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Pleistocene glaciations in southern Poland – a revision

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A revised stratigraphy the Lower and Middle Pleistocene in southern Poland is presented, based on geological evidence from key sites, better constraints on the number and age of Scandinavian ice sheet advances, and the stratigraphic setting of the interglacial sequences. Identification of the palaeomagnetic Brunhes/Matuyama boundary and an admixture of glacially derived material of northern provenance in fluvial deposits demonstrate that the oldest Scandinavian ice sheet advance (Nidanian Glaciation) in Poland and the first warming of the oldest interglacial (Podlasian) occurred in the late Early Pleistocene. The first ice sheet advance in the Oświęcim Basin is recorded by a till of the Nidanian Glaciation. A single till and its geological setting relative to deposits of the Podlasian and Ferdynandovian interglacials show that, contrary to previous opinions, the ice sheet advance of the early Middle Pleistocene Sanian 1 Glaciation was a single, the most extensive glacial event in the Sandomierz Basin and in western Ukraine. The Sanian 2 and the Odranian ice sheets were considerably less extensive in eastern Poland. The revised Pleistocene stratigraphy and palaeogeography of southern Poland is a significant step forward towards reliable correlation of the Polish climatostratigraphic units with the European stratigraphy.

Key words: Nidanian Glaciation, Sanian 1 Glaciation, Sanian 2 Glaciation, Ferdynandovian pollen succession, mixed gravels.

INTRODUCTION

At its maximum extent, the Scandinavian ice sheet reached the Carpathians and the Sudetes in southern Poland. In the marginal part of the Carpathians, the maximum ice sheet limit of the Pleistocene glaciation, at first named the Cracovian or the South Polish one, could be determined based on occurrence of erratic boulders and an admixture of the Scandinavian material in other deposits (cf. Lindner, 2001). In the Early Pleistocene, gravels were deposited in the Carpathian foreland by the Carpathian rivers (Łyczewska, 1948; Laskowska-Wysoczańska, 1971; Mojski, 1984, 1985; Starkel, 1984). These are characterized by low petrographic diversity while their accumulation was associated with a preglacial interval that preceded the first ice sheet advance into this area (cf., Gradziński and Unrug, 1959; Kucia-Lubelska, 1966; Dżułyński et al., 1968; Nawrocki and Wójcik, 1990; Lindner and Siennicka-Chmielewska, 1998). Based on plant fossils in clay balls found in these fluvial gravels, these preglacial deposits were found then to represent the late Miocene and the Pliocene (Brud and Worobiec, 2003; Zastawniak-Birkenmajer and Birkenmajer, 2012).

A depression in the southern Sandomierz Basin favoured location of a river valley along the margin of the Carpathians in the Early Pleistocene, the river draining south-east to the Dnister River valley (Lindner and Marks, 2015). A lack of the Scandinavian material in these oldest fluvial deposits indicated that the river was supplied by the Carpathian tributaries. The first ice sheet advance in southern Poland (cf., Fig. 1) led to an admixture of Scandinavian material in the fluvial deposits, these being known as the mixed gravels (Hilber, 1882; Tietze, 1883; Uhlig, 1884; Łoziński, 1907; Romer, 1907; Stupnicka, 1962; Łanczont, 1997; Łanczont et al., 2011; Lindner and Marks, 2013).

The sites with records of interglacial pollen successions enabled determination of the ice sheet limit and age of the Scandinavian glaciation in the Sandomierz Basin and the marginal part of the Carpathians (Fig. 1). Maximum limits of two ice sheets were determined in this area, correlated with the Sanian 1 and the Sanian 2 glaciations (Fig. 2). This was primarily based on the occurrence of Scandinavian erratic material, but also interpreted from the pollen spectrum and a geological setting of the Jasionka site (Dąbrowski, 1967; Głazek et al., 1976). The pollen succession examined was assumed to represent the Ferdynandovian Interglacial and a till above the interglacial deposits at Jasionka was considered as evidence of the ice sheet advance during the Sanian 2 Glaciation (Lindner, 1988a, b, 2001). This glaciation was postulated to be the most extensive

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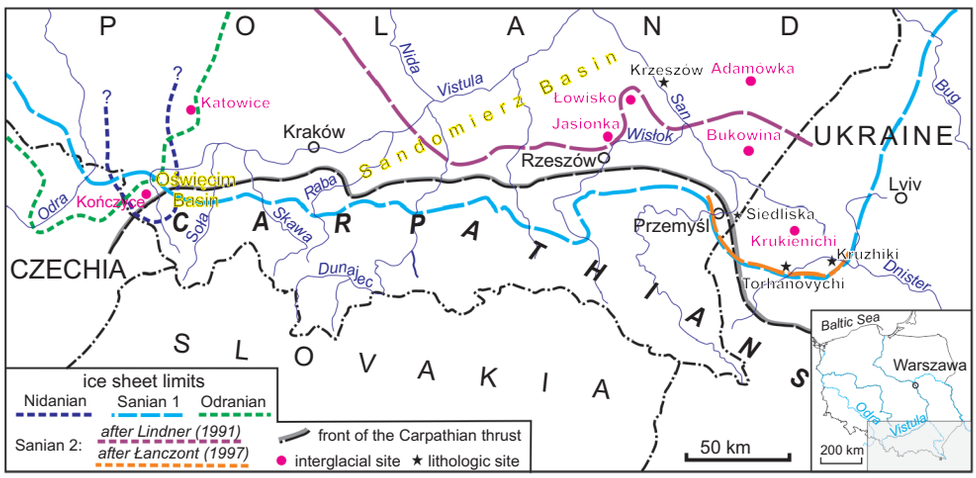

Fig. 1. Location sketch with key sites and ice sheet limits in southern Poland; after Lindner (1991, 2001), Łanczont (1997), Łanczont et al. (2003, 2019); Lindner and Marks (2013, 2015), modified

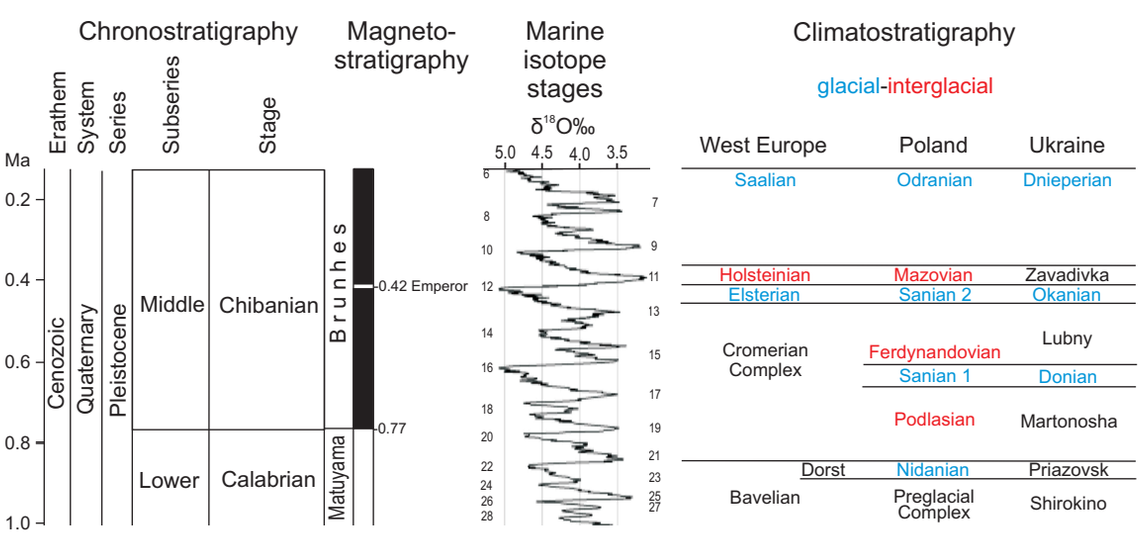

Fig. 2. Global chronostratigraphy and magnetostratigraphy of the late Early and Middle Pleistocene (Laj and Channel, 2007; Head et al., 2021), their correlation with marine isotope stages (Lisiecki and Raymo, 2005) and the Quaternary climatostratigraphy in western Europe (cf. Gibbard et al., 2005), Poland and Ukraine (after different sources)

in southeastern Poland and western Ukraine, with ice sheet lobes advancing locally into the Carpathian basins (Butrym et al., 1988; Łanczont, 1997; Łanczont et al., 2003, 2019) and was at first correlated with the Wilga Glaciation, defined at the Ferdynandów site in southern Podlasie (cf., Janczyk-Kopikowa et al., 1981). Based on thermoluminescence dating of a till (cf. Lindner, 1992), the Sanian 2 ice sheet was then considered to reach only the central part of the Sandomierz Basin (Lindner, 2001; cf. Gozhik et al., 2012). Then, the maximum ice sheet extent was associated either with the Sanian 1 Glaciation in the Sandomierz Basin (Lindner, 2001) or with the Sanian 2 Glaciation in the Polish-Ukrainian border area (Łanczont, 1997; Łanczont et al., 2019). Alternatively, the first ice sheet in the Oświęcim Basin was associated with the Nidanian Glaciation (Wójcik et al., 2004; Lindner et al., 2013).

Fluvial runoff, parallel to the Carpathians margin, was interrupted during the Sanian 1 Glaciation but it was reactivated after the ice sheet retreat in an ice-marginal spillway (Laskowska-Wysoczańska, 1967). At that time, fluvial deposits were already enriched in Scandinavian material and the waters drained into the Dnistr Valley (cf. Lindner and Marks, 2015).

In southwestern Poland, the northern margin of the Sudetes was reached or slightly overpassed by the ice sheets of the Sanian 2 and the Odranian glaciations (Szczepankiewicz, 1969; Walczak, 1972; Przybylski et al., 2013). In the northern Czechia, glacial deposits of two Scandinavian glaciations were recognized, the Odranian Glaciation being the most extensive in the Moravian Gate (Nývlt, 1998, 2011).

This paper provides a revised stratigraphy of the late Lower and early Middle Pleistocene in southern Poland. This is com-

bined with a better-constrained number and age of ice sheet advances, including from the stratigraphic setting of interglacial sequences recorded at key sites in this region. It is a step towards more reliable correlation of the climatostratigraphic units defined in Poland with the European stratigraphy (Marks, 2023; cf. Gibbard et al., 2005).

SOURCE MATERIAL

The analysis is based on results published previously by other researchers. A critical review of the type sections in the Sandomierz Basin and the Oświęcim Basin enabled reinterpretation of results of previous investigations and application of a modern stratigraphic classification (cf. Marks et al., 2014; http://quaternary.stratigraphy.org/stratigraphic-guide).

Lithostratigraphy, biostratigraphy (mainly palynostratigraphy), magnetostratigraphy and chronostratigraphy of the geological successions at key sites were established and regional climatostratigraphic units were distinguished. In this analysis, apart from a lithogenetic classification of the deposits, a boundary was established, that separated older fluvial gravels of Carpathian derivation from mixed gravels enriched in Scandinavian material. Pollen spectra of the organic deposits enabled distinction of interglacial successions and their placing within the Polish stratigraphic scheme. The location of the Brunhes/Matuyama palaeomagnetic boundary at Kończyce was a key chronological marker of the Lower/Middle Pleistocene boundary. Application of lithostratigraphy, palynostratigraphy and magnetostratigraphy laid the foundations for a chronostratigraphic subdivision that could be used for correlation with climatostratigraphic units elsewhere in Poland.

MAIN TYPE SECTIONS

There are only 4 key sites with deposits of the late Early and early Middle Pleistocene interglacials and tills of the Scandinavian glaciations in southern Poland: Kończyce, Jasionka, Łowisko and Bukowina (Fig. 1). The age of tills was estimated based on the petrography of the underlying and overlying fluvial deposits, pollen successions and palaeomagnetic data (cf. Marks, 2022).

KOŃCZYCE

The first Scandinavian ice sheet in southern Poland is recorded by a till at Kończyce in the Oświęcim Basin (Fig. 1). This till, together with the overlying organic deposits (cf. Fig. 2), is located beneath the Brunhes/Matuyama palaeomagnetic boundary (Wójcik et al., 2004; cf. Lindner et al., 2013). Fluvial sand and gravel at the bottom of the section are devoid of northern provenance material ice-derived from Scandinavia and the Baltic Basin (Fig. 3) and are overlain by glaciofluvial sand and gravel, locally with a till that was correlated with the Narevian Glaciation or alternatively with the hypothetical Olza or Carpathian Glaciation (cf. Wójcik et al., 2004). Above the glaciofluvial deposits there is organic silt with a pollen spectrum representing part of an interglacial succession (Fig. 3), with high contents of oak (*Quercus*), alder (*Alnus*), linden (*Tilia*) and hazel (*Corylus*), and smaller participation of elm (*Ulmus*), hornbeam (*Carpinus*) and fir (*Abies*). Location of these deposits beneath the Brunhes/Matuyama boundary suggested unequivocally a correlation with the Augustovian pollen succession and of the underlying till with the Nidanian Glaciation (cf. Lindner et al., 2013). The thickness of the organic deposits and the characteristics of the pollen spectrum indicate a younger part of the bipartite Augustovian succession (cf. Ber et al., 1998; Winter, 2006, 2008). *Abies* was common at Kończyce, this tree being typical of mountain and upland areas, while it was absent at that time from sites in the lowland area of northeastern Poland (cf. Lindner et al., 2013).

In the other part of the exposure, above the interglacial succession there are fluvial deposits of a braided river, typical for a cool climate (Wójcik et al., 2004), in turn overlain by silt and organic silt with peat interbeds of a meandering river, characteristic of a temperate climate (Fig. 3). The pollen succession in these organic deposits recorded 2 distinct warmings, separated by a cooling. Each warming is indicated by a high participation of alder (*Alnus*), hornbeam (*Carpinus*) and hazel (*Corylus*). This pollen succession was correlated with the Ferdynandovian Interglacial (cf. Wójcik et al., 2004).

JASIONKA

This site, located 8 km to the north of Rzeszów (Fig. 1), is important for the stratigraphy of the early Middle Pleistocene in the Sandomierz Basin (Laskowska-Wysoczańska, 1967). Marine clays of the Miocene at this site are overlain by fluvial sand and gravel, devoid of northern provenance material, but containing a bed of organic silt, gyttja and peat of a buried oxbow lake (Fig. 4).

The pollen succession indicates initial pine forest communities with an admixture of spruce and birch, rare oak and elm. Progressive warming led to the predominance of mixed pine-oak forest with spruce and birch, and deciduous forest with oak and elm, and an admixture of linden and rare hornbeam. It undoubtedly represents a moderately warm climatic optimum, followed by a cooling and a wetter climate, reflected by a dominant pine forest and the occurrence of alder (Dąbrowski, 1967). The appearance of mistletoe (*Viscum*) indicated mean winter temperatures of >–8°C and mean summer temperatures >16°C, such seasonal temperature difference suggesting a continental climate. There was also some larch (*Larix*) and aspen (*Populus*), whereas progressive cooling resulted in an increased participation of birch and spruce, a maximum of alder and then a predominance of a boreal forest which became gradually thinner (Fig. 4).

The pollen succession at Jasionka was initially considered to represent an interstadial (Dąbrowski, 1967), then correlated with the Kozi Grzbiet Interglacial (cf. Głazek et al., 1976), named later the Malopolanian Interglacial (Różycki, 1978). Finally, it was found to be decidedly different from the succession of the Ferdynandovian Interglacial (Stuchlik and Wójcik, 2001) and correlated with the younger part of the Podlasian Interglacial (cf. Lindner et al., 2013). The organic deposits at Jasionka are overlain by glaciofluvial sand and gravel, between two tills of the Sanian 1 Glaciation (Lindner and Marks, 2015). The upper till may reflect a local advance of the ice sheet margin during general retreat of the ice sheet. Such a local till bed was also noted by the author in 2022 at Krzeszów on the San River (cf. Fig. 1).

ŁOWISKO

This site is located on the Vistula and San interfluves in the Sandomierz Basin (Stuchlik and Wójcik, 2001). Marine clay of

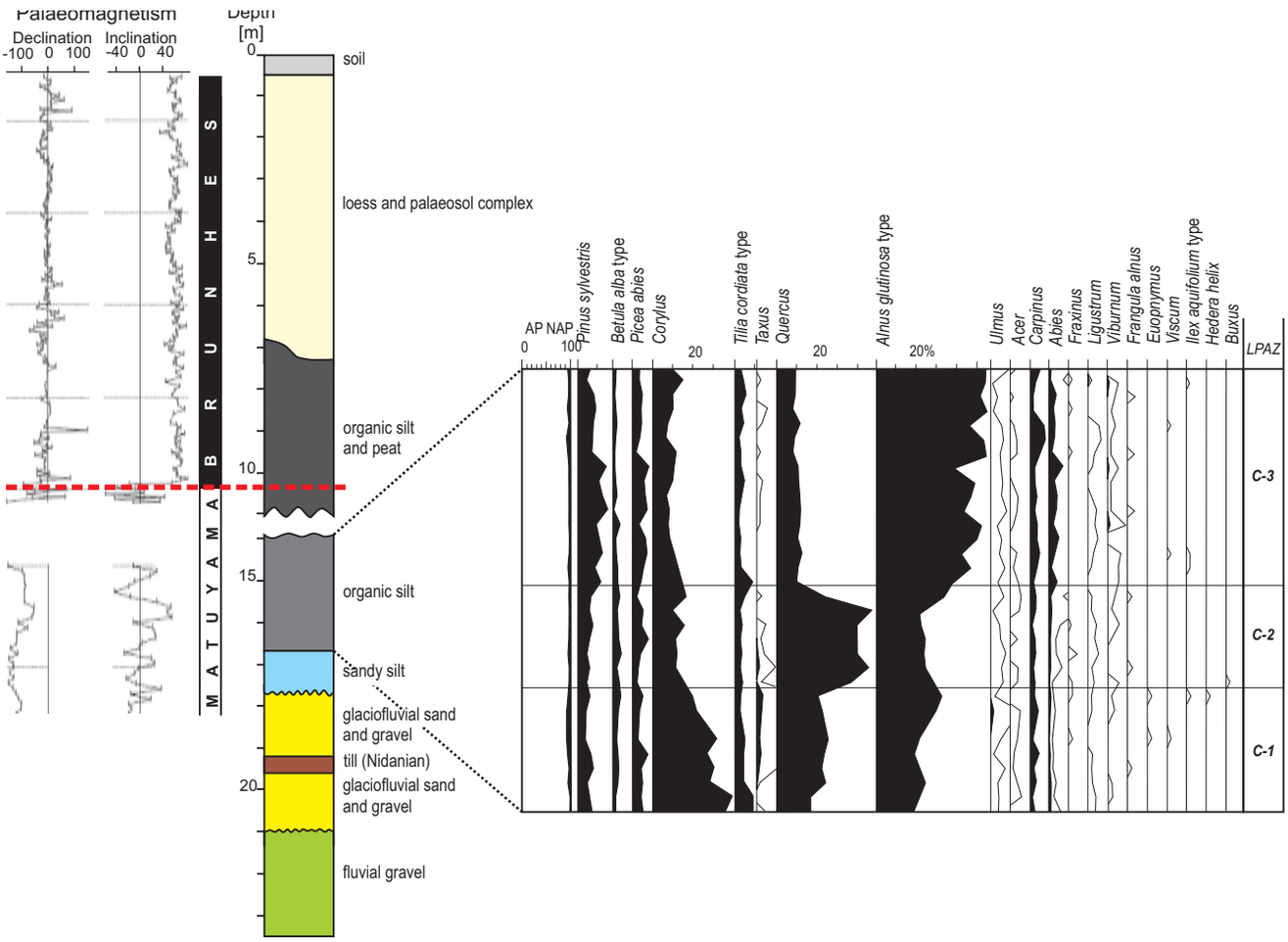

Fig. 3. Kończyce: lithology, pollen spectrum and palaeomagnetic characteristics; after Wójcik et al. (2004), modified

the Miocene is overlain by fluvial sand and gravel with pebbles of the Carpathian sandstone, quartz and flint (Fig. 5). A lack of northern provenance material indicates deposition prior to the first ice sheet advance in the Sandomierz Basin (Laskowska-Wysoczańska, 1971; Starkel, 1971, 1984; cf. Gozhik et al., 2012). Organic silt and silt are present above the fluvial deposits.

A pollen succession represented the final part of the interglacial when a warm and wet climate prevailed, with mixed forest communities composed of oak, linden, elm, hornbeam and alder (Stuchlik and Wójcik, 2001). Thermophilous trees declined and were gradually replaced, at first by a boreal forest and then by a tundra vegetation (Fig. 5). The partial pollen succession at Łowisko is difficult to interpret stratigraphically but it resembles the pollen succession at Jasionka and differs significantly from the Augustovian and Ferdynandovian successions (Stuchlik and Wójcik, 2001). The closest similarity of the Łowisko palynological spectrum to the that of Jasionka (Stuchlik and Wójcik, 2001) suggests its setting in a terminal part of the Domuratovian succession, that is, in the terminal part of the Podlasian Interglacial (cf. Lindner and Marks, 2015). The interglacial deposits at Łowisko are overlain by silt with heavy minerals of northern provenance that represent accumulation in a proglacial lake, subsequently mantled by a till of the Sanian 1 Glaciation (Fig. 5).

BUKOWINA

This site, located in the eastern part of the Sandomierz Basin, played an important role in determination of ice sheet extents during the Sanian 1 and Sanian 2 glaciations (cf. Lindner, 2001). At the bottom of the section, marine clays of the Miocene are overlain by glaciofluvial gravel and sand with an admixture of northern provenance material (Wieczorek, 1999), derived probably from eroded till of the Sanian 1 Glaciation (Fig. 6). Above, there is a fluvial sand with a fining-upwards trend, overlain by gyttja and peat of an oxbow palaeolake and accompanied by sand and silt deposited on a floodplain. The pollen spectrum of these organic deposits is similar to that of the second optimum of the Ferdynandovian succession (Granoszewski, 1999). At the top of the section is fluvial sand of the Odranian Glaciation and aeolian sand of the Vistulian Glaciation (Wieczorek, 1999).

DISCUSSION

A till beneath deposits of the Podlasian Interglacial at Kończyce is evidence of the oldest glaciation in Poland, the

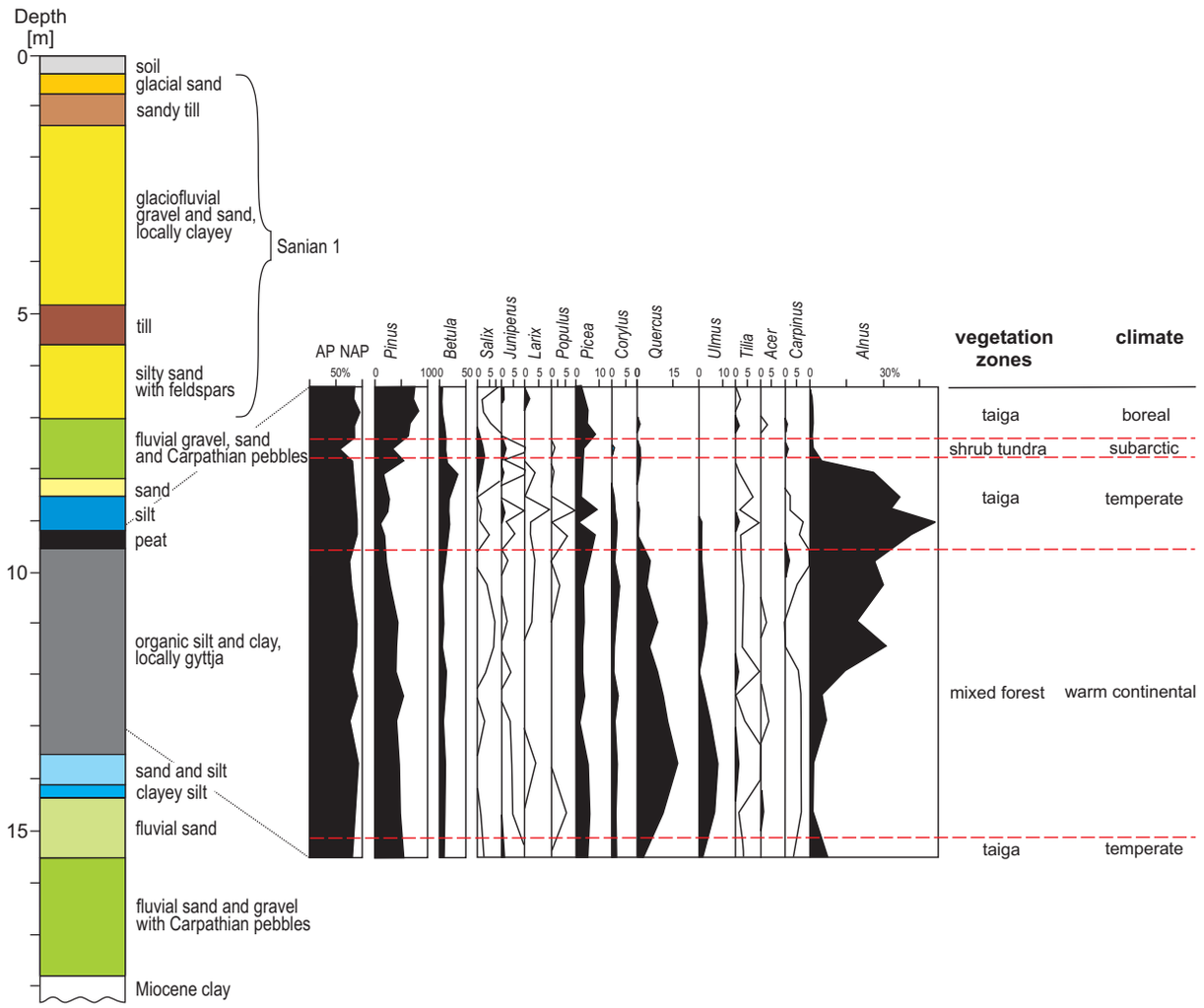

Fig. 4. Jasionka: lithology and pollen spectrum; after Laskowska-Wysoczańska (1967) and Dąbrowski (1967), simplified and modified

same as initially identified at the Kozi Grzbiet site in the Holy Cross Mountains, based on the occurrence of northern provenance material in glaciofluvial deposits located below the Brunhes/Matuyama boundary (Głazek et al., 1976, 1977). At present, this glaciation is named the Nidanian Glaciation; it corresponds to the Narevian Glaciation in Belarus and might correlate with the Dorst Substage of the Bavelian Stage in Western Europe (cf. Lindner et al., 2013). During the Podlasian Interglacial, fluvial deposition of mixed gravels occurred in the Oświęcim Basin (Stupnicka, 1962; Lindner and Marks, 2013).

Pollen successions and locations of interglacial sites in southeastern Poland enabled determination of the age and extents of ice sheet advances in the Sandomierz Basin and the marginal part of the Carpathians. The presence of two ice sheets distinguished in this area, and correlated with the Sanian 1 and the Sanian 2 glaciations, was based on the assumption that the pollen succession at Jasionka represented the Ferdynandovian Interglacial (Lindner, 1988a, b, 2001) as supported by pollen analysis (cf. Dąbrowski, 1967) and subsequent stratigraphic interpretation (Głazek et al., 1976). A till above the interglacial deposits was then considered as evidence of the Sanian 2 ice sheet advance into the central part of the Sandomierz Basin (Lindner, 2001; cf. Gozhik et al., 2012).

Revision of the number and extents of the Scandinavian ice sheets in the Sandomierz Basin was possible, after the pollen succession at Jasionka was found to represent a younger part of the Podlasian Interglacial and the pollen succession at Łowisko was correlated with that at Jasionka (Stuchlik and Wójcik, 2001; cf. Lindner and Marks, 2013). On the other hand, there is no till above the Ferdynandovian succession at Bukowina, the latter being underlain by glaciofluvial deposits of the Sanian 1 Glaciation (Wieczorek, 1999). Generally, only a single till was recorded in the Sandomierz Basin (cf. Wojtanowicz, 1971, 1985, 1997; Łanczont et al., 1988; Dolecki et al., 1996; Łanczont, 1997) and its stratigraphic setting is obvious at Jasionka and Łowisko where it is underlain by organic deposits of the Podlasian Interglacial (Fig. 7). Based on the stratigraphic setting of the mixed gravels in the Sandomierz Basin (Łanczont, 1997; Łanczont et al., 2011; Lindner and Marks, 2013), a regional boundary between the preglacial and glacial Pleistocene may be distinguished (cf. Stuchlik and Wójcik, 2001).

The chronology and extent of the Scandinavian ice sheets in southern Poland was based on the geological setting of the Brunhes/Matuyama boundary at Kończyce, supported by occurrence of the mixed gravels in the Oświęcim and the Sandomierz basins (Fig. 7). The relation of the fluvial succes-

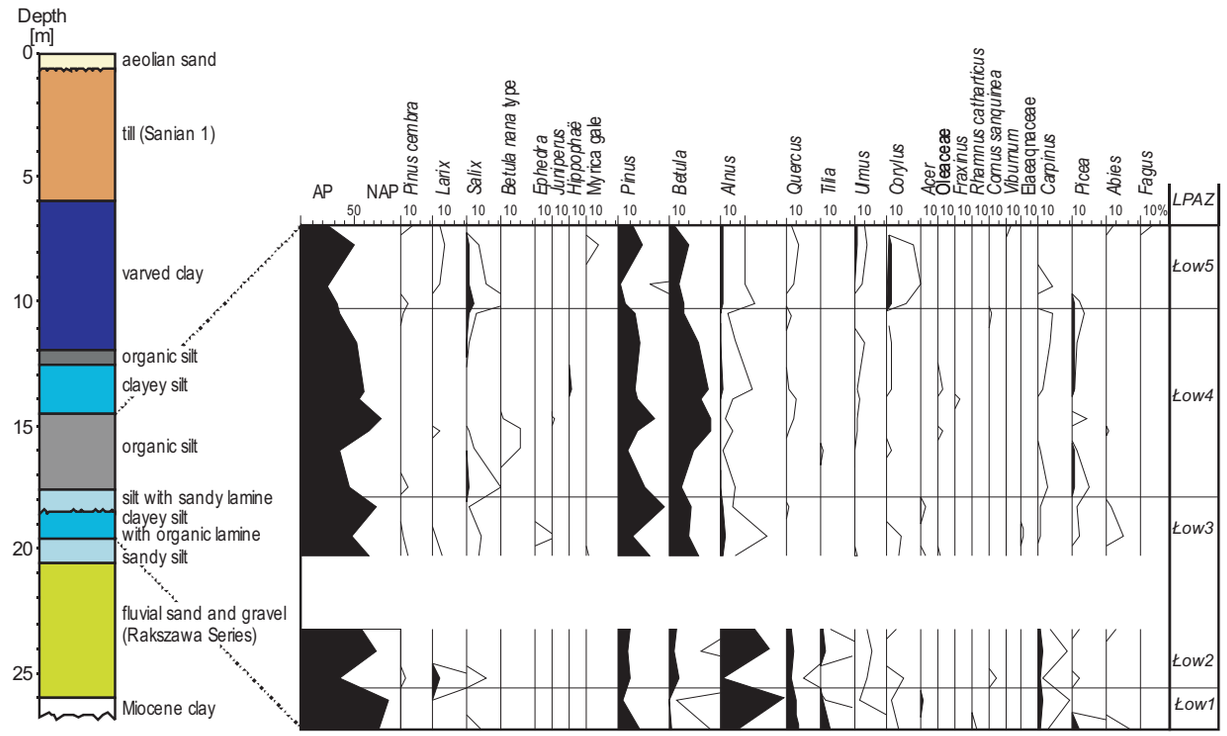

Fig. 5. Łowisko: lithology and pollen spectrum;
after Stuchlik and Wójcik (2001), Lindner and Marks (2015), modified

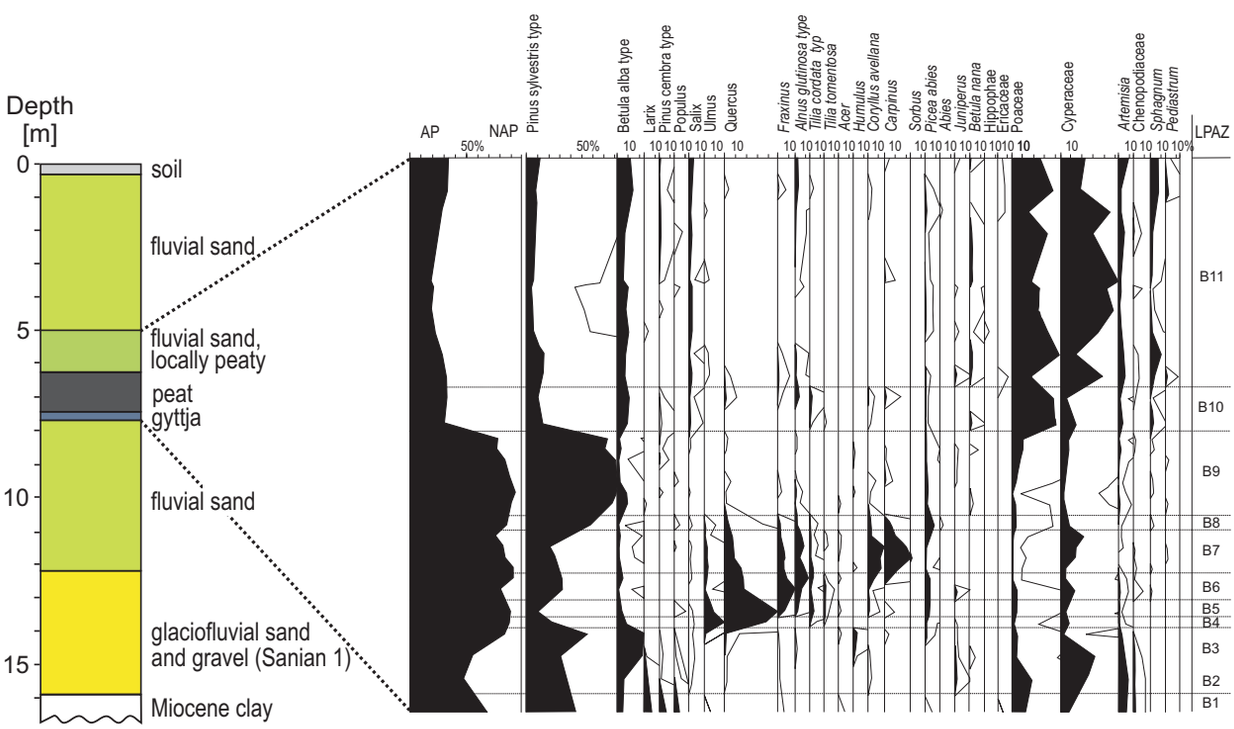

Fig. 6. Bukowina: lithology and pollen spectrum;
after Wieczorek (1999) and Granoszewski (1999), simplified and modified

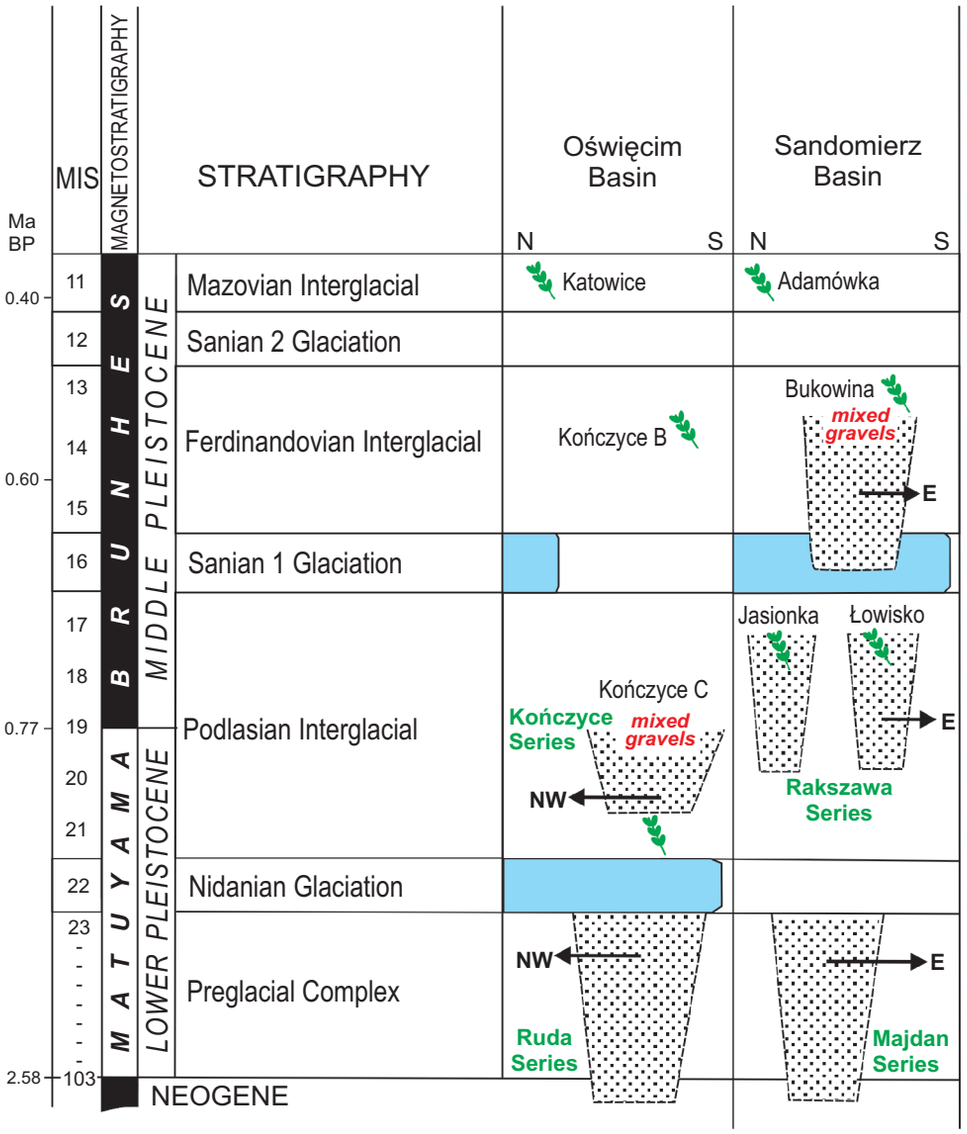

Fig. 7. Age and extents of the late Early and early Middle Pleistocene ice sheet advances in southern Poland (blue), sites with interglacial pollen spectra (green branches) and fluvial gravels (dotted) in the northern foreland of the Carpathians; arrows indicate direction of river discharge, MIS – marine isotope stages; after Lindner and Marks (2013, 2015), modified

sion of the Sandomierz Basin to the Dnister terraces is also important, because the Brunhes/Matuyama boundary was identified there in deposits of terrace H at Mikhailovka (Matoshko et al., 2004). Thus, the late Early Pleistocene Nidanian ice sheet advance was the first into the Oświęcim Basin, and the Sanian 1 advance into the Sandomierz Basin (Lindner and Marks, 2015).

The most extensive ice sheet advance in western Ukraine has been correlated with the Sanian 2 Glaciation, with a single till was recorded in this region, including the Kruzhiki and Torhanovychi sites (Łanczont et al., 2003, 2019). On the other hand, two tills were recorded in the vicinity of the Vistula River Gorge through the South Polish Uplands. Among these, the older till was correlated with the Sanian 1 Glaciation and the younger till with the Odranian Glaciation (Muchowski 1992; Pożaryski et al., 1994). A less extensive ice sheet advance during the Sanian 2 Glaciation was suggested by the geological setting of the interglacial sites in southern Podlasie. In this area, a till of the Sanian 2 Glaciation was commonly identified above the deposits of the Ferdynandovian Interglacial though not at every site (cf. Żarski et al., 2009: figs. 4 and 6). Therefore, a revised stratigraphy of tills suggests that the Sandomierz Basin and the western Ukraine were occupied only by the ice sheet of the Sanian 1 Glaciation (Fig. 8).

CONCLUSIONS

A maximum limit of the Pleistocene ice sheet in southern Poland may be determined, based on dispersion of northern provenance erratic boulders, the occurrence of the first ice sheet in this region being indicated by admixture of northern provenance material in fluvial deposits. Tills and ice sheet extents of 4 glaciations have been generally distinguished in southern Poland including the Nidanian, Sanian 1, Sanian 2 and Odranian. A revised stratigraphy of the Lower and Middle Pleistocene, based on constraining the stratigraphic setting of

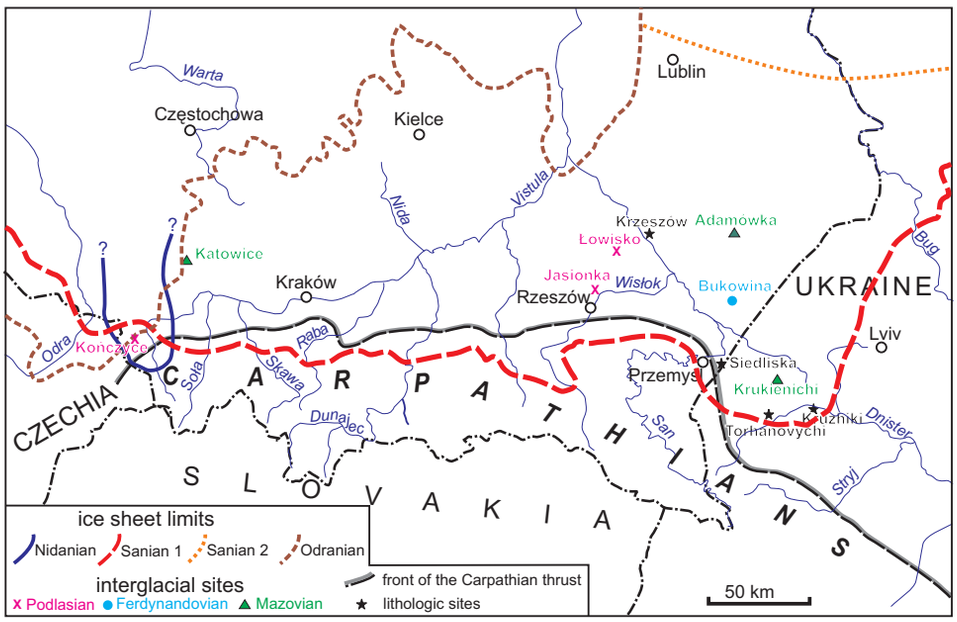

Fig. 8. Key sites and ice sheet extents in southern Poland; after Lindner and Marks (2015) and Łanczont et al. (2019), modified

the interglacial sequences at key sites, enabled revision of the number and the ages of Scandinavian ice sheet advances into this region. Identification of the palaeomagnetic Brunhes/Matuyama boundary and the presence of northern provenance material in fluvial deposits showed that the Nidanian Glaciation and the first warming of the Podlasian Interglacial occurred already in the late Early Pleistocene. This first ice sheet advance was recorded by a till of the Nidanian Glaciation and mixed gravels at the Kończyce site in the Oświęcim Basin. In the Sandomierz Basin a single till was recorded and its geological setting relative to deposits of the Podlasian and Ferdynandovian interglacials at Jasionka, Łowisko and Bukowina showed that, contrary to previous opinion, there was a single ice sheet advance of the Sanian 1 Glaciation, the most extensive in southern Poland and western Ukraine. The Sanian 2 and the Odranian ice sheet advances were most extensive in southwestern Poland though they were considerably less extensive in eastern Poland. This revision of the Lower-Middle Pleistocene stratigraphy and palaeogeography in southern Poland helps reliable correlation of the Polish climatostratigraphic units with the European stratigraphy.

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REFERENCES

Ber, A., Janczyk-Kopikowa, Z., Krzyszkowski, D., 1998. A new interglacial stage in Poland (Augustovian) and the problem of the oldest Pleistocene till. Quaternary Science Reviews, **17** 761–773. https://doi.org/10.1016/S0277-3791(97)00057-7.

Brud, S., Worobiec, G., 2003. Results of investigations on plant macroremains found in deposits of the Witów Series (southern Poland) (in Polish with English summary). Przegląd Geologiczny, **51**: 392–401.

Butrym, J., Maruszczak, H., Wojtanowicz, J., 1988. Thermoluminescence chronology of the Sanian (=Elsterian II) inland-ice deposits in the San and the upper Dniestr river basins (in Polish with English summary). Annales Societatis Geologorum Poloniae, **58**: 191–205.

Dąbrowski, M.J., 1967. Pollen analysis of an interstadial profile from Jasionka near Rzeszów (in Polish with English summary). Acta Geologica Polonica, **17**: 509–520.

Dolecki, L., Łanczont, M., Nowak, J., 1996. Mesopleistocene glacial sediments in borderland between Poland and Ukraine (in Polish with English summary). In: Geneza, litologia i stratygrafia utworów czwartorzędowych, **2** (ed. A. Kostrzewski): 83–95. Wydawnictwo Naukowe UAM, Poznań.

Dżułyński, S., Krysowska-Iwaszkiewicz, M., Oszast, J., Starkel, L., 1968. On Lower Quaternary gravels in the Sandomierz Basin (in Polish with English summary). Studia Geomorphologica Carpatho-Balcanica, **2**: 63–74.

Gibbard, P.L., Boreham, S., Cohen, K.M., Moscariello, A., 2005. Global chronostratigraphical correlation table for the last 2.7 million years. Boreas, **34**: insert.

Głazek, J., Lindner, L., Wysoczański-Minkowicz, T., 1976. Interglacial Mindel I/Mindel II in fossil-bearing karst at Kozi Grzbiet in the Holy Cross Mts. Acta Geologica Polonica, **26**: 376–393.

Głazek, J., Kowalski, K., Lindner, L., Młynarski, M., Stworzewicz, E., Tuchołka, P., Wysoczański-Minkowicz, T., 1977. Cave deposits at Kozi Grzbiet (Holy Cross Mts, Central Poland) with vertebrate and snail faunas of the Mindelian I/Mindelian II

interglacial and their stratigraphic correlations. Proceedings 7th International Speleological Congress, Sheffield: 211–214.

Gozhik, P., Lindner, L., Marks, L., 2012. Late Early and early Middle Pleistocene limits of Scandinavian glaciations in Poland and Ukraine. Quaternary International, **271**: 31–37. https://doi.org 10.1016/j.quaint.2010.07.027

Gradziński, R., Unrug, R., 1959. Origin and age of the "Witów series" near Cracow (in Polish with English summary). Rocznik Polskiego Towarzystwa Geologicznego, **29**: 181–195.

Granoszewski, W., 1999. Pollen analysis of interglacial deposits from Bukowina (sheet Laszki) (in Polish). In: VI Konferencja: Stratygrafia plejstocenu Polski, Czudec, 31 sierpnia–4 września 1999 (eds. T. Malata, P. Marciniec, P. Nescieruk, A. Wójcik and Z. Zimnal): 19–20. Państwowy Instytut Geologiczny, Kraków.

Head, M.J., Pillans, B., Zalasiewicz, J.A., Alloway, B., Beu, A.G., Cohen, K.M., Gibbard, P.L., Knudsen, K.L., Kolfschoten, T. van, Lirer, F., Litt, T., Liu, J., Marks, L., McManus, J., Piotrowski, J.A., Räsänen, M., Rasmussen, S.O., Saito, Y., Tesakov, A., Turner, C., Walker, M., Zazo-Cardeña, C., 2021. Formal ratification of subseries for the Pleistocene Series of the Quaternary System. Episodes, **44**: 241–247. https://doi.org/10.18814/epiiugs/2020/020084

Hilber, V., 1882. Geologische Aufhnamen um Jarosław und Leżajsk in Galizien. Verhandlungen der Geologischen Reichsanstalt, 1882: 243–247. http://quaternary.stratigraphy.org/stratigraphic-guide

Janczyk-Kopikowa, Z., Mojski, J.E., Rzechowski, J., 1981. Position of the Ferdynandów Interglacial, Middle Poland, in the Quaternary stratigraphy of the North European Plain. Biuletyn Instytutu Geologicznego, **335**: 65–79.

Kucia-Lubelska, M., 1966. The age of Witów series based on the heavy mineral assemblages (in Polish with English summary). Rocznik Polskiego Towarzystwa Geologicznego, **36**: 303–313.

Laj, C., Channel, J.E.T., 2007. Geomagnetic excursions.Treatise on Geophysics, **5**: 373–416. https://doi.org/10.1016/B978-044452748-6.00095-X

Laskowska-Wysoczańska, W., 1967. The interstadial of the Cracovian Glaciation from Jasionka near Rzeszów (in Polish with English summary). Acta Geologica Polonica, **17**: 495–507.

Laskowska-Wysoczańska, W., 1971. Quaternary stratigraphy and palaeogeomorphology of the Sandomierz Lowland and the Foreland of the Middle Carpathians, Poland (in Polish with English summary). Studia Geologica Polonica, **34**: 1–109.

Lindner, L., 1988a. Glacial and interglacial units of the Pleistocene in the Holy Cross Mts (in Polish with English summary). Przegląd Geologiczny, **36**: 31–39.

Lindner, L., 1988b. Stratigraphy and extents of Pleistocene continental glaciations in Europe. Acta Geologica Polonica, **38** 63–83.

Lindner, L., 1991. Problems of the age and extent of the Scandinavian glaciations at the margin of the Polish Carpathians, southern Poland (in Polish with English summary). Przegląd Geologiczny, **49**: 819–821.

Lindner, L., 1992. Quaternary stratigraphy (climatostratigraphy) (in Polish). In: Czwartorzęd: osady, metody badań, stratygrafia (ed. L. Lindner): 441–633. Wyd. PAE, Warszawa.

Lindner, L., 2001. Problems of the age and extent of the Scandinavian glaciations at the margin of the Polish Carpathians (southern Poland) (in Polish with English summary). Przegląd Geologiczny, **49**: 819–821.

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.

Lindner, L., Marks, L., 2015. Early and Middle Pleistocene fluvial series in northern foreland of the Carpathians (Poland and Ukraine) and their relation to Dnistr River terraces. Quaternary International, **357**: 22–32. https://doi.org /10.1016/j.quaint.2014.09

Lindner, L., Marks, L., Nita, M., 2013. Climatostratigraphy of interglacials in Poland: Middle and Upper Pleistocene lower boundaries from a Polish perspective. Quaternary International, **292**: 113–123. https://doi.org /10.1016/j.quaint.2012.11.018

Lindner, L., Siennicka-Chmielewska, A., 1998. The Witów Series and the problem of the Tertiary/Quaternary boundary in South-Eastern Poland. Mededelingen Nederlands Institut voor Toegepaste Geowetenschappen TNO, **60**: 287–292.

Lisiecki, L.E., Raymo, M.E., 2005. A Pliocene-Pleistocene stack of 57 globally distributed benthic $\delta^{18}O$ records: Pliocene-Pleistocene benthic stack. Paleoceanography, **20**. https://doi.org/10.1029/2004PA001071

Łanczont, M. 1997. Profile of the Quaternary deposits at Siedliska (foreland of the Przemyśl Carpathians, south-eastern Poland) and its paleogeographic aspect. Studia Geomorphologica Carpatho-Balkanica, **31**: 5–29.

Łanczont, M., Butrym, J., Pękala, K., 1988. Stratigraphic and palaeogeographic significance of Quaternary deposits from the Optyń Hill near Przemyśl, East Carpathians. Quaternary Studies in Poland, **8**: 79–84.

Łanczont, M., Pidek, I.A., Bogucki, A., Wieliczkiewicz, F., Wojtanowicz, J., 2003. The key profile of the Mazovian interglacial from (Krukienice) in the San and Dniester interfluve (Ukraine) (in Polish with English summary). Przegląd Geologiczny, **51**: 597–608.

Łanczont, M., Bogucki, A., Hołub, B., Jacyszyn, A., Kusiak, J., 2011. Żwiry mieszane na przedgórzu Karpat Przemyskich i Dobromilskich – rozmieszczenie, zestawienie poglądów o ich pochodzeniu (in Polish). In: Zbirnik naukovikh prac do XVII ukrainsko-polskovo seminaru, Sambir, Ukraina, 15–18 veresnia 2011 (eds. A. Bogucki, M. Łanczont, T. Madeyska, Y. Yelovichova, J. Krawchuk and A. Melnik): 139–153. Lvivskij Nacjonalnij Universitet imeni Ivana Franka, Lviv.

Łanczont, M., Bogucki, A., Yatsyshyn, A., Terpiłowski, S., Mroczek, P. Orłowska, A., Hołuba, B., Zieliński, P., Komar, M., Woronko, B., Kulesza, P., Dmytruk, R., Tomeniuk, O., 2019. Stratigraphy and chronology of the periphery of the Scandinavian ice sheet at the foot of the Ukrainian Carpathians. Palaeogeography, Palaeoclimatology, Palaeoecology, **530**: 59–77. https://doi.org/10.1016/j.palaeo.2019.05.024

Łoziński, W., 1907. Quartärstudien im Gebiete der nordischen Vereisung Galiziens. Jahrbuch der Kaiserlich-Königlichen Geologischen Reichsanstalt, Wien, **52**: 375–398.

Łyczewska, J., 1948. Report of geological field works in north-western corner on Brzesko Nowe map 1:100 000 (Carpathian foreland) (in Polish with English summary). Biuletyn Państwowego Instytutu Geologicznego, **42**: 46–75.

Marks, L., 2022. Zlodowacenia plejstoceńskie w południowej Polsce (in Polish). In: Metodyka rekonstrukcji zmian klimatu i środowiska zapisanych w pokrywach lessowych (eds. M. Łanczont, M. Hołub and P. Mroczek): 57–61. XXI Terenowe Seminarium Korelacja lessów i osadów glacjalnych Polski i Ukrainy, Interdyscyplinarne Seminarium Naukowe Glacjał i peryglacjał Europy Środkowej, Jarosław, 6–8 października 2022 r., Lublin.

Marks, L., 2023. Quaternary stratigraphy of Poland – current status. Acta Geologica Polonica, 73, in press.

Marks, L., Ber, A., Lindner, L. ed., 2014. Zasady polskiej klasyfikacji i terminologii stratygraficznej czwartorzędu (in Polish). Polska Akademia Nauk, Komitet Badań Czwartorzędu, Warszawa.

Matoshko, A.V., Gozhik, P.F., Danukalova, G., 2004. Key Late Cenozoic fluvial archives of eastern Europe: the Dniester, Dnieper, Don and Volga. Proceedings of the Geologists' Association, **115**: 141–173.

Mojski, J.E., ed., 1984. Budowa geologiczna Polski I, Stratygrafia 3b, Kenozoik, Czwartorzęd (in Polish). Wyd. Geol., Warszawa.

Mojski, J.E., 1985. Geology of Poland I, Stratigraphy 3b, Cainozoic, Quaternary. Wyd. Geol., Warszawa.

Muchowski, J., 1992. Deposits of the Odra Glaciation on the southwestern part of the Lublin Upland (in Polish with English summary). Studia Geologica Polonica, **99**: 105–119.

Nawrocki, J., Wójcik, A., 1990. On age of the "Witów series" in the light of palaeomagnetic studies. Studia Geomorphologica Carpatho-Balcanica, **24**: 3–9.

Nývlt, D., 1998. Kontinentální zalednění severních Čech (in Czech). Sbornik České Geografické Společnosti, **103**: 445–457.

Nývlt, D., Engel, Z., Tyráček, J., 2011. Pleistocene glaciations of Czechia. Developments in Quaternary Science, **15**: 37–46.

Pożaryski, W., Maruszczak, H., Lindner, L., 1994. Chronostratigraphy of Pleistocene deposits and evolution of the Middle Vistula River valley with particular attention to the gap through the South Polish Uplands (in Polish with English summary). Prace Państwowego Instytutu Geologicznego, **147**: 1–58.

Przybylski, B., Krzyszkowski, D., Badura, J., Urbański, K., 2013. Plejstocen przepola Sudetów Środkowych (in Polish). In: XX Konferencja Stratygrafia plejstocenu Polski Plejstocen przedpola Sudetów Środkowych, Lasocin, 2–6.09.2013. Państwowy Instytut Geologiczny – Państwowy Instytut Badawczy, Warszawa: 9–15.

Romer, E., 1907. Quelques remarques sur les dépôts glaciaires dans la région au Sud du Przemyśl (in Polish with French summary). Kosmos, **32**: 423–440.

Różycki, S.Z., 1978. From Mochty to a synthesis of the Polish Pleistocene (in Polish with English summary). Rocznik Polskiego Towarzystwa Geologicznego, **48**: 445–478.

Starkel, L., 1971. Phases of erosion and accumulation in the Quaternary evolution of valleys of the Polish Flysch Carpathians and their foreland. Studia Geomorphologica Carpatho-Balcanica, **5**: 183–189.

Starkel, L., 1984. Eoplejstocen – Karpaty i Kotliny Przedkarpackie (in Polish). In: Budowa geologiczna Polski, 1, Stratygrafia, 3b, kenozoik, czwartorzęd (ed. J.E. Mojski): 73–81. Wyd. Geol., Warszawa.

Stuchlik, L., Wójcik, A., 2001. Pollen analysis of Malopolanian Interglacial deposits at Łowisko (Kolbuszowa Upland, southern Poland). Acta Palaeobotanica, **41**: 15–26.

Stupnicka, E., 1962. Age and origin of mixed gravels in the Cieszyn Upland (SW Poland). Acta Geologica Polonica, **12**: 263–294.

Szczepankiewicz, S., 1969. Sediments and forms of the far extents of Scandinavian glaciations in SW Poland. Geographia Polonica, **17**: 149–159.

Tietze, E., 1883. Beiträge zur Geologie von Galizien. Jahrbuch der kaiserlich-königlichen Geologischen Reichsanstalt, **33**: 279–309.

Uhlig, V., 1884. Ueber ein Vorkommen von Silur-blöcken im nordischen Diluvium Westgaliziens. Verhandlungen der kaiserlich-königlichen Geologischen Reichsanstalt, **16**: 335–336.

Walczak, W., 1972. Sudety I Przedgórze Sudeckie (in Polish). In: Geomorfologia Polski, 1 (ed. M. Klimaszewski): 167–231. Państwowe Wydawnictwo Naukowe, Warszawa.

Wieczorek, D., 1999. Sytuacja geologiczna osadów organicznych w profilu Bukowina (otw. Bukowina 4) na arkuszu Laszki (985) SMGP 1:50 000 (wschodnia część Kotliny Sandomierskiej) (in Polish). In: VI Konferencja: Stratygrafia plejstocenu Polski, Czudec, 31 sierpnia – 4 września 1999 (eds. T. Malata, P. Marciniec, P. Nescieruk, A. Wójcik and Z. Zimnal): 70–77. Państwowy Instytut Geologiczny, Kraków.

Winter, H., 2006. Problem of Pleistocene interglacials and glaciations – general remarks (in Polish with English summary). Przegląd Geologiczny, **54**: 142–144.

Winter, H., 2008. Palynological record of vegetation and climate changes of Augustovian Interglacial at the Żarnowo Site (Augustów Plain, northeastern Poland) (in Polish with English summary). Przegląd Geologiczny, **56**: 1011–1118.

Wojtanowicz, J., 1971. The loess Island near Krzeszów on San (in Polish with English summary). Annales Universitates Mariae Curie-Skłodowska, **26**: 67–88.

Wojtanowicz, J., 1985. The TL dated profile of the Quaternary deposits at Giedlarowa (Sandomierz Basin) and its palaeogeographical importance (in Polish with English abstract). Studia Geomorphologica Carpatho-Balcanica, **19: 37–44.**

Wojtanowicz, J., 1997. Glina morenowa, utwór pylasty i less w profilu Krzeszów (in Polish). In: Glacjał i peryglacjal Kotliny Sandomierskiej i przedgórza Karpat w okolicy Przemyśla, Seminarium terenowe, Krasiczyn, 22–24 września 1997 (ed. M. Łanczont): 143–148. Zakład Geografii Fizycznej i Paleogeografii Uniwersytetu Marii Curie-Skłodowskiej, Komitet Badań Czwartorzędu PAN, Stowarzyszenie Geomorfologów Polskich, Lublin.

Wójcik, A., Nawrocki, J., Nita, M., 2004. Pleistocene in the Kończyce profile (Oświęcim Basin) – sediment genesis and age analysis at the background of stratigraphic schemes of the Quaternary (in Polish with English summary). Biuletyn Państwowego Instytutu Geologicznego, **409**: 5–50.

Zastawniak-Birkenmajer, E., Birkenmajer, K., 2012. Problem of the Pliocene/Pleistocene boundary in fresh-water deposits at Mizerna, West Carpathians (in Polish with English abstract). Przegląd Geologiczny, **60**: 276–283.

Żarski, M., Małek, M., Albrycht, A., 2009. Plejstocen południowego Podlasia (in Polish). In: Strefa marginalna lądolodu zlodowacenia warty i pojezierza plejstoceńskie na południowym Podlasiu (eds. M. Żarski and S. Lisicki): 20–36. XVI Konferencja Stratygrafia plejstocenu Polski, Zimna Woda k. Łukowa, 31.08–4.09. 2009. Państwowy Instytut Geologiczny – Państwowy Instytut Badawczy, Warszawa.