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LESZEK LINDNER & LESZEK MARKS

Pleistocene glaciations and interglacials in the Vistula, the Oder, and the Elbe drainage basins (Central European Lowland)

ABSTRACT: Extents of Scandinavian glaciations within the three main river drainage basins of the Central European Lowland exhibit principal similarities, but also outstanding peculiarities. Most glacial events during the Pleistocene are well pronounced in the Vistula drainage basin, less so in the Oder, and the least — in the Elbe one. Such pattern is thought to have resulted from location of the Vistula drainage basin at the southern termination of the Baltic Channel. The latter has controlled many a time the main route of the Scandinavian icesheets that advanced the Central European Lowland.

INTRODUCTION

Most of the previous synthetic stratigraphic subdivisions of the Quaternary in Central Europe were regarded valid for a single country or, when put together, for a stratigraphic scheme prepared for several countries (*see e.g.* LINDNER 1988b, 1991). Such schematic approach to stratigraphic problems of Europe neglected significant regional differences, the latter resulting from isolation of drainage basins of the main Central European rivers. This paper presents an analysis of similarities and differences in Quaternary evolution of the main rivers emplaced in the Central European Lowland, *i.e.* of the Vistula, the Oder, and the Elbe (*cf.* Text-fig. 1).

The Authors' opinion on the mode of icesheet transgressions southwards of the Baltic Channel are coincident with suggestions of HALICKI & OLCZAK (1953), who presented connections of gravimetric anomalies and icesheet extents in the Central European Lowland.

VISTULA DRAINAGE BASIN

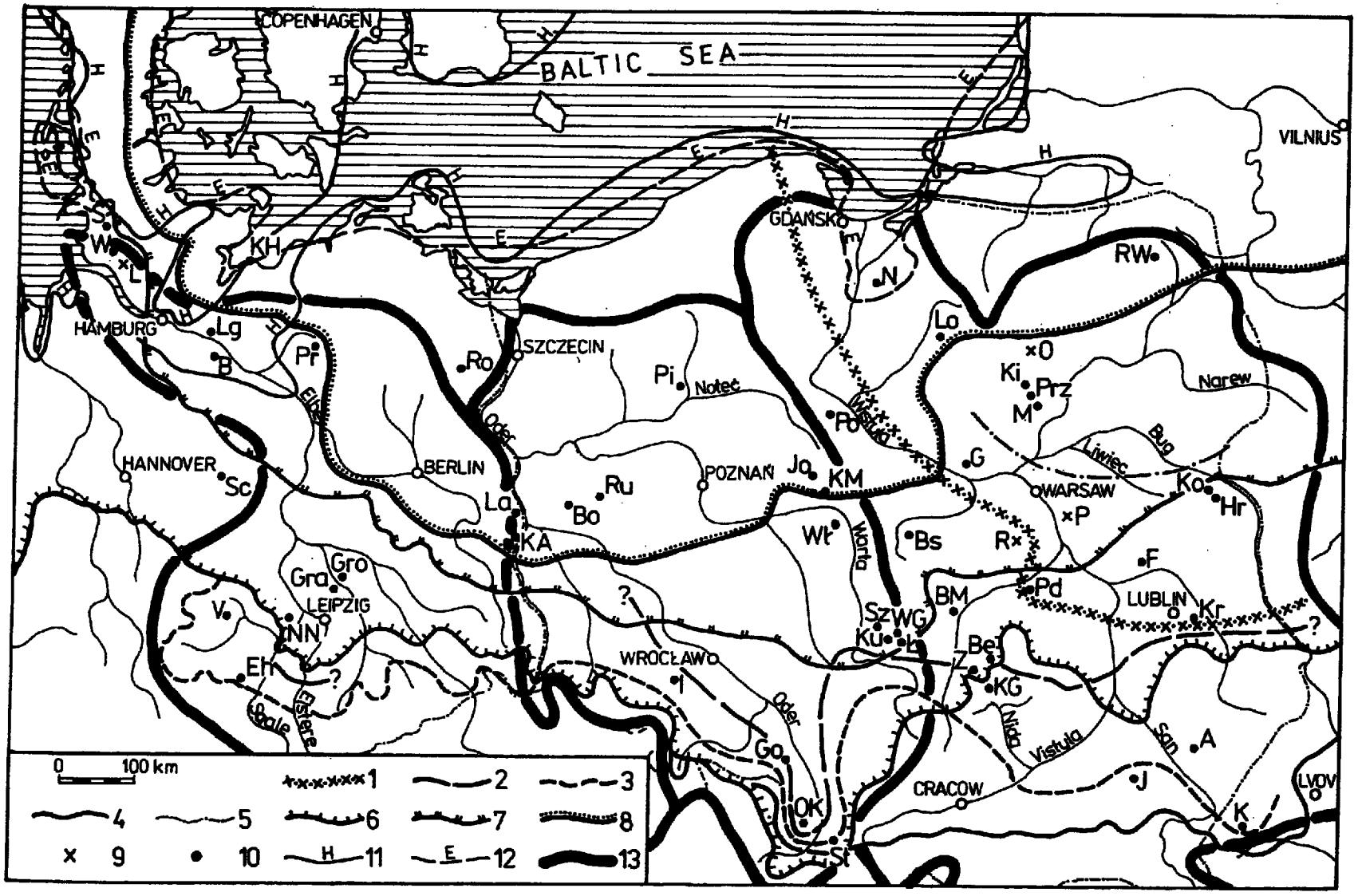
The Prepleistocene in the Vistula drainage basin is represented by two cool intervals, *i.e.* Różce = Praetiglian and Otwock = Eburonian, and by two intervening warm intervals, *i.e.* Ponurzyca = Tiglian and Celestynów = Waalian (STUCHLIK 1987; BARANIECKA 1990, 1991). In the Vistula drainage basin there occur deposits of all the Scandinavian glaciations (Narewian, Nidanian, Sanian *1*, Sanian *2*, Liwiecian, Odranian, Wartanian, and Vistulian) and interglacials (Podlasian, Małopolanian, Ferdynandowian, Mazovian, Zbójnian, Lubawian, and Eemian) that have been noted in the Central European Lowland. The greatest extent in this drainage basin was reached by the Sanian *2* icesheet that advanced as far as the Carpathians (*see* Text-figs 1 and 2).

The earliest Scandinavian glaciation in this drainage basin is the Narewian, the icesheet of which occupied northeastern and mid-eastern Poland (STRASZEWSKA 1968; RÓŻYCKI 1980; HARASIMIUK & *al.* 1988; LINDNER 1988a,b; DOLECKI & *al.* 1991). The Podlasian Interglacial is represented by numerous cycles of alluvial series, that indicate a long-lasting interval (STRASZEWSKA 1968, BAŁUK 1991).

The icesheet of the Nidanian Glaciation reached the drainage basin of the Nida River, the left tributary of the Vistula (LINDNER 1978, RÓŻYCKI 1978), and the northern slope of the Lublin Upland (HARASIMIUK & *al.* 1988, DOLECKI & *al.* 1991). A residuum of its glacial sediments is known among others from the gorge of the Middle Vistula Valley through the Central Polish Uplands. It is represented by till and varved-clay balls within alluvia of the Małopolanian Interglacial age (POŻARYSKI & *al.* 1994). The latter has paleontologic evidence in the key site Kozi Grzbiet (GŁAZEK & *al.* 1976) and pollen spectrum at Przasnysz (BAŁUK 1991, BAŁUK & MAMAKOWA 1991). The icesheet of the Sanian *1* Glaciation occupied almost the whole drainage basin of the Vistula, reaching as far as the northern Sandomierz Basin (*see* LINDNER 1988b). Lacustrine organic sediments of the Ferdynandowian Interglacial are noted in the Vistula drainage basin in their key site at Ferdynandów (JANCZYK-KOPIKOWA & *al.* 1981) but also in several other sites, indicating a bi-optimal floristic succession (JANCZYK-KOPIKOWA 1991). Fluvial sediments of this interglacial form a thick gravel-sandy series in the Middle Vistula gorge through the Central Polish Uplands (POŻARYSKI & *al.* 1994). The icesheet of the Sanian *2* Glaciation occupied the greatest area in the Vistula drainage basin among all the Pleistocene glaciations, reaching the Carpathians (LASKOWSKA-WYSOCZAŃSKA 1971, BUTRYM & *al.* 1988, LINDNER 1988b).

Residuum of glacigenic series of this glaciation is preserved in the Central Polish Uplands within the buried river valleys of the Mazovian Interglacial age (RÓŻYCKI 1964, POŻARYSKI & MOJSKI 1987, LINDNER 1988a), the Middle Vistula gorge through the Central Polish Uplands including (POŻARYSKI & *al.* 1993, 1994). Fluvial and lacustrine sediments of this interglacial belong to the best

Extents of Scandinavian glaciations in the Vistula, the Oder, and the Elbe drainage basins against extents of the Eemian and Holstein seas, as well as the main key sites of interglacial and preglacial sediments



1 — Narewian Glaciation, 2 — Nidanian Glaciation, 3 — Sanian *1* (Elsterian *1*) Glaciation, 4 — Sanian *2* (Elsterian *2*) Glaciation, 5 — Liwiecian (Fuhne?) Glaciation, 6 — Odranian (Fuhne?, Drenthe?) Glaciation, 7 — Wartanian (Drenthe?, Warthe) Glaciation, 8 — Vistulian (Weichselian) Glaciation

9 — SITES OF PREGLACIAL SEDIMENTS: L — Lieth, O — Opaleniec, P — Ponurzyca, R — Różce

10 — SITES OF INTERGLACIAL SEDIMENTS: A — Adamówka, B — Breetze, Be — Bedlno, BM — Barkowice Mokre, Bo — Boczów, Bs — Besiekierz, Eh — Ehringsdorf, F — Ferdynandów, G — Główczyn, Go — Gościęcin, Gra — Grabschütz, Gro — Gröbern, Hr — Hrud, I — Imbramowice, J — Jasionka, Jo — Jóźwin, K — Krukienice, KG — Kozi Grzbiet, KH — Klein Höved, Ki — Kijewice, KM — Konin-Marantów, Ko — Komarno, Kr — Krępiec, Ku — Kuców, KA — Kerkwitz-Atterwasch, La — Lawitz, Lg — Lauenburg, Lo — Losy, Ł — Łękińsko, M — Maków Mazowiecki, N — Nowiny, NN — Neumark-Nord, OK — Opava-Kateřinky, Pi — Piła, Pd — Podgórze, Po — Popioły, Pr — Pritzwalk, Prz — Przasnysz, Ro — Röpersdorf, Ru — Rusinów, RW — Raczki Wielkie, S — Schalkholz, Sc — Schöningen, St — Stonava, Sz — Szczerców, V — Voigtstedt, W — Wacken, WG — Wola Grzymalina, Wł — Władysławów, Z — Zbójno

EXTENTS OF: 11 — Holstein sea, 12 — Eemian sea

13 — WATERSHED of the Vistula, the Oder, and the Elbe drainage basins

known in the Vistula drainage basin. In fact, this is just the key area for sediments of the Mazovian Interglacial, although recent studies indicate (*cf.* JANCZYK-KOPIKOWA 1991), that there is no single definite key site in this area. The Liwiecian Glaciation had a limited extent in the Central European Lowland and its sediments are known from the northeastern part of the Vistula drainage basin only (LINDNER 1984, 1988a,b; BARANIECKA 1990). Recent investigations indicate that the icesheet of this time advanced further southwards, as far as the Middle Vistula drainage basin (ŻARSKI 1994). The successive interglacial (Zbójnian) has its key site in the Holy Cross Mts (*see* LINDNER 1988a).

The icesheet of the Odranian Glaciation reached the northern margin of the Central Polish Uplands. The following interglacial is known in the Vistula drainage basin as the Lubawian (also: Lublinian, Grabówka or Pilica), best documented in the site Losy near Lubawa (KRUPIŃSKI & MARKS 1986). The icesheet of the Wartanian Glaciation reached, according to the prevailing opinions (*e.g.* MOJSKI 1985, BARANIECKA 1993), the Lower Pilica valley and farther to the east the Siedlce and Terespol areas (*see* Text-fig. 2).

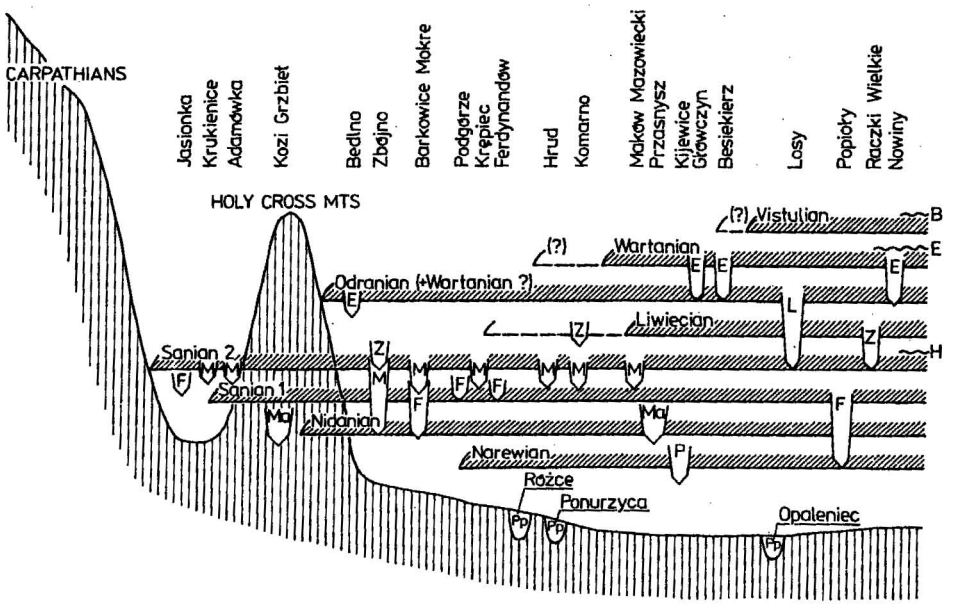


Fig. 2. Scandinavian glaciations (obliquely hachured are extents of glacial deposits) in the Vistula drainage basin, against intervening sea ingressions (**H** — Holsteinian, **E** — Eemian, **B** — Baltic), and the main key sites of preglacial (**Pp** — Prepleistocene) and interglacial sediments (**P** — Podlasian, **Ma** — Małopolanian, **F** — Ferdynandowian, **M** — Mazovian, **Z** — Zbójnian, **L** — Lubawian, **E** — Eemian)

Compiled *after* LINDNER (1988b, *modified*); based on data *from* BAŁUK (1991), BARANIECKA (1975, 1991), BIŃKA & *al.* (1987), BOGUTSKY & *al.* (1980), GŁAZEK & *al.* (1976), JANCZYK-KOPIKOWA (1991), JANCZYK-KOPIKOWA & *al.* (1981), JEZIORSKI (1992), KLATKOWA (1972), KRUPIŃSKI & LINDNER (1991), KRUPIŃSKI & MARKS (1986), KRUPIŃSKI & *al.* (1991), LINDNER & *al.* (1991), MAKOWSKA (1986), NIKLEWSKI (1968), *and* STUCHLIK (1975)

Lacustrine organic sediments of the Eemian Interglacial are known from numerous sites in the Middle Vistula drainage basin, whereas marine sediments of this age are common in the Lower Vistula region. The latter form two series of stratigraphic significance, representing the so-called Sztum and Tychnowy seas (MAKOWSKA 1986). The icesheet of the Vistulian Glaciation advanced several times the northern part of the Vistula drainage basin. Older sediments of this glaciation (Toruń Glaciation) are separated from the younger ones (Baltic Glaciation) by marine sediments of the Krastudy Interglacial (MAKOWSKA 1986).

ODER DRAINAGE BASIN

In the Oder drainage basin there occur sediments of six main Pleistocene Scandinavian glaciations *i.e.* Nidanian (=Opava), Sanian *1* (=Kravaře *1*), Sanian *2* (=Kravaře *2*), Odranian (=Oldřišov), Wartanian, and Vistulian. They are separated by lacustrine organic sediments of the Małopolanian, Ferdynandowian, Mazovian (Holsteinian), Zbójnian, Lubawian, and Eemian interglacials. The greatest extent in the Oder drainage basin is represented by the Odranian Glaciation (Oldřišov) that reached the Sudetes and entered the Moravian Gate in the Czech Republic (*see* Figs 1 and 3).

The icesheet of the oldest glaciation in the Oder drainage basin (Nidanian, Opava) entered the Moravia. In a stratigraphic setting of the Małopolanian Interglacial there occur older organic sediments in the section Opava-Kateřinky, but also fluvial and ice-dam series, and a paleosol of the Otice Interglacial (MACOUN 1980, 1985, 1987). The icesheet of the Sanian *1* Glaciation occupied almost the whole Oder drainage basin and reached the Sudetes, being presumably indicated by the lowest of the three tills in this area (BADURA & *al.* 1992). It also entered the Moravia as the Kravaře *1* Glaciation (MACOUN 1985). Lacustrine sediments of the Ferdynandowian Interglacial were noted only in the open brown-coal mine Bełchatów (KUSZELL 1991, MARCINIAK 1991). In such a stratigraphic setting there are also younger organic sediments in the section Opava-Kateřinky (MACOUN 1980), considered as an equivalent of the Uhlirov and Muglinov warming (MACOUN 1987). In northern foreland of the Sudetes, the Sanian *2* Glaciation is probably indicated by the middle of the three tills in this area (*see* BADURA & *al.* 1992), whereas in the Kleszczów Graben near Bełchatów — by the middle gravel pavement within the Czyżów Formation (*see* KRZYSZKOWSKI 1991). In the Moravia, the icesheet of this glaciation deposited glacial sediments of the so-called Kravaře *2* Glaciation. Lacustrine sediments of the Mazovian Interglacial are represented in the Oder drainage basin in the sites at Gościęcin (ŚRODOŃ 1957), Kuców (KRZYSZKOWSKI 1989) and Boczów (JANCZYK-KOPIKOWA & SKOMPSKI 1977), whereas in the

Moravia in the site Stonava — by the Jaktar Interglacial (MACOUN & *al.* 1965). A probable occurrence of sediments of the Zbójnian Interglacial in the Oder drainage basin results from analyzed sites with organic sediments at Konin-Marantów (BORÓWKO-DŁUŻAKOWA 1967, JANCZYK-KOPIKOWA 1991) and within the Czyżów Formation in the Bełchatów open brown-coal mine (KRZYSZKOWSKI 1991).

Sediments of the Oder Glaciation indicate maximum extent of Scandinavian glaciations in the Oder drainage basin (*see* SZPONAR 1986). The icesheet of this glaciation entered also the Moravia where it is known as the Oldřišov Glaciation (MACOUN 1980). The following interglacial is represented by sediments of the Uecker Interglacial in the site Röpersdorf, however of ambiguous geological setting (*cf.* ERD 1987), which is located at watershed of the Oder and Elbe drainage basins (*see* Text-figs 1 and 3). The extent of the Warta Glaciation is demarcated in the Oder drainage basin near Trzebnica and in the Widawka drainage basin. Numerous sites of lacustrine sediments are known in the eastern (among others Szczerców, Władysławów, Jóźwin, Rusinów and Piła) and western (Imbramowice) parts of the Oder drainage basin (*see* MAMAKOWA 1989, TOBOLSKI 1991). The icesheet of the Vistulian Glaciation occupied only the northern part of the Oder drainage basin (*see* Text-fig. 1).

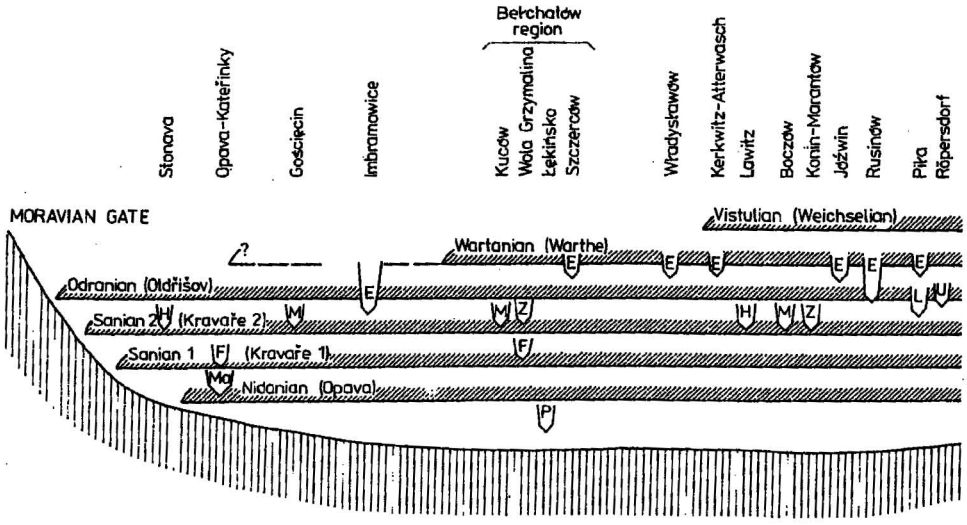


Fig. 3. Scandinavian glaciations (obliquely hachured are extents of glacial deposits) in the Oder drainage basin, against the main key sites of interglacial sediments (P — Podlasian, Ma — Małopolanian, F — Ferdynandowian, M — Mazovian, H — Holsteinian, Z — Zbójnian, L — Lubawian, U — Uecker, E — Eemian)

Compiled *after* LINDNER & MARKS (1994, *modified*); based on data *from* BORÓWKO-DŁUŻAKOWA (1967), CEPEK (1967), DĄBROWSKI & *al.* (1987), ERD (1987), JANCZYK-KOPIKOWA & SKOMPSKI (1977), JURKIEWICZOWA (1961), KRZYSZKOWSKI (1989, 1991), KUSZELL (1991), MACOUN (1980, 1985, 1987), MACOUN & *al.* (1965), MAMAKOWA (1989), STARK & *al.* (1932), ŚRODOŃ (1957, 1961), *and* TOBOLSKI (1991)

ELBE DRAINAGE BASIN

The Prepleistocene sequence in the Elbe drainage basin is composed of two series of alluvial sediments in the Leipzig area (terraces *Sitteler* and *Grössgorschener*), in which there are relics of frost wedges (EISSMANN 1975, 1990). In Schleswig-Holstein the Prepleistocene sediments at Lieth represent several climatic fluctuations (MENKE 1980b).

In the Elbe drainage basin there are sediments of the three main Scandinavian glaciations, *i.e.* Elsterian, Saalian, and Weichselian, separated to the north (in Lower Saxony and Schleswig-Holstein) by sediments of the Holstein and Eemian seas (Text-fig. 4). Glacial sediments are also separated by lacustrine organic sediments of the Holstein, Wacken (Dömnitz), and Eemian interglacials. In the prevailing part of the Elbe drainage basin the largest extent was reached by the icesheet of the Elsterian Glaciation, whereas in the westernmost part of this region by the icesheet of the Saalian Glaciation (EISSMANN 1975, 1990).

The icesheet of the Elsterian *1* Glaciation advanced at least as far south as Bad Schandau (*see* CEPEK 1967, 1986; EISSMANN 1975, 1990; WIEGANK 1982,

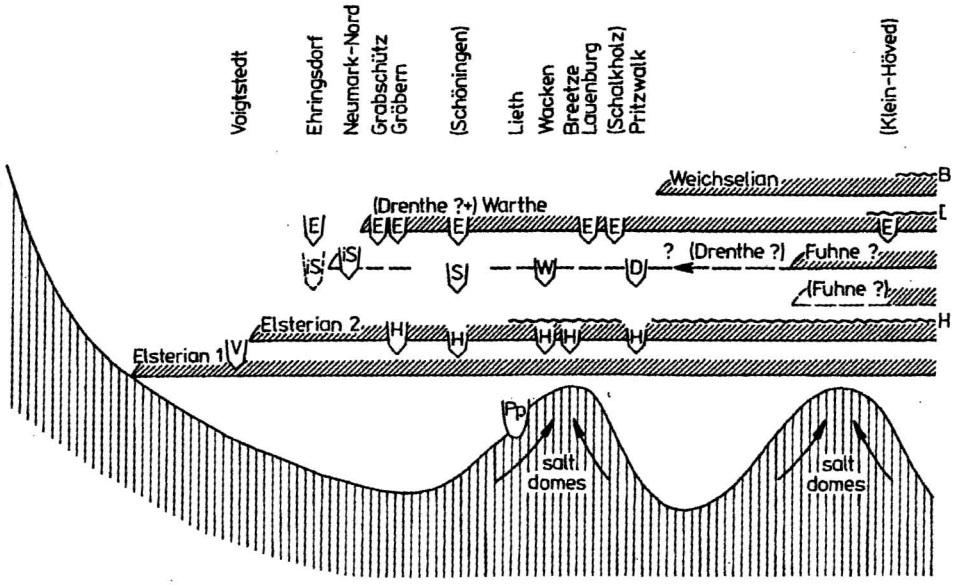


Fig. 4. Scandinavian glaciations (obliquely hachured are extents of glacial deposits) in the Elbe drainage basin, against intervening sea ingressions (H — Holsteinian, E — Eemian, B — Baltic) and the main key sites of preglacial (Pp — Prepleistocene) and interglacial sediments (V — Voigtstedt, H — Holsteinian, W — Wacken, D — Dömnitz, S — Schöningen, iS — intra-Saalian, E — Eemian)

Compiled *after* LINDNER & MARKS (1994, *modified*); based on data *from* BENDA & MEYER (1973), BLACKWELL & SCHWARCZ (1986), BÜLOW (1992), CEPEK (1986), DUPHORN & *al.* (1973), ERD (1978, 1987), LITT (1990), MANIA (1990), MENKE (1980a,b,c), MEYER (1965), STEINICH & *al.* (1992), URBAN & *al.* (1991), WANSA & WIMMER (1990), *and* WOLDSTEDT & DUPHORN (1974)

1987). Sediments of the younger, *i.e.* the Elsterian *2* Glaciation (considered usually as a stadial of the Elsterian Glaciation) are separated by uni-cyclic fluvial sediments (Militz Interval), particularly well distinguished in the Leipzig area (EISSMANN 1990). This interval is also represented by lacustrine sediments at the site Voigtstedt (ERD 1978), and in western Germany — by the Frimmersdorf Interglacial (URBAN 1979). The extent of the icesheet of the Elsterian *2* Glaciation (Stadial) in Germany has been recognized only in fragments to the south of Leipzig (EISSMANN 1990).

The Holsteinian Interglacial is represented in the northern part of the Elbe drainage basin by marine and brackish sediments (MEYER 1991). They usually form a continuous sequence with the underlying Late Elsterian ice-dam lacustrine clays (*see* MARKS 1994).

A cooling after the Holsteinian Interglacial starts in the Elbe drainage basin with periglacial and glaciofluvial sediments of the Fuhne (Mehlbeck) interval (*see* URBAN & *al.* 1991). In Meklenburg this period is represented by a separate till bed (BÜLOW 1992). The successive warming is indicated by organic sediments of the Dömnitz (Wacken, Schöningen) Interglacial (URBAN & *al.* 1991). The icesheet of the Drenthe Stadial of the Saalian Glaciation delimited, in the westernmost part of the Elbe drainage basin, the maximum extent of Scandinavian glaciations (EHLERS 1990). The Drenthe Stadial can be in fact an older glacial episode within the Warthe Stadial (*see* MARKS 1991). A warm interval that subdivides the Saalian Glaciation in the Elbe drainage basin, can be represented by interglacial sediments at the sites Ehringsdorf (BLACKWELL & SCHWARCZ 1986) and Neumark-Nord (MANIA 1990). The icesheet of the Warthe Stadial occupied only the northern part of the Elbe drainage basin (*see* Text-fig. 1). Lacustrine sediments of the Eemian Interglacial are known from a southern part of this basin, among others from Grabschütz and Gröbern (LITT 1990, WANSA & WIMMER 1990). On the other hand, in the northern part of this basin there occur marine sediments of the same age (WOLDSTEDT & DUPHORN 1974). The icesheet of the Weichselian Glaciation occupied only the northeastern part of the Elbe drainage basin (*see* Text-fig. 1).

CONCLUSIONS

The Scandinavian glaciations in drainage basins of the three main rivers of the Central European Lowland indicate considerable similarities which, however, are also associated with outstanding differences (*see* Text-fig. 5). As many as eight glaciations are recorded in the Vistula drainage basin, four of them before the Mazovian (Holsteinian) Interglacial, and three between this and the Eemian Interglacial. Slightly less, *i.e.* six glaciations, are distinguishable in the Oder drainage basin, the Lusatia region including (CEPEK & NOWEL

1991). Only three glaciations have so far been noted in the Elbe drainage basin. Such variability does probably result from the fact that the Vistula and, to a smaller degree, the Oder drainage basin occurred at the main direction of the Scandinavian icesheets advancing along the Baltic Channel what had particularly been well expressed during the Saalian Glaciation. Such different sequence in each of the three discussed drainage basins suggests that they have existed in a more or less similar form during most of the Quaternary time and, therefore, could exert a reasonable influence on extents and advance of particular icesheets during successive Pleistocene glaciations.

More detailed studies of this problem would presumably explain numerous doubts, arising from correlation of the Saalian Glaciation in Germany

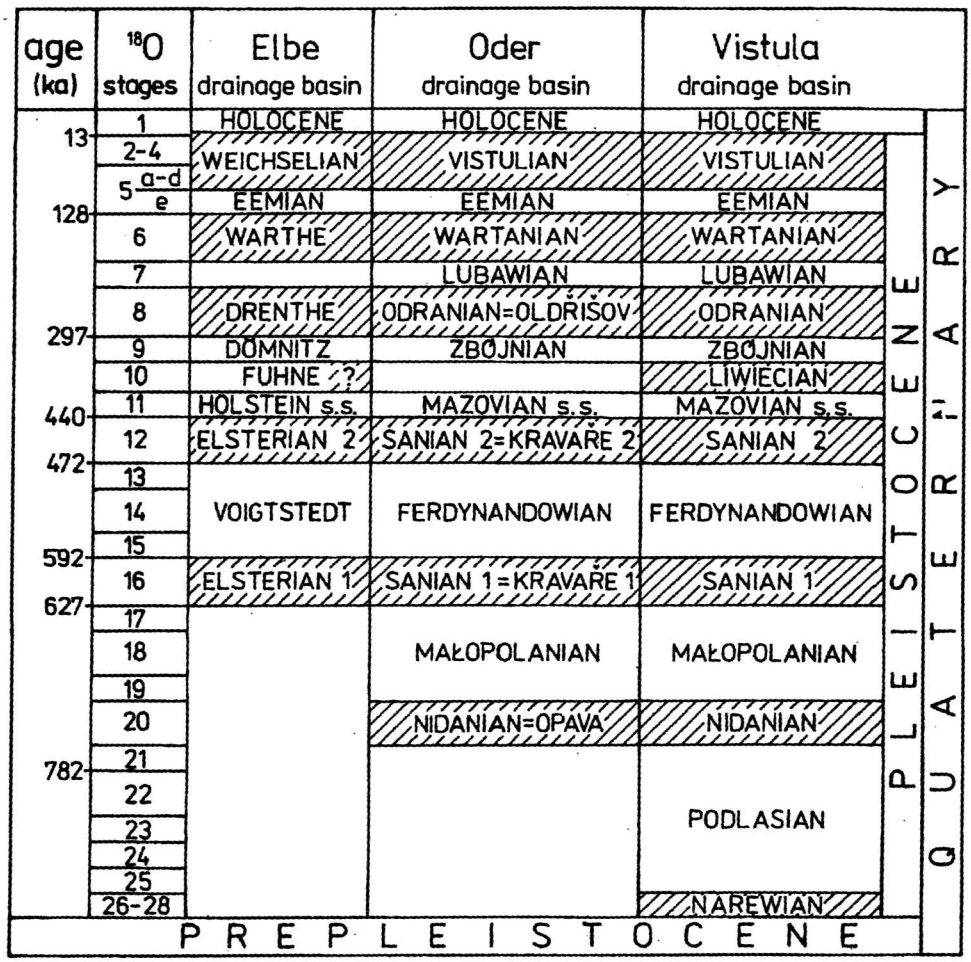


Fig. 5. Correlation of main climatostratigraphic units of the Quaternary in the Elbe, the Oder, and the Vistula drainage basins; ^{18}O stages *after* Bowen & *al.* (1986); obliquely hachured are glacial deposits

(with its stadials Drenthe and Warthe) and the Odranian and Wartanian glaciations in Poland, but also a discussed stratigraphic position of interglacials within these cold stages. The present state of knowledge does not exclude a possibility that the Odranian and Wartanian glaciations distinguished in Poland do constitute, similarly as in Germany, the phases of a single glaciation only (*see* MARKS 1991, FEDOROWICZ & *al.* 1992), corresponding to the ^{18}O stage *6* in deep-sea sediments (*cf.* MARTINSON & *al.* 1987). Moreover, it does not seem impossible that the icesheet of the Wartanian Glaciation, at least in the Vistula drainage basin, occupied a larger area than previously accepted, even larger than the Odranian Glaciation.

Institute of Geology
of the University of Warsaw,
Al. Żwirki i Wigury 93,
02-089 Warszawa, Poland

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L. LINDNER i L. MARKS

PLEJSTOCEŃSKIE ZLODOWACENIA SKANDYNAWSKIE I INTERGLACJAŁY W DORZECZACH WISŁY, ODRY I ŁABY

(Streszczenie)

Dotychczasowe syntetyczne opracowania stratygrafii czwartorzędu środkowej Europy obejmowały przeważnie obszar jednego lub kilku państw. Zacierało to istotne różnice regionalne, wynikające ze skomplikowanej i w dużym stopniu odrębnej ewolucji poszczególnych dorzeczy wielkich rzek europejskich. Ich układ przyczyniał się z jednej strony do określonego sposobu transgresji lądolodów skandynawskich, a z drugiej strony był przez nie w istotny sposób przekształcany. Poglądy autorów odnośnie sposobu transgresji lądolodów skandynawskich na południe od rynny bałtyckiej nawiązują do sugestii Halickiego i Olczaka (1953) o związku anomalii grawimetrycznych z zasięgami zlodowaceń na Niżu Europejskim.

Rozwój zlodowaceń w obrębie dorzeczy trzech głównych rzek Niżu Środkowoeuropejskiego wykazuje znaczące podobieństwa, ale także istotne różnice (*patrz* fig. 1 i 5). Największą liczbę zlodowaceń (osiem) stwierdzono w dorzeczu Wisły, w tym cztery poniżej i cztery powyżej osadów interglacjału mazowieckiego (*patrz* fig. 2). Nieco mniej zlodowaceń (sześć) wyróżniono w dorzeczu Odry (*patrz* fig. 3) i prawdopodobnie również na Łużycach. Najmniejszą liczbę zlodowaceń (trzy) stwierdzono w dorzeczu Łaby (*patrz* fig. 4). Zróżnicowanie to wynikać może z faktu, iż dorzecze Wisły i w mniejszym stopniu Odry stanowiły tę część Niżu Środkowoeuropejskiego, która leżała n głównym kierunku transgresji lądolodów skandynawskich, przemieszczających się wzdłuż rynny bałtyckiej, co szczególnie wyraźnie zaznaczyło się podczas zlodowaceń środkowopolskich (Saale=Soławy). Wyjaśnienie wielu aspektów tej prawidłowości rozwiałoby zapewne liczne wątpliwości związane z korelacją zlodowacenia Soławy w Niemczech (gdzie występują stadiały Drenthe i Warthe=Warty) oraz zlodowaceń Odry i Warty w Polsce, jak również z ewentualnym występowaniem odrębnych interglacjałów w obrębie tego piętra zimnego.

Przy obecnym stanie wiedzy nie można wykluczyć, że wyróżniane na obszarze Polski zlodowacenia Odry i Warty stanowią, podobnie jak na obszarze Niemiec, fazy jednego tylko zlodowacenia, odpowiadającego piętru 6 izotopów tlenu w osadach głębokomorskich. Należy także liczyć się z możliwością większego niż dotychczas przyjmowano, przynajmniej w dorzeczu Wisły, zasięgu zlodowacenia Warty, przekraczającego zasięg zlodowacenia Odry.