Annales Societatis Geologorum Poloniae (2013), vol. 83: 29–36.

ORIGIN AND AGE OF PLEISTOCENE 'MIXED GRAVELS' IN THE NORTHERN FORELAND OF THE CARPATHIANS

Leszek LINDNER & Leszek MARKS

University of Warsaw, Department of Climate Geology, Żwirki i Wigury 93, 02-089 Warsaw, Poland; e-mail: l.lindner@uw.edu.pl, leszek.marks@uw.edu.pl

Lindner, L. & Marks, L., 2013. Origin and age of Pleistocene 'mixed gravels' in the northern foreland of the Carpathians. *Annales Societatis Geologorum Poloniae*, 83: 29–36.

Abstract. Accumulations of pebbles in the northern foreland of the Carpathians in Ukraine and Poland, composed mostly of Carpathian sandstones, but with a small admixture of Scandinavian rocks, have been known for many years as the 'mixed gravels'. The occurrence of these gravels in the San–Dnistr and Vistula–Odra interfluves proves that they are of fluvial origin and were deposited by rivers that flowed northwards during the Podlasian (Martonosha and Shirokino) and Ferdynandovian (Lubny) Interglacials. The Scandinavian material was derived from eroded glacial deposits of Nidanian (Turskian) and Sanian 1 (Vyzhivskian, equivalent to Donian) Glaciations.

Key words: fluvial interglacial deposits, Carpathian and Scandinavian erratics, early Middle Pleistocene, northern foreland of Carpathians, Ukraine and Poland

Manuscript received 28 March 2013, accepted 3 July 2013

INTRODUCTION

The origin and age of the so-called 'mixed gravels' is among the more important problems of research on the Quaternary in the northern foreland of the Carpathians. The term was introduced into geological literature about 130 years ago in Austrian Galicia (Hilber, 1882; Tietze, 1883; Uhlig, 1883) for accumulations of clastic material, dominated by gravels of Carpathian derivation, but with an admixture of Scandinavian rocks. In the 'mixed gravels' type area of the San–Dnistr and Vistula–Odra interfluves (Fig. 1) the percentage of Scandinavian erratics is 5–10% (Stupnicka, 1962; Łanczont, 1997). The mixed gravels have been generally identified either southwards of the extensive till area of the youngest South Polish Glaciation (Sanian 2 = Okanian) or beneath/above this till (Łanczont *et al.*, 2011).

The occurrence of the mixed gravels beneath the till seems obvious, because of the erosion of them by the younger Carpathian rivers. However, their location beyond the extent of the till is more problematic. The latter is even more interesting if a possible advance of the Scandinavian ice sheet during the Middle Pleistocene glaciation (Nidanian?, Sanian 1, equivalent to Donian?) is considered (cf. Lindner, 2001; Boguckyj *et al.*, 2004; Gozhik *et al.*, 2012). In the present paper, a discussion of the origin and location of the mixed gravels is based mainly on an analysis of younger interglacial deposits that occur in the northern foreland of the Carpathians.

HISTORY OF INVESTIGATIONS AND PRESENT STATE OF KNOWLEDGE

Knowledge of the origin of the mixed gravels indicates (cf. Łanczont 1997; Łanczont *et al.*, 2011) that they can be treated as glacial, redeposited glacial, dam-lake or fluvial deposits.

The mixed gravels were treated as glacial deposits by Łoziński (1909), who analyzed glacial phenomena at the edge of the deposits covering the Pleistocene along the Carpathians and the Sudetes, and by Friedberg (1906), who identified them in the interfluves of San and Dnistr where they were considered to demarcate the southern limit of the Scandinavian glaciations. Romer (1907) also found large Scandinavian boulders to the south-east of Przemyśl and considered them to be evidence for the advance of the Scandinavian ice sheet in this area. Laskowska-Wysoczańska and Wysoczański-Minkowicz (1992) interpreted the mixed gravels as an age equivalent of a till of the Cracovian (i.e. South Polish) Glaciation. These gravels contained not only flysch material, but also red and gray granites, gneisses, porphyries and Scandinavian quartzitic sandstones (Uhlig, 1883, 1884, 1888). They were found to represent directly a till, deposited by glacial lobes that entered the Carpathian valleys from the north.

Halicki (1951) and Stupnicka (1962) found the mixed gravels to have been a product of redeposited glacial deposits. Therefore, they considered their origin and deposition to

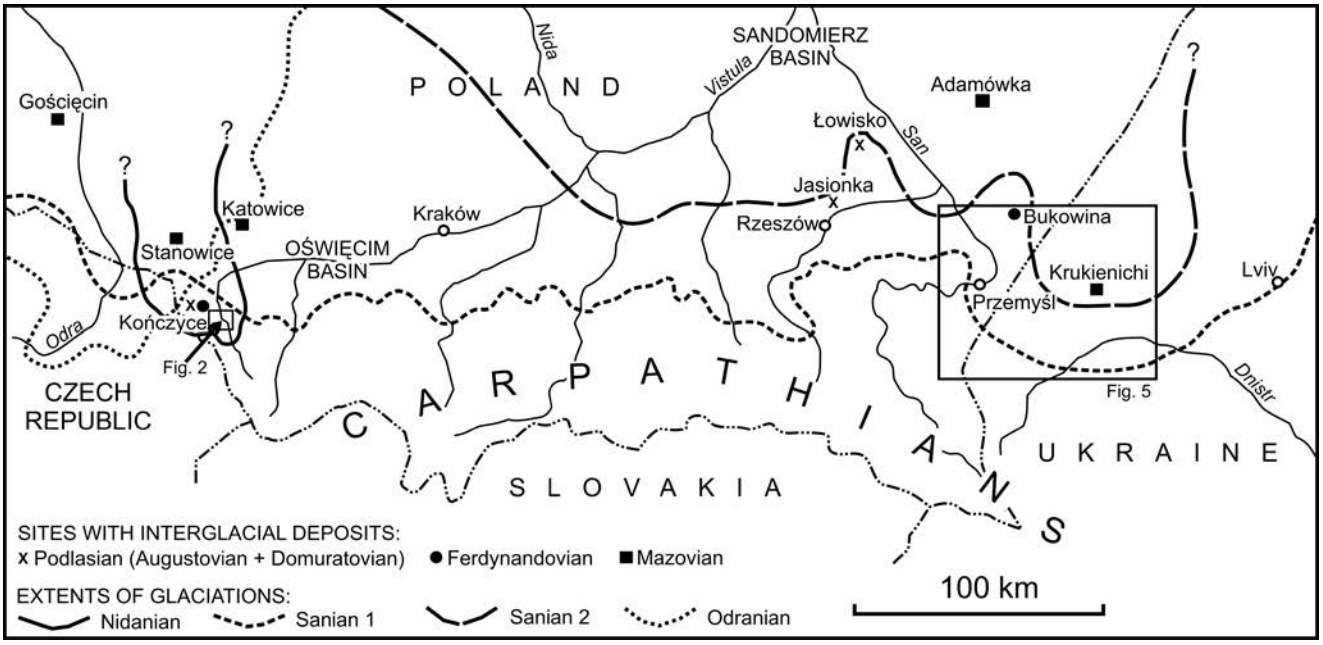

Fig. 1. Age and extents of Scandinavian ice sheet and main sites of interglacial deposits in northern foreland of the Carpathians (modified after Lindner, 2001)

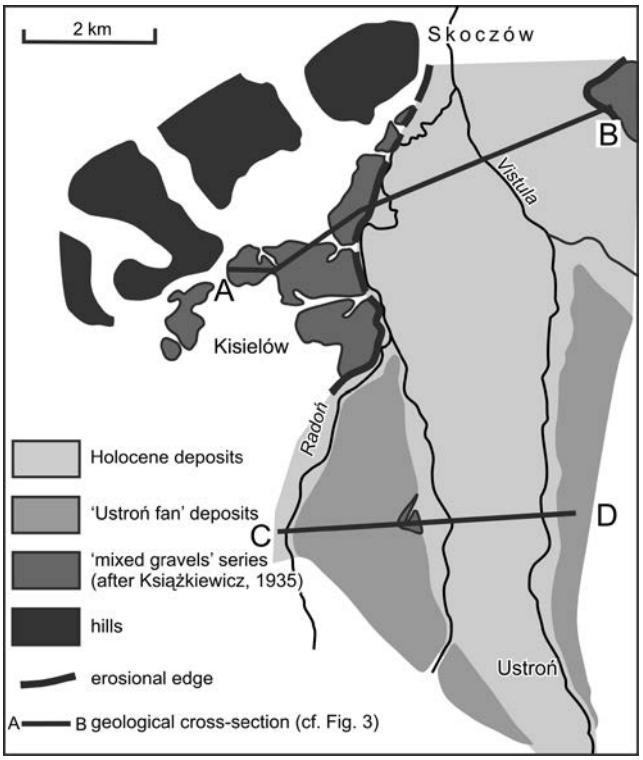

Fig. 2. Occurrence of Quaternary deposits in Vistula valley between Ustroń and Skoczów (simplified, after Stupnicka, 1962)

be not fully connected with the direct presence of the Scandinavian ice sheet in the interfluves of the Vistula and the Odra, especially in the Cieszyn Foreland and south-western Oświęcim Basin. They ascribed these gravels in this area to younger river terraces and to alluvial fans.

Other scientists connected the origin of the mixed gravels with deltaic deposition in dammed reservoirs. According to Przepiórski (1938), the waters of the Carpathian rivers flooded a relatively thin ice body during the advance of the Scandinavian ice sheet to the northern edge of the Carpathians, spreading both flysch and Scandinavian materials that were finally deposited in vast dammed reservoirs. Also Teisseyre (1938) found that the gravels, deposited in such reservoirs in the vicinity of Sambor, were derived both from the Carpathians and from the glacial tills.

These opinions are close to the view that deposition of the mixed gravels occurred in various flowing waters, either fluvial, glaciofluvial or fluvio-periglacial (Łomnicki, 1900; Szajnocha, 1901). Therefore, the gravels mentioned could be channel deposits of lateral rivers, supplied with both Carpathian and glacial meltwaters. The deposition of these gravels could occur, not only during ice sheet advance (Pawłowski, 1920), but also during its time of maximum extent and the deglaciation that followed (Książkiewicz, 1935).

PALAEOGEOGRAPHICAL RECONSTRUCTION

Most studies of the San–Dnistr and Vistula–Odra interfluves found the mixed gravels to have been evidence of a Scandinavian glaciation during the late Early and early Middle Pleistocene (cf. Lindner *et al.*, 2013). However, taking such a general view into consideration, there is the question of whether these gravels really represent a glacial episode and if so, which one of the three possible (Nidanian, Sanian 1 or Sanian 2). Alternatively, perhaps, they represent a residuum of glacial deposits that were eroded by the Carpathian rivers. Therefore, they should indicate an erosional-

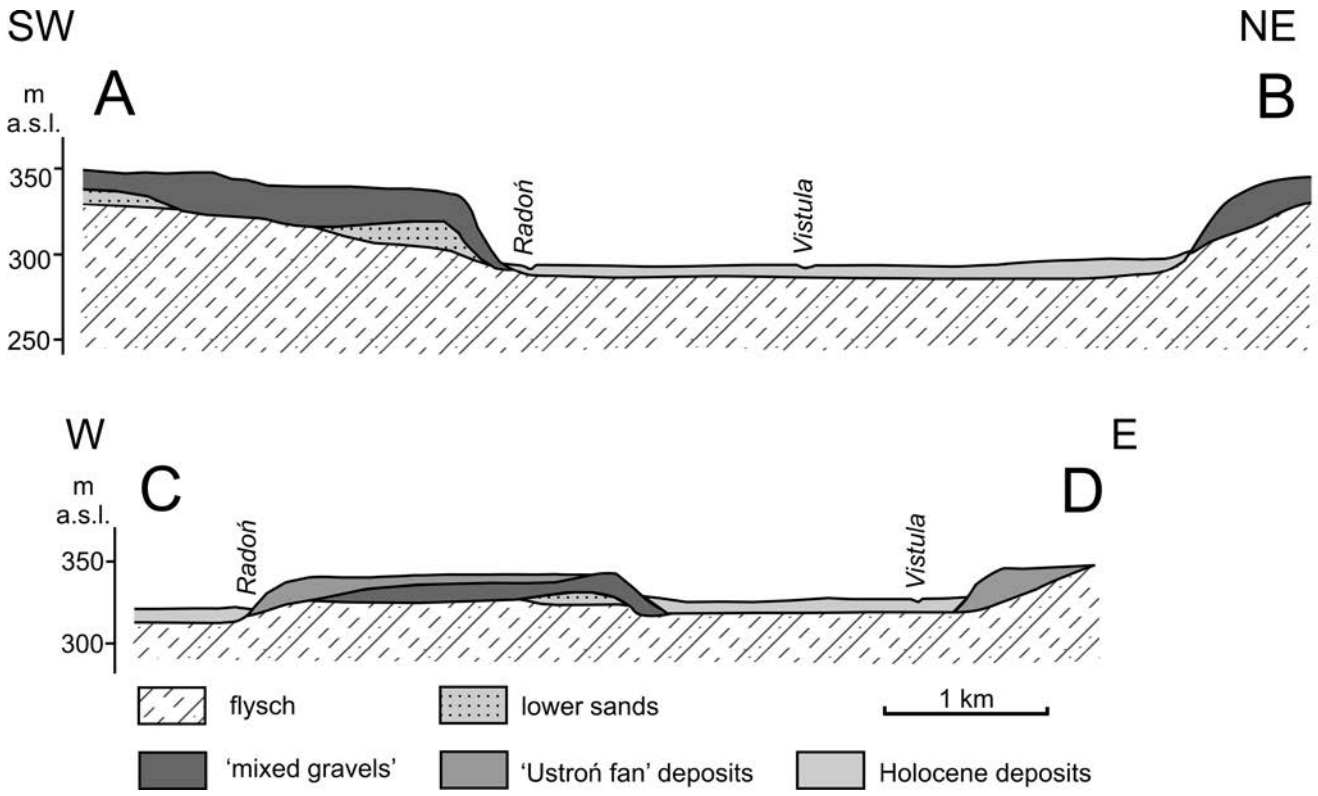

Fig. 3. Schematic geological sections A–B and C–D across the Upper Vistula valley (simplified, after Stupnicka, 1962); for location, see Fig. 2

depositional episode during the terminal part of the glaciation and partly also during the interglacial that followed.

To answer these questions, the problem of the origin of the mixed gravels and also their palaeogeographical setting should be discussed first. The most reliable explanation seems to be the deposition of these gravels in the Vistula valley and in its tributaries in the interfluves of the Vistula and the Odra in the border area of the Cieszyn Foreland and the Oświęcim Basin. According to Stupnicka (1962), the mixed gravels, also examined in this area by Książkiewicz (1935), were located mainly on the western side of the Vistula valley and its tributary, the Radoń, between Ustroń in the south and Skoczów in the north (Fig. 2). These gravels, described at several exposures, were up to 30 m thick and were underlain by lower sands, defined by Książkiewicz (1935) as the 'glacial sands' deposited during the maximum extent of the Scandinavian ice sheet. They should represent deposits formed 'in result of mixing of waters with glacial material and the Carpathian waters with flysch pebbles'. In the northern part of the area, they occurred at the land surface, building a distinct terrace at both sides of the Vistula valley. They were overlain in the south by the Late Pleistocene alluvial clays of 'the Ustroń fan' (Fig. 3; Stupnicka, 1962).

According to the present authors, these mixed gravels at Kończyce (about 12 km to the west of Skoczów) presumably correspond with the supra-till gravels of the 'upper fluvial series' and with the interglacial 'lower series of the organic silts' at the bottom (Kończyce C after Wójcik *et al.*, 2004). These gravels are up to 6 m thick and are composed mainly of pebbles of Carpathian sandstones, among which 'there were single gravels of crystalline Scandinavian rocks'. Their occurrence was connected with the erosion of glacial deposits (Wójcik *et al.*, 2004). The age of these gravels (Fig. 4) can be determined on the basis of reference to the overlying 'upper series of organic silts' of the Ferdynandovian Interglacial, with the Brunhes/Matuyama boundary (780 ka BP) at the bottom. The latter proves that deposition of gravels of 'the upper fluvial series' at Kończyce could have been initiated at the termination of the older glaciation (Nidanian in Fig. 6) and continued during the younger interglacial. Therefore, it seems possible that the mixed gravels of the Vistula and Odra interfluves could represent fluvial deposits, deposited mainly during an interglacial period in this part of Poland after the first, more extensive Scandinavian glaciation.

In the case of the San and Dnistr interfluves (Fig. 5), the mixed gravels were deposited, according to the opinions of all of the authors cited, also during or after the first advance of the Scandinavian ice sheet. The question is: was it the same ice sheet as in the Oświęcim Basin? Such a dilemma could be solved by referring to the geological setting of the site with interglacial deposits at Krukienichi (Figs 1, 5). This site has been recently re-examined and lake-marshy deposits of the Mazovian (Likhvin) Interglacial were found above a till of the Sanian 2 (Okanian) Glaciation (Łanczont *et al.*, 2003). It is to be emphasized that below this till there are sands, underlain by thick (8–10 m) Carpathian gravels with crystalline material of Scandinavian derivation (Boguckij *et al.*, 1980; Nowak, 2000), interpreted as fluvial de-

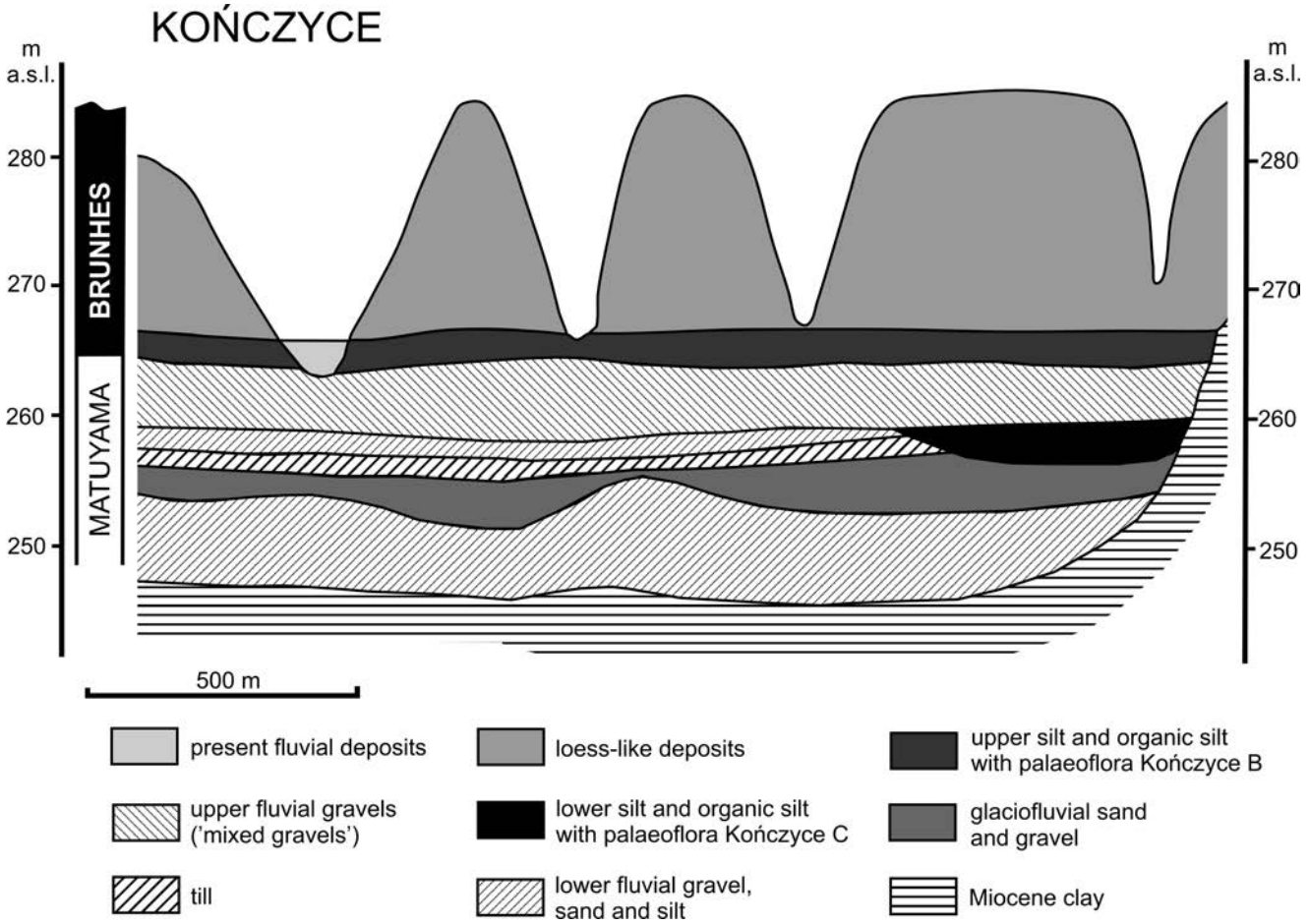

Fig. 4. Fragment of geological section across Quaternary deposits in vicinity of Kończyce (modified after Wójcik *et al.*, 2004); the palaeomagnetic Brunhes/Matuyama boundary is indicated

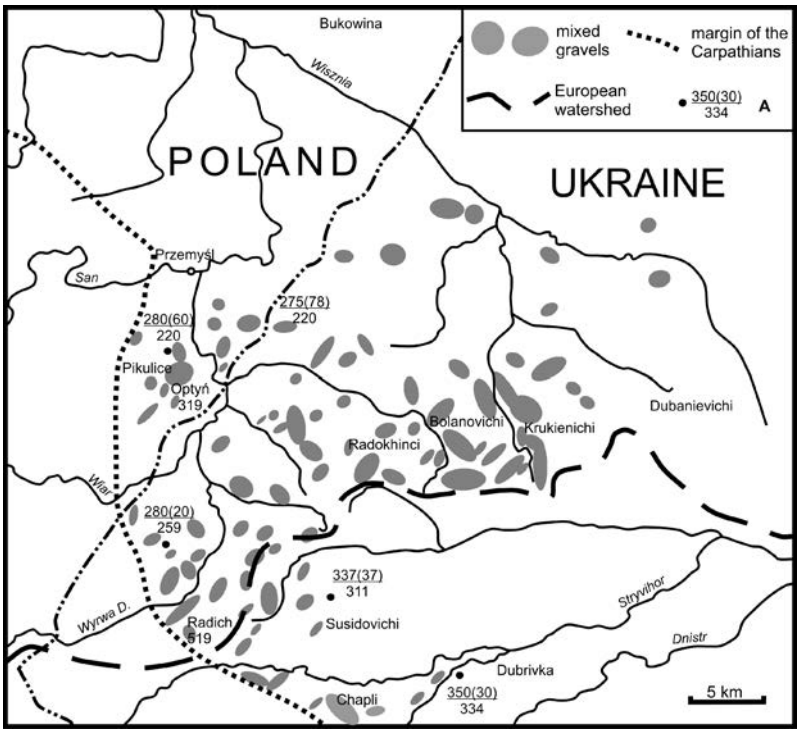

Fig. 5. Sites with mixed gravels in the San and Dnistr interfluves (supplemented, after Łanczont, 1997). A – site with the mixed gravels, indicated are: altitude of the top (numerator), bottom (denominator) and height above valley bottom (in brackets)

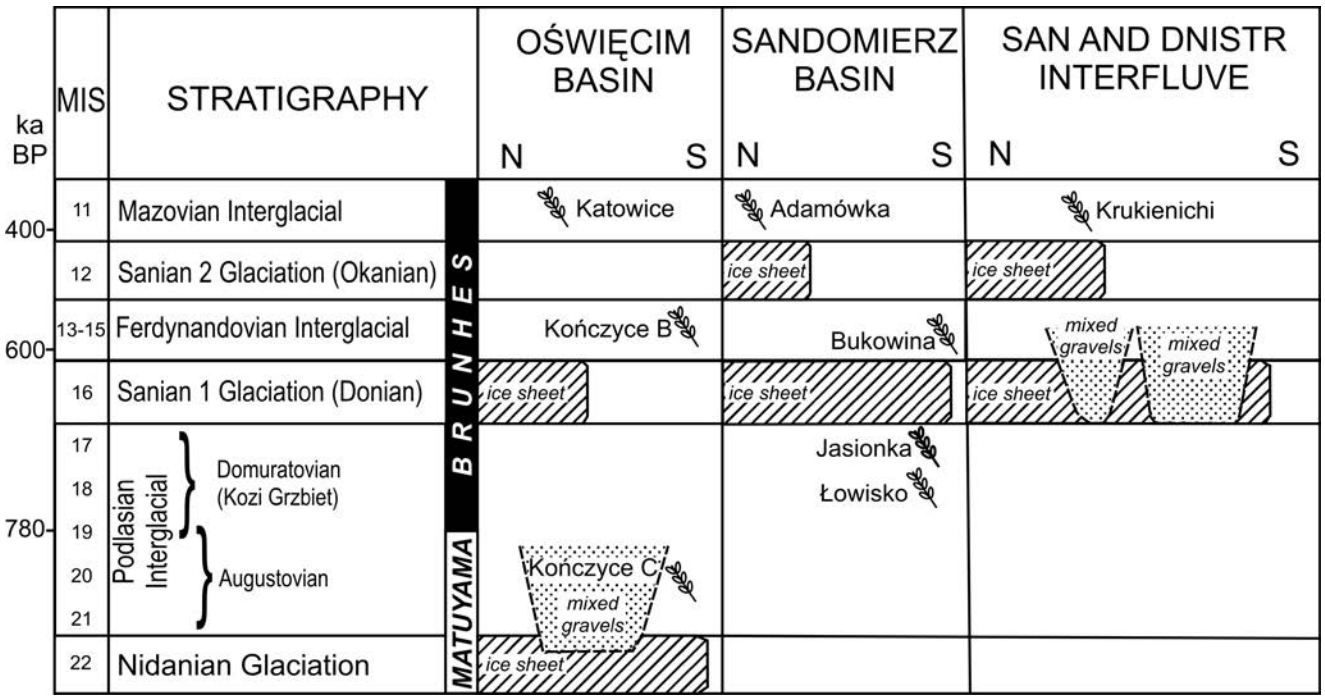

Fig. 6. Age and extent of Scandinavian ice sheets against interglacial sites with fossil flora and location of the mixed gravels in the northern foreland of the Carpathians; MIS – marine isotope stages

posits of the Ferdynandovian Interglacial (Lindner, 1992). Presumably, their deposition could be a result of the erosion of older deposits, that is, of the Sanian 1 (Donian) Glaciation (Gozhik *et al.*, 2012). Such an interpretation makes genetic and age correlation of these gravels with the mixed gravels in this area possible (Fig. 6). They were considered by Łanczont (1997) and Łanczont *et al.* (2011) as the 'primary (transgressive) mixed gravels'.

The occurrence of a till of the Sanian 1 Glaciation at the northern edge of the Carpathians was indicated by the lower till in the Zarzecze brickyard (Fig. 1; cf. Malata and Wójcik, 1999). This till was not identified by Łanczont *et al.* (2000), whereas the upper till and underlying sands, varved clays and a lag concentrate were correlated with the Sanian 2 Glaciation. However, this site was indicated by Łanczont *et al.* (2000) and Łanczont and Wojtanowicz (2005) in the cross-section Zalesie–Zarzecze, where presence of the ice sheet of the Sanian 1 Glaciation seems to be represented by the lower till in the Zalesie borehole and, after the erosion of it, by a lag concentrate identified in the Zarzecze section, mentioned above.

Possible advances of the Scandinavian ice sheet (Sanian 1 equivalent to Donian and Sanian 2 equivalent to Okanian) in this area are also indicated in the key section at Dubanievichi (Fig. 5). A till of the Sanian 2 Glaciation, with a gravel and boulder lag at the bottom, is underlain by loess-like deposits with pockets of a till of the Sanian 1 Glaciation (Boguckij *et al.*, 2004). It is assumed in other papers considering this area that a till or a relic lag to the south of the Dnistr-Stryvihor valley system should represent the Sambor Phase and to the north of it, the Krukienichi Phase of the same Sanian 2 Glaciation (Bogucki *et al.*, 2000, 2009; Boguckij and Łanczont, 2011; Jacyszyn *et al.*, 2011).

Such a general pattern of the Scandinavian ice sheet limits, interglacial deposits and mixed gravels in the interfluves of the Vistula–Odra (e.g. in the Oświęcim Basin) and of the San–Dnistr was reconsidered and correlated with interglacial palaeobotanic sequences and ice sheet limits in the Sandomierz Basin (Fig. 6). The last re-examination of previous investigations (Gozhik *et al.*, 2012) proved that a subtill fossil flora from the site Łowisko represented the Kozi Grzbiet (Domuratovian) Interglacial (Malopolanian after Stuchlik and Wójcik, 2001), whereas supratill organic deposits at Bukowina (Granoszewski, 1999) corresponded to the Ferdynandovian Interglacial. Presumably, it excludes a possible ice-sheet advance of the Sanian 2 Glaciation to the northern edge of the Carpathians. The subtill organic deposits at Jasionka, connected with the Ølgod warming in Denmark (cf. Dąbrowski (1967), should correspond with the Kozi Grzbiet Interglacial (cf. Głazek *et al.* 1976). The older gravels with crystalline material and Lower Triassic (Werfenian) quartzites in this section were found to have been derived from the Tatra Mountains (cf. Laskowska-Wysoczańska, 1967a, b). The overlying till in turn is older than the lake deposits at Adamówka that represent the Mazovian Interglacial (Bińka *et al.*, 1987) and quite easily could be correlated with the sites of this interglacial in the Odra drainage basin at Gościęcin, Stanowice and Katowice (Nita, 2009) and with interglacial deposits at Krukienichi, in western Ukraine (Łanczont *et al.*, 2003).

FINAL REMARKS AND CONCLUSIONS

All of the data presented suggest most convincingly that the mixed gravels are mostly of fluvial, partly fluvio-peri-

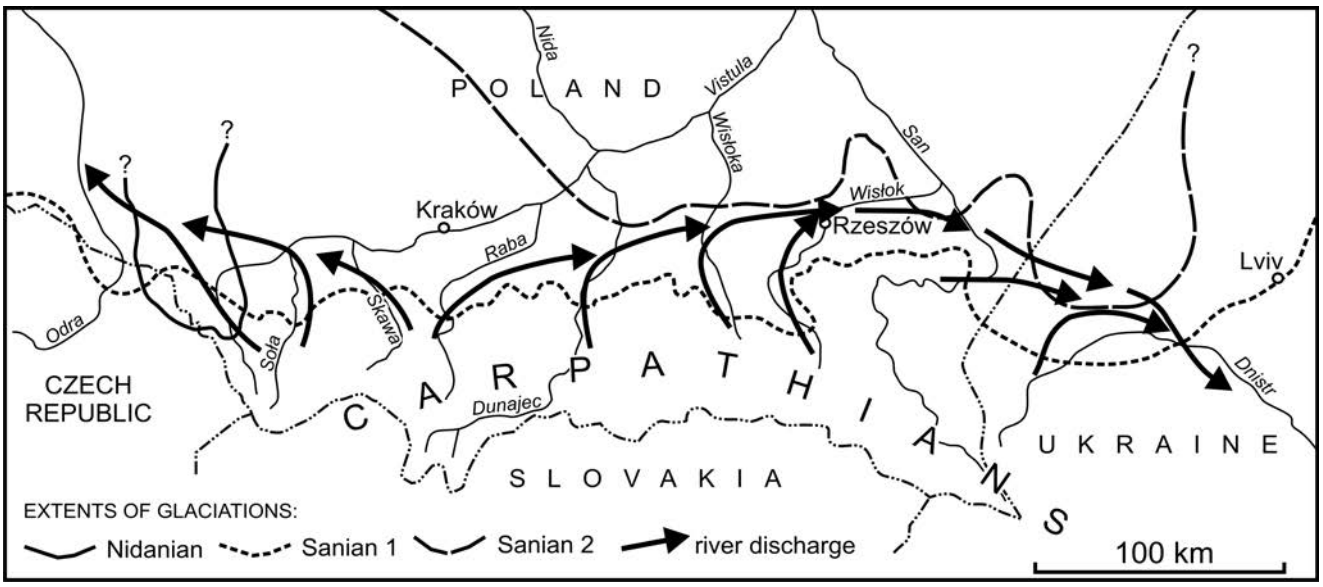

Fig. 7. Palaeogeographical sketch of valley pattern, making accumulation of the mixed gravels possible in the northern foreland of the Carpathians, and limits of Scandinavian glaciations

glacial and partly interglacial origin. Deposition of these gravels occurred usually to the north of the areas with *in situ* occurrences of rocks of the Carpathian flysch, that is, to the north of the Carpathian nappes (Fig. 5). Predominance of Carpathian over Scandinavian material in these gravels proves unequivocally the prevailing role of the Carpathian rivers. When flowing from the south northwards, they first eroded flysch rocks and then the accumulations of freshly deposited glacial deposits.

In the interfluves of the Vistula and the Odra, these rivers shaped the valley bottoms, inclined from 350–340 m a.s.l. near Ustroń and Skoczów to about 270–260 m a.s.l. near Kończyce. Also in the case of the interfluves of the San and the Dnistr, the valley bottoms occurred from 350–337 m a.s.l. near Dubrivka and Susidovichi to 280–275 m a.s.l. near Przemyśl (Fig. 6) and about 260 m a.s.l. near Krukienichi. These facts probably support the idea of the occurrence of buried valley systems that are sloping northwards in both interfluves. Therefore, they support a fluvial origin for the gravels described.

The deposition of the mixed gravels in the interfluves of the Vistula and the Odra followed the incision of a till that was older than the Brunhes/Matuyama boundary (780 kyrs BP). This glaciation was named the Olza Glaciation or the Carpathian Glaciation and was correlated with the Narevian Glaciation in the Polish Lowland (Wójcik *et al.*, 2004). The present state of knowledge suggests (Lindner, 2009; Gozhik *et al.*, 2012) that this till should be correlated with the Nidanian Glaciation (Fig. 6). Recent re-examination of the Polish stratigraphy (Lindner *et al.*, 2013) proved that the warming, corresponding to the activity of rivers that eroded glacial deposits of this glaciation, should be referred to the terminal part of the younger, tri-optimal Podlasian Interglacial. This interglacial comprises the overlapping periods of warming, represented by Augustovian and Domuratovian pollen successions, the latter being an age equivalent of the Kozi Grzbiet Interglacial (Fig. 6).

In the case of the San and Dnistr interfluves, the mixed gravels to the south of the Dnistr-Stryvihor valley system quite commonly occur beneath aeolian deposits (Bogucki *et al.*, 1999). Therefore, they seem to be a relic of the eroded deposits of the older glaciation, considered by the authors cited to represent the older Sambor Phase of the Sanian 2 Glaciation, and by others (cf. Gozhik *et al.*, 2012; Lindner *et al.*, 2013) the Sanian 1 Glaciation. Such an opinion strongly confirms the suggestion of Przepiórski (1938), who found two boulder horizons in the mixed gravels at Pikulice, near Przemyśl, that they are evidence of two advances of the Scandinavian ice sheet. The evidence presented here indicates that these gravels are younger than the Sanian 1 Glaciation and represent mainly the Ferdynandovian Interglacial (Lubny).

The material presented and the attempt to interpret its palaeogeography suggest that the area of the interfluves of the Vistula and the Odra, which was more open northwards, was occupied by the Scandinavian ice sheet already during the Nidanian Glaciation (MIS 22). In the remaining part of the northern foreland of the Carpathians, including the interfluves of the San and the Dnistr, the ice sheet was at its most extensive later, during the Sanian 1 Glaciation (MIS 16). Therefore, this was much earlier than suggested by Mojski (2005), but in agreement with the investigations of Zimnal and Marciniec (2005). The extent of the ice sheet during the younger Sanian 2 Glaciation (MIS 12) was smaller (Figs 1, 7). It reached the Lower Nida drainage basin (Lindner, 1988), the northern part of the Sandomierz Basin and the San–Dnistr interfluve (Gozhik *et al.*, 2012).

Therefore, deposition of the mixed gravels as a fluvial accumulation, resulting from the erosion of the glacial series of the Nidanian and Sanian 1 Glaciations by the Carpathian rivers, occurred in the whole northern foreland of the Carpathians (Fig. 7). These gravels are best preserved within the Vistula–Odra and San–Dnistr interfluves, owing to their watershed location and related minor post-deposi-

tional erosion. Such gravel accumulations must have occurred also at the mouths of most Carpathian rivers. During the Podlasian and Ferdynandovian interglacials the Vistula, Soła and Skawa Rivers flowed north-westwards to the Odra valley. The waters of the Raba, Dunajec, Wisłoka, Wisłok and San entered the Fore-Carpathian channel (among others Łoziński, 1909; Teisseyre, 1938; Laskowska-Wysoczańska, 1971, 1995; Wojtanowicz, 1978; Nitychoruk, 1991; Zimnal, 2001) and flowed eastwards to the present Dnistr valley.

The palaeogeographical development of a fluvial pattern in the northern foreland of the Carpathians, as presented above, corresponds to the valley system of Starkel (1984), developed during both the Tiglian Interglacial in the Odra drainage basin and the South Polish Glaciation in the Dnistr drainage basin.

Acknowledgements

The valuable comments of Petro Voloshyn (Lviv University, Ukraine) and the anonymous reviewer were of great help in improving the manuscript. Special thanks are given to the Editor-in-Chief, Alfred Uchman, for his editorial remarks.

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