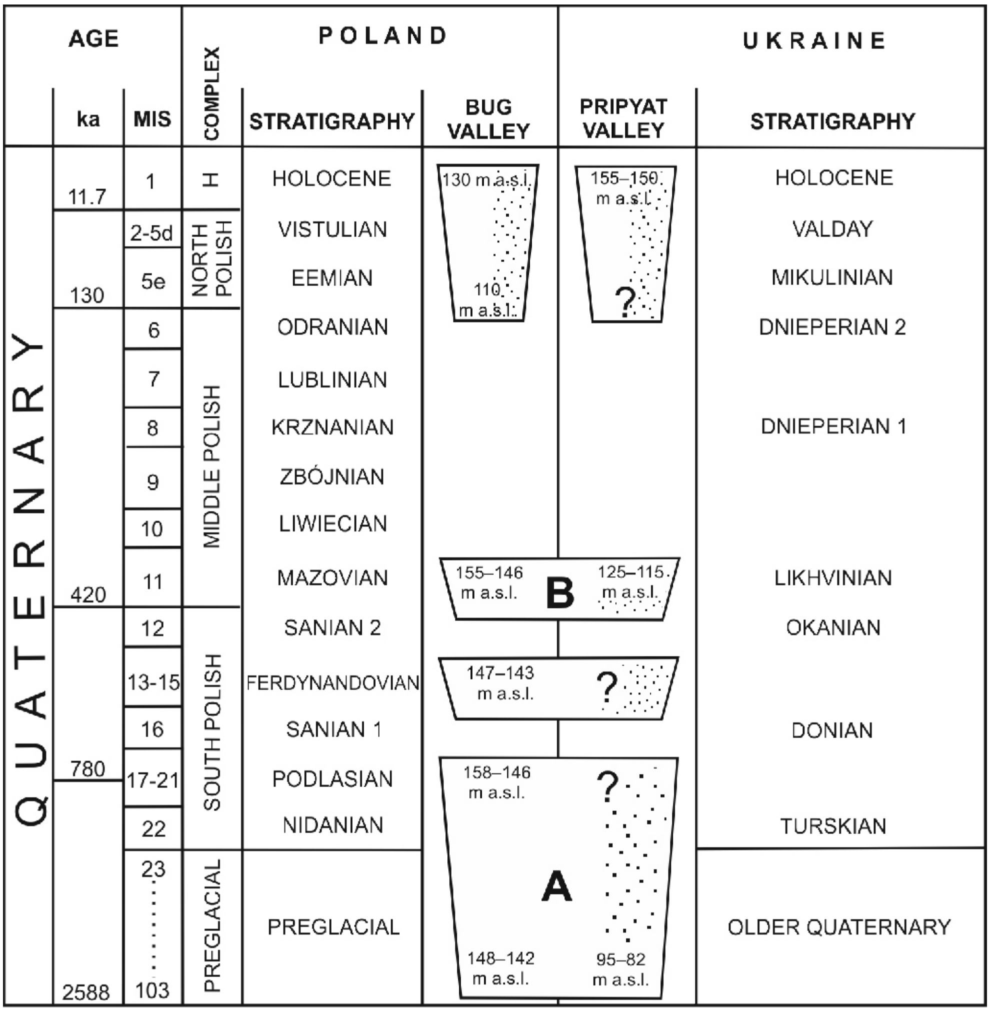

Fig. 4. Position of the studied river valleys (A, B) in the Quaternary stratigraphy of Poland and Ukraine

DISCUSSION

Geological cross-sections through the Quaternary deposits of the Bug and Pripyat valleys described in this paper document both the Early and Middle Pleistocene alluvia of these rivers (Fig. 4). The Early Pleistocene river deposits comprise sands and gravels characterized by a lack of Scandinavian material that overlie Upper Cretaceous rocks in the Bug valley near Turka and Berezhtsi, as well as sands with clasts of Cretaceous marls recorded in the vicinity of Tur Lake in the Pripyat valley system. These deposits are correlated with the Preglacial and Podlasian/Turskian-Donian Interglacial (MIS 103-23 and MIS 21-17, respectively). Their eastward position in the vicinity of Berezhtsi compared to the contemporary Bug River valley (Fig. 2A) suggests that the proto-Bug valley was located to the east of the modern valley and then moved westwards as recorded in the Ruda–Hniszów area (Figs. 3 and 5). In the light of a lack of unequivocal proof of neotectonics it appears that the proto-Bug was a higher section of the oldest part of the Pripyat valley system at that time, which is indicated by the higher elevation of the Early Pleistocene deposits near Berezhtsi than in the vicinity of Tur Lake (148–142 and 95–82 m a.s.l., respectively; Fig. 4). Presumably the proto-Bug waters ran to the east at that time, which determined the formation and development of the lower-lying valley system of the proto-Pripyat in north-western Ukraine (Fig. 5).

Based on geological cross-sections and palaeofloral sites preserved in the area studied, the Middle Pleistocene alluvia of the proto-Bug and proto-Pripyat particularly well represent the Mazovian/Likhvinian/Alexandrian Interglacial (MIS 11c). They were observed in the Ruda-Hniszów area (155–146 m a.s.l.) and farther towards the east in the Pripyat–Turia valley (125–115 m a.s.l.; Fig. 4), where they may represent an older part of the valley system of these rivers, constituting the lower section of the Mazovian proto-Bug river valley identified in the vicinity of Ruda and Hniszów (Fig. 5). Mazovian river deposits fill palaeovalleys cut into older tills and are represented by sands and gravels with Scandinavian material. As in the case of the Early Pleistocene succession, their higher position in mid-eastern Poland also imply a possibility of deposition by proto-Bug waters flowing to the east and affecting the development of the proto-Pripyat river at a lower topographic level.

The record of evolution of the Bug and Pripyat valley systems during the Mazovian/Likhvinian/Alexandrian Interglacial (MIS 11c) may by supplemented by malacological data. The occurrence of mollusc taxa typical of the Ponto-Caspian province and associated with the Black Sea drainage basin has been used here. Due to palaeohydrographic changes, their contribu-

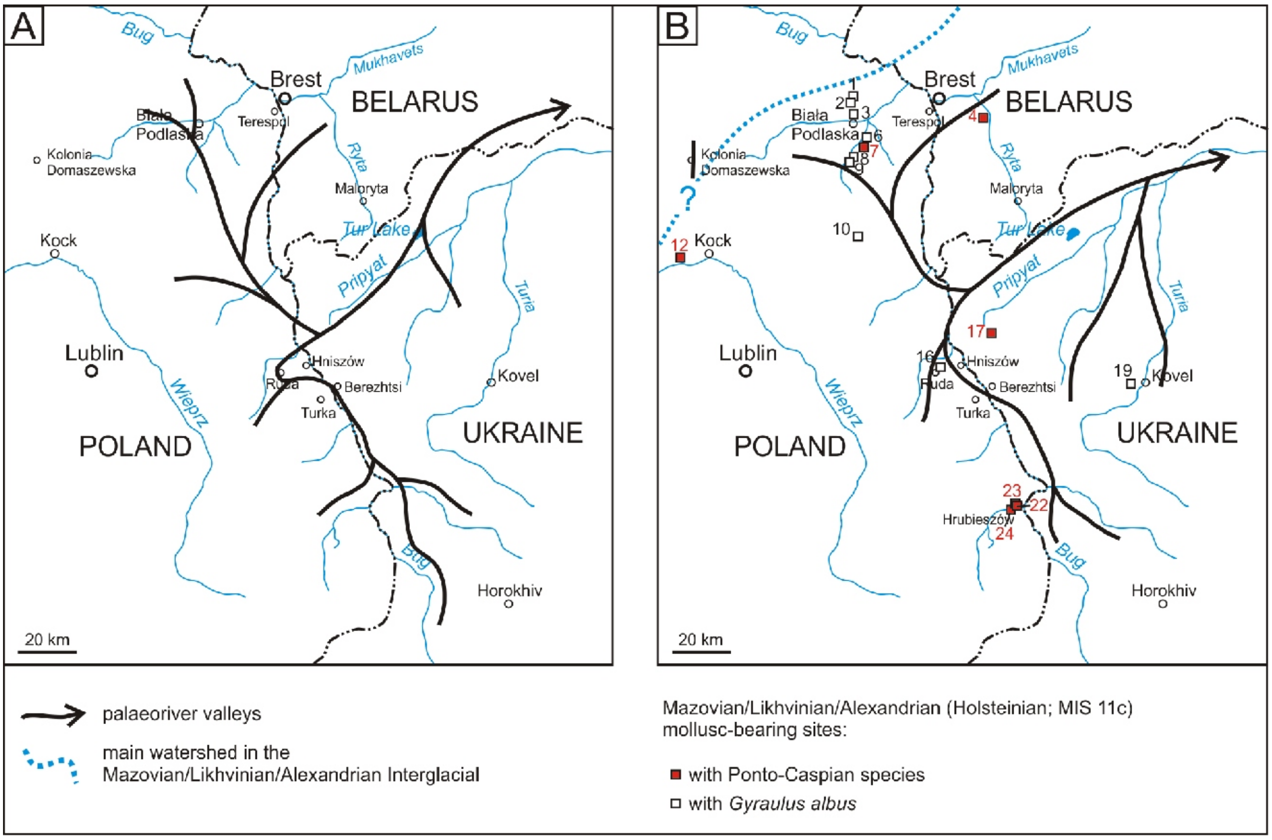

Fig. 5. Probable course of river valleys in the Polish-Ukraine-Belarus cross-border areas

A – in the Preglacial and Podlasian/Turskian–Donian/Brest Interglacial; **B** – in the Mazovian/Likhvinian/Alexandrian Interglacial with characteristic mollusc-bearing sites: 1 – Ossówka, 2 – Hrud, 3 – Roskosz, 4 – Malyya Radvanichi, 6 – Ortel Królewski, 7 – Szymanowo, 8 – Szelest, 9 – Rossosz, 10 – Opole 5, 12 – Krępa, 16 – Ruda 5, 17 – Rohovi Somliary, 19 – Kalinovka, 22 – Hrubieszów, 23 – Tatarska Góra, 24 – Michałówka

tion in mollusc assemblages decreased gradually after the Mazovian/Likhvinian/Alexandrian Interglacial and this method was helpful in indicating the Black Sea drainage in Belarus during the Alexandrian (MIS 11c) and Muravian (MIS 5e) Interglacials (Sanko, 1999; Sanko et al., 2011). Because the dispersal of molluscs is mostly affected by the pattern of the river network, mollusc assemblages may indirectly reflect the interglacial river pattern. Molluscs can also be transported by various organisms (fish, waterfowl, etc.), which allows them to reach new places and environments, usually within 10–20 km from the original release site (Boag, 1986; Alexandrowicz and Alexandrowicz, 2011; Reynolds et al., 2015).

Despite incomplete documentation, a key section for reconstruction of the watershed in the Mazovian/Likhvinian/Alexandrian Interglacial in the area studied is located at Malyya Radvanichi in Belarus (Karaszewski, 1972). In the alluvial succession assigned to the Mindel-Riss Interglacial (Mazovian/Likhvinian/Alexandrian) that occurs in the Ryta River valley, a left bank tributary of the Mukhavets River, at present in the Baltic Sea drainage basin (Fig. 1), Polański in the 1930s described a mollusc fauna of a large river of the Polesie region which belonged to the Black Sea drainage system (Karaszewski, 1972; Sanko, 1999). This interpretation was based on the similarity of the interglacial molluscs at Radvanichi to a contemporary fauna typical of the lower courses of the rivers of the Black Sea drainage (Karaszewski, 1972). An incomplete species list hinders the correlation of Radvanichi with Polish sections, but the occurrence of *Valvata naticina* = *Borysthenia naticina* as well as numerous forms of *Vivipara* (*Paludina*) *fasciata* (O.F. Müller, 1774) = *Viviparus viviparus* (Linnaeus, 1758) similar to those inhabiting the lower Dnieper today and resembling subfossil forms known from the Odessa region should be highlighted (Karaszewski, 1972). A Black Sea fauna with the first occurrence of *C. fluminalis* in Belarus was also recorded at Izin near Pinsk (Fig. 1) in deposits of Alexandrian age within the Black Sea drainage area (Sanko, 1999). Correlation of Belarusian sequences revealed >7% of Ponto-Caspian species in the Alexandrian Interglacial and their gradual reduction (to <4%) in the Muravian Interglacial and in the Holocene (Sanko, 1999), which may indicate some palaeohydrographic changes in the region during the Late Pleistocene.

Despite the occurrence of rich mollusc assemblages, it is hard to find such unequivocal proof of the expansion of Ponto-Caspian species in the upper course of Bug river in eastern Poland. The best malacological record has been derived from lake environments (e.g., Lindner et al., 1991a; Albrycht et al., 1995; Szymanek, 2011, 2012, 2013, 2014), usually depleted in *B. naticina*, *L. naticoides* and *C. fluminalis* which preferred flowing waters (Alexandrowicz and Alexandrowicz, 2011). In the Polish-Ukraine-Belarus cross-border areas they occur in deposits of lakes with higher energy conditions, with evidence of flow or wave action (e.g., at Szymanowo), and in alluvial deposits (e.g., Tatarska Góra, Michałówka, Hrubieszów, Rohovi Smoliary).

Ten shells of *Borysthenia naticina* found in lacustrine sandy silts and sands at Szymanowo near Biała Podlaska represent a single record of this species in the upper Bug region in eastern

Poland. An overflow through the Szymanowo Lake has not been unequivocally documented, but a high frequency of rheophile species may indicate higher energy conditions (Szymanek, 2014). Presumably a lack of this species in the neighbouring sections at Ortel Królewski, Hrud, and Roskosz reflects local differences in lake conditions and dynamics (Szymanek, 2011, 2012, 2013). However, in mollusc assemblages of all lacustrine sequences of eastern Poland as well as in the Ukrainian site at Kalinovka (Dmytruk and Yatsyshyn, 2005; despite the lack of typical Ponto-Caspian species) *Gyraulus albus* occurs consistently and abundantly. Considering the lack of this species in palaeolakes of western (Boczów; Skompski, 1989; Fig. 1) and central Poland (Zwierzyniec; Skompski, 1989; Bałuk et al., 1991; Fig. 1), its association with different palaeohydrographic conditions during the Mazovian Interglacial (in Belarus postulated for the Muravian; Sanko, 1999; Sanko et al., 2011) appears highly probable.

Drainage of the upper Bug region towards the Black Sea in the Mazovian/Likhvinian/Alexandrian Interglacial (MIS 11c) may be also implied by the presence of *L. naticoides* in fluvio-lacustrine deposits in the vicinity of Kock and Hrubieszów (Figs. 1 and 5). Investigation of most of the sites remains incomplete, but records of *L. naticoides* at Krępa (Jesionkiewicz, 1982), Tatarska Góra (Prószyński, 1952), Michałówka (Mojski, 1956, 1965), and in the terrace of the Huczwa River near Hrubieszów (also *B. naticina*; Prószyński, 1952; Jahn, 1956) as well as the occurrence of *C. fluminalis* at Rohovi Smoliary (Ukraine, 13 km NE of Hniszów; Prószyński, 1952) makes those sections comparable with the Black Sea rather than with the mid-European region and appears significant for palaeogeographical reconstruction. Location of the main watershed in northern Belarus in the Middle Pleistocene farther to the west compared to the modern one (Marks and Pavlovskaya, 2003) may confirm the suggestion that the main part of the area studied in the Mazovian/Likhvinian/Alexandrian Interglacial might have been drained by the proto-Bug waters associated with the proto-Pripyat which flowed east towards the Dnieper River flowing into the Black Sea. It seems that the Mazovian/Likhvinian/Alexandrian watershed ran to the north of Kock, Biała Podlaska and Brest, but its exact position has not yet been determined. For example, at Kolonia Domaszewska, in the Samica River valley, a Mazovian meandering river flowing to the north was investigated (Terpiłowski et al., 2014; Zieliński et al., 2016), but there is no clear evidence of whether it drained towards the Baltic or the Black Sea (Fig. 5).

It seems that the Bug River valley in the vicinity of Brest and Terespol was formed by extraglacial waters of the Warta Stadial of the Odranian Glaciation, which eroded through the end moraines of this stadial near Mielnik and started to flow to the north (Terpiłowski and Dobrowolski, 2004) and then to the west (Straszewska, 1968). Definite outflow might have occurred between the Warta Stadial and Eemian Interglacial (MIS 6 and 5e, respectively), forming sandy terraces preserved along the valley sides and interpreted as the highest river terrace (19 m high; Kondracki, 1933), kame terraces (Nitychoruk et al., 2006) or the lower glacifluvial plains (Nitychoruk et al., 2007). The palaeo-river bed reached its maximum depth in the region in the Eemian/Mikulinian/Muravian Interglacial, lying ~20–15 m below the present one, near Terespol at 130 m a.s.l. (Lindner and Astapova, 2000; Nitychoruk et al., 2007; Figs. 2D and 4).

CONCLUSIONS

In this study archival geological and malacological data were used to reconstruct the probable course of the proto-Bug and proto-Pripyat river valleys in the Polish-Ukraine-Belarus cross-border areas in the Early and Middle Pleistocene. The major conclusions may be summarized as follows:

1. Geological cross-sections through Quaternary deposits in the Bug and Pripyat valleys document both the Early and Middle Pleistocene alluvia of these rivers.
2. In the Early Pleistocene the proto-Bug valley likely ran east of the present Bug River valley and then migrated westwards.
3. The higher elevation of the Early Pleistocene fluvial deposits in mid-eastern Poland implies that they accumulated from proto-Bug waters. They flowed eastwards and affected the formation and development of the lower-lying valley system of the proto-Pripyat in northwestern Ukraine at that time.
4. Middle Pleistocene alluvia of the proto-Bug and proto-Pripyat particularly well-represent the Mazovian/Likhvinian/Alexandrian Interglacial (MIS 11c). Their higher position in mid-eastern Poland again suggests the possibility of accumulation by proto-Bug waters flowing to the east and determining the development of the lower-lying proto-Pripyat.
5. The malacological record of the Mazovian/Likhvinian/Alexandrian sites and the occurrence of the Ponto-Caspian species *Lithoglyphus naticoides*, *Borysthenia naticina* and *Corbicula fluminalis* suggest that during this interglacial the area studied belonged to the Black Sea drainage basin. The watershed between the Baltic and the Black Sea might have occurred in its northern part.
6. Combined geological and malacological data show that during the Mazovian/Likhvinian/Alexandrian Interglacial the main part of the area studied was drained by the proto-Bug waters connected with the proto-Pripyat running eastwards to the Dnieper River entering the Black Sea.

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