Polish Geological Institute Special Papers, 25 (2009): 13–20
Quaternary of the Gulf of Gdańsk and Lower Vistula regions in northern Poland...

GEOLOGY OF THE LOWER VISTULA REGION, NORTHERN POLAND

Dariusz GAŁĄZKA[1], Leszek MARKS[1]

Abstract. Depression in the Quaternary bedrock in the Lower Vistula Region was a main route for the Scandinavian ice sheets advancing into the Polish Lowland. At the end of the Elsterian Glaciation the receding ice sheet dammed the meltwaters in the Lower Vistula Valley and in its vicinity. The Holstein sea presumably occupied the Gulf of Gdańsk as indicated by brackish deposits of this age in the Kaliningrad District. During the Eemian Interglacial an extensive sea bay existed in the Lower Vistula Region. The Lower Vistula Region is a stratotype area for the Vistulian Glaciation (Weichselian), with several ice sheet advances, also before the Last Glacial Maximum.

Key words: ice sheet advances, Eemian sea, Vistulian, Quaternary, Lower Vistula Region, Poland.

Abstrakt. Rzeźba podłoża czwartorzędu w regionie Doliny Dolnej Wisły sprzyjała transgresji lądolodów skandynawskich w plejstocenie na obszar Niżu Polskiego. W trakcie recesji lądolodu zlodowaceń południowopolskich w tym obszarze i w jego najbliższym sąsiedztwie powstały rozległe zbiorniki zastoiskowe. W interglacjale holsztyńskim morze występowało prawdopodobnie na obszarze Zatoki Gdańskiej, na co wskazują osady brakiczne w Obwodzie Kaliningradzkim. W interglacjale eemskim duża zatoka morska występowała w północnej części regionu Doliny Dolnej Wisły. Obszar ten jest stratotypowy dla ostatniego zlodowacenia (wisła, weichselian), kiedy lądolód wkraczał kilkakrotnie, także przed stadiałem głównym.

Słowa kluczowe: transgresje lądolodu, morze eemskie, zlodowacenie wisły, czwartorzęd, Dolina Dolnej Wisły, Polska.

INTRODUCTION

The Lower Vistula Region comprises the Vistula valley, the Vistula delta and their surroundings, including fragments of the Kaszuby Lakeland and the Tuchola Forest in the west, the Elbląg Upland, the Iława and Chełmno–Dobrzyń Lakelands as well as the Lubawa Elevation in the east (Fig. 1). Geology and geomorphology of this area has been studied by German and Polish scientists, already since the 19th century (among others Keilhack, 1899; Tornquist, 1910; Sonntag, 1919; Galon, 1934; Roszko, 1955).

GEOLOGY

The Quaternary deposits are up to 305 m thick and rest mostly on the Palaeogene and Cretaceous sediments. A relief of the Quaternary bedrock has been modelled predominantly by glacial erosion, with minor influence of fluvial erosion, the latter basically within the region of the Vistula valley (Fig. 2). It does seem obvious if looking at the morphology of the Quaternary bedrock that most intensive glacial erosion occurred in a NNW–SSE transect i.e. from the Gulf of Gdańsk towards Toruń, but not exactly along the Lower Vistula Valley.

The Cretaceous marls are exposed mostly in the north and north-east whereas Palaeocene and Eocene sands, claystones and marls occur further to the south (Fig. 2). The most widespread are the Lower Oligocene glauconitic sands and clays,

[1] Polish Geological Institute – National Research Institute, Rakowiecka 4, 00-975 Warsaw, Poland;
e-mails: dariusz.galazka@pgi.gov.pl, leszek.marks@pgi.gov.pl

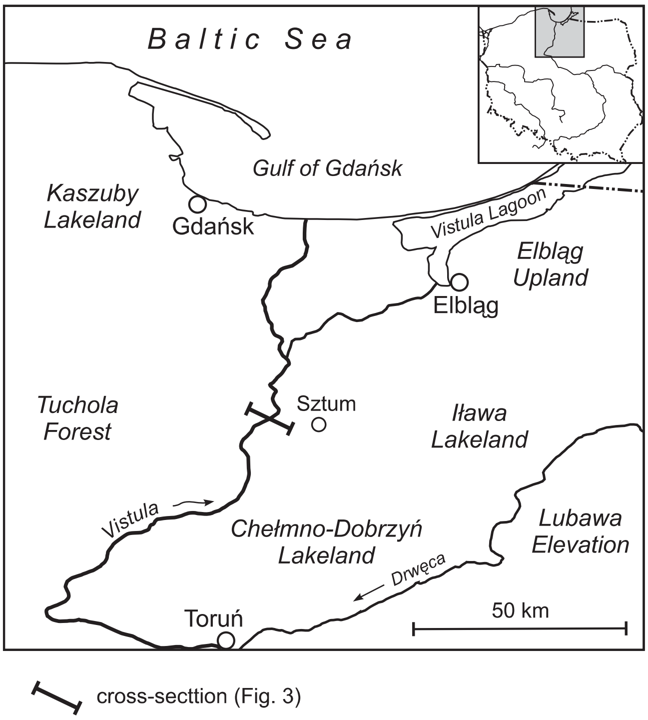


Fig. 1. Location sketch of the study area; indicated is a geological cross-section (Fig. 3)

and only in the west, south-east and partly south they are overlain by the Miocene sands. The latter are strongly glaciotectonicly deformed, both in the south-east at the Lubawa Elevation but also in the west, along the edge of the Kaszuby Lakeland (cf. Mojski, 1979).

During the Pleistocene the area was occupied by several Scandinavian glaciations (Lindner, Marks, 1995), and the sedimentary sequence of the Quaternary is represented by glacial, glaciofluvial, glaciolacustrine, fluvial, lake and occasionally also by marine deposits (Fig. 3).

The oldest are the tills of the South Polish Glaciations (Elsterian), representing Sanian 1 and Sanian 2 ice sheet advances (Makowska, 2001). A sequence of the South Polish Glaciations is terminated by vast clay series of the ice-dam lakes that have developed in the Lower Vistula Valley (Marks, 1995). The overlying marine and brackish deposits, attributed to the Holsteinian Interglacial, have been reported from Domnowo in the neighbouring Kaliningrad District of Russia

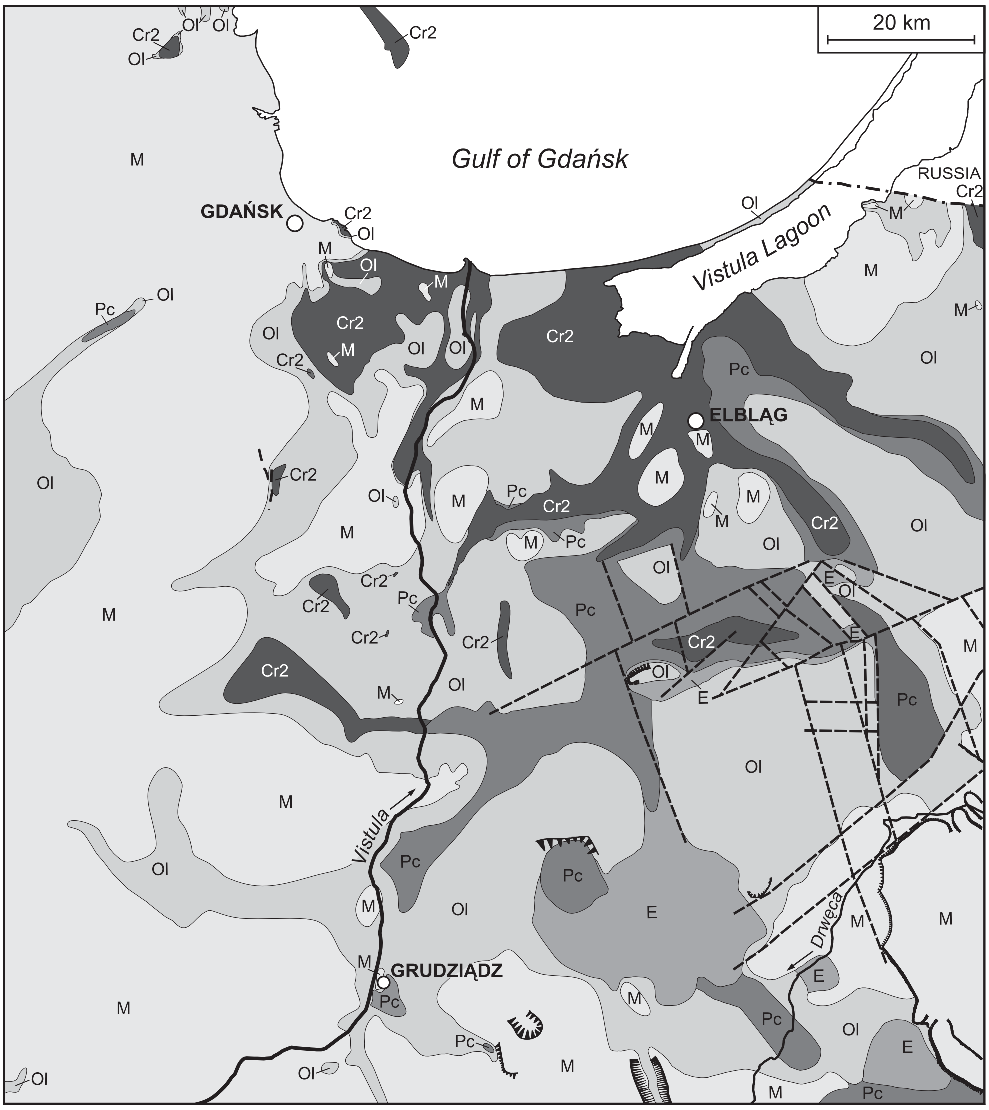


Fig. 2. Quaternary substrate according to the Geological Map of Poland 1:200,000 sheets: Elbląg, Grudziądz and Iława after Makowska (1974, 1978, 1979) and Gdańsk by Mojski, Sylwestrzak (1978), modified

M – Miocene, Ol – Oligocene, E – Eocene, Pc – Palaeocene, Cr2 – Upper Cretaceous; indicated are tectonic faults and erosive (?) edges

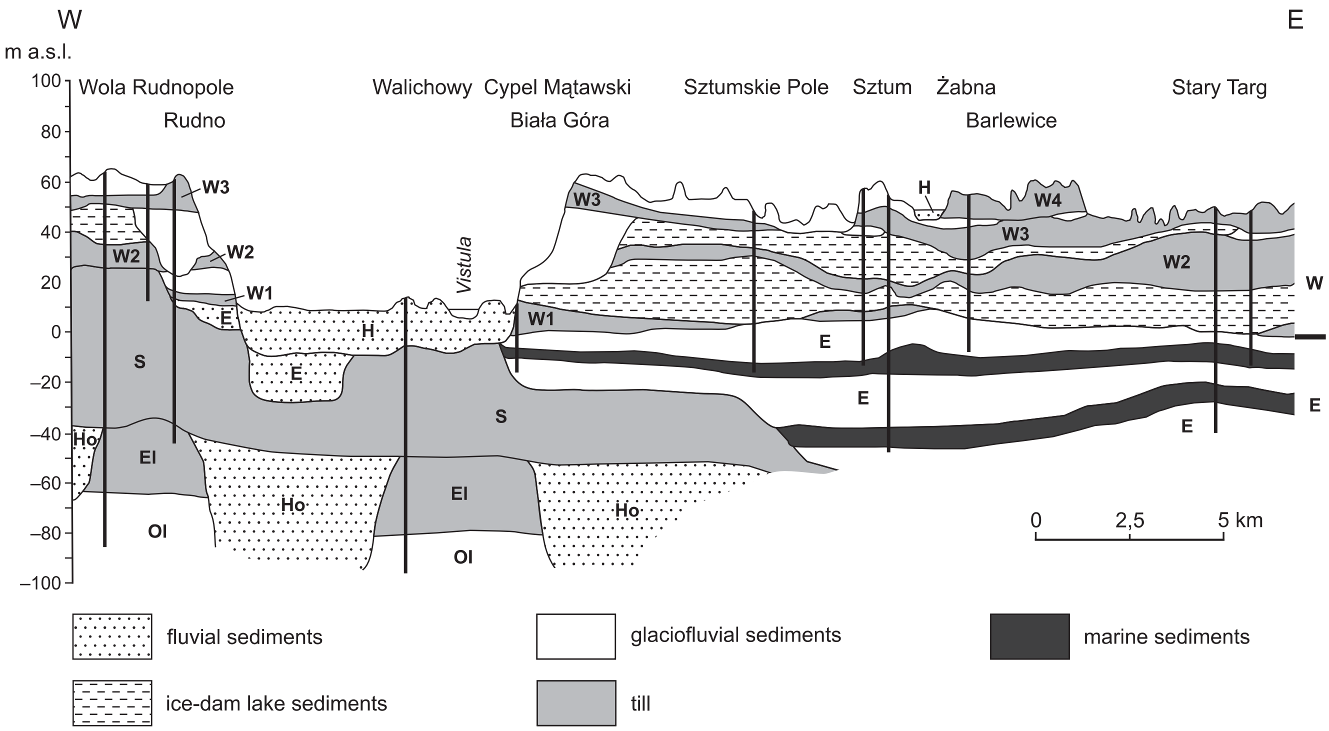


Fig. 3. Setting of Eemian marine sediments: geological cross-section in the vicinity of Sztum after Makowska (1984), modified

H – Holocene; Quaternary: W – Weichselian (Vistulian): glacial phases W1-W4, E – Eemian Interglacial, S – Saalian (Middle Polish Glaciations), Ho – Holsteinian (Mazovian Interglacial), El – Elsterian (South Polish Glaciations); Ol – Oligocene

(Kondratiene, Gudelis, 1983; Marks, 1988), but also as reworked, from the occasional glacial rafts in tills of the Middle Polish Glaciations (Saalian) in Poland (Makowska, 1986). It does seem also probable that interglacial marine sediments of the so-called Sztum Sea, located by Makowska (1986) beneath the Eemian sequence, represent the Holsteinian sequence.

Tills of the Middle Polish Glaciations (Saalian) represent the Odranian and Wartanian ice sheet advances (Makowska, 2001). They were suggested to have been separated by interglacial lake deposits at Grabówka (Makowska, 1977) but it has not been supported so far by any reliable evidence.

However, the most significant for a stratigraphy of the region are the Eemian beach and offshore clays, sands and silts with mollusc shells. They represent a marine ingression of the so-called Tychnowy Sea of Makowska (1986, 1991), univocally correlated with the Eemian Interglacial. A coastline of the Eemian sea occurred some 60 km to the south from the present sea shore in the Gulf of Gdańsk and marine sediments interfinger with terrestrial deposits through extensive accumulations of river deltas in the south and the south-east (Fig. 4). The sea bay in the Lower Vistula Valley lasted for about 3000 years, starting from the very beginning of the Eemian Interglacial. It was warmer and more saline than the present Baltic Sea, due to its more open contact with waters of the North Sea (cf. Head *et al.*, 2005). The marine sediments are in turn mantled by peaty silts and shales, deposited during a terminal part of the Eemian Interglacial (Fig. 3 and Table 1).

The Lower Vistula Region is a key area for the Vistulian (Weichselian) glacial period. Great progress in stratigraphic subdivision of sediments of the last glaciation, not only for

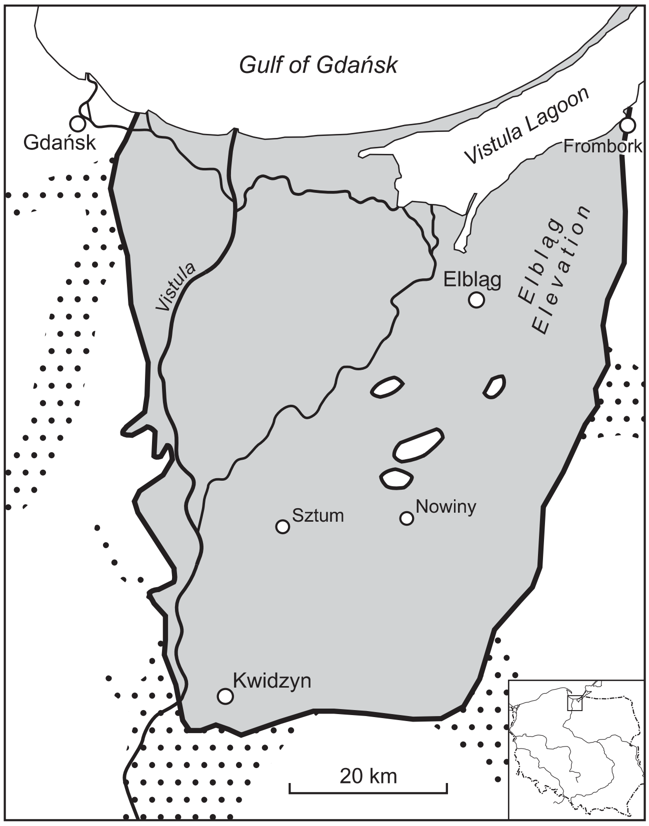
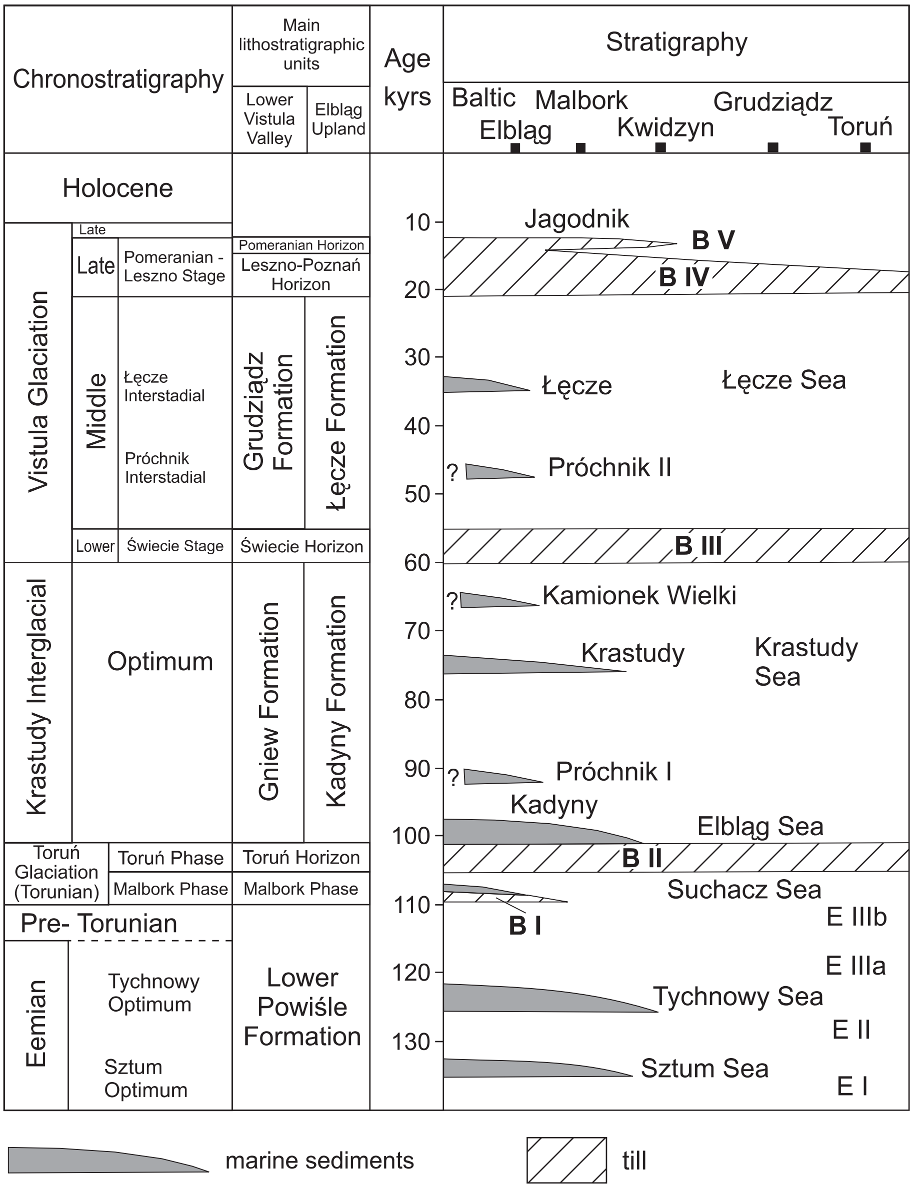


Fig. 4. Eemian sea (grey) and river valleys (dotted) in the Lower Vistula Region after Makowska (1986), slightly modified

Table 1

Late Pleistocene marine and glacial deposits in the Lower Vistula Region according to Makowska (1986), slightly modified; BI – BV are glacial phases. EI, EII, EIIIa and EIIIb are fluvial series of the Eemian Interglacial



Poland but also for the whole Central Europe, was stimulated by Makowska (1976). In the Lower Vistula Region the marine sediments of the Eemian Interglacial were found to occur several dozen metres deeper than previously accepted and they contact with fluvial sediments to the south (Makowska, 1979). The beginning of the Vistulian Glaciation is represented by a thick series of fluvial vari-grained and fine-grained sands, containing abundant interbeds of lacustrine silts, as well as gyttja and peat. Glacial deposits comprise from 2 to 5 tills that represent successive ice sheet advances and are commonly separated by glaciofluvial sands and ice-dam lake silts and locally, also by interstadial fluvial sediments. The whole sequence of the Eemian and Lower Vistulian sediments, both marine and inland ones, in the presented region was ascribed by Makowska (1986) to the informal lithostratigraphic unit of the Lower Vistula Region Formation (Table 1). She stated that the Eemian sediments are overlain by tills of three stadials, namely Toruń, Świecie and Main ones. These newly defined stadials of the last glaciation were supposed to have been separated by distinct and long-lasting intervals when ice sheet considerably retreated from the Polish territory (*op. cit.*). At present it is obvious that some of the tills of the Vistulian Glaciation are separated by widespread interstadial fluvial sediments (Wysota *et al.*, 1996; Gałązka *et al.*, 1998, 1999). Occurrence of the latter indicates that during the Vistulian a runoff occurred to the south in northern Poland and a base level of erosion must have been located several dozen metres higher.

VISTULIAN ICE SHEET LIMITS

Pre-LGM ice sheet limits during the Vistulian were determined firstly in this region by Makowska (1976). Since that time, a discussion has developed and several contradictory opinions were presented, not only on a number but also on extent of the pre-LGM ice sheet advances during the Vistulian (e.g. Mojski, 1985; Marks, 1988; Wysota, 2002). It was possible due to geological mapping for the Detailed Geological Map of Poland in scale 1:50 000.

Ice sheet limit during the oldest, the Toruń Stadial was postulated as far south as Toruń (Makowska, 1976), however evidence for this glacial episode in Poland is still considerably insufficient. Ice sheet limit during the Świecie Stadial of the Middle Vistulian has not been determined in detail but even a revision of the ice sheet maximum limit of the Vistulian Glaciation, connected with this stadial was postulated (Marks, 1988, 1991; Niewiarowski *et al.*, 1995; Lisicki, 1997). An ice sheet of the Świecie Stadial advanced at least as far south as Iława in the Iława Lakeland and Olsztyn in the Mazury Lakeland, both to the east of the Lower Vistula Valley. The Middle Vistulian glacial episodes have presumably their equivalents in Scandinavia and in Germany (Lindner, Marks, 1995; Marks *et al.*, 1995; Houmark-Nielsen, 2008), however there is a lack of glacial sediments of this age in northeastern Poland (Ber, 1988) and in Lithuania (Satkūnas *et al.*, 1998), therefore this problem needs further investigation.

The Main Stadial in Poland is composed of three glacial phases i.e. Leszno (Brandenburg), Poznań (Frankfurt) and Pomeranian ones (Fig. 5). During LGM the Vistula Palaeo-ice Stream advanced *via* the Gulf of Gdańsk to the Lower Vistula Region, presumably already about 22 ka ^{14}C BP (Marks, 2002). Strong control exerted by topography is indicated by the highly elevated inter-stream areas, namely the Lubawa Elevation and the Elbląg Upland. The ice sheet during its advance formed two ice streams (the Vistula and the Mazury Palaeo-ice streams) that diverged around the Elbląg Upland and the Lubawa Elevation, leaving at first a portion of the higher area ice-free. Along the margins and at the top of the Elbląg Upland there are prominent linear ridges that were

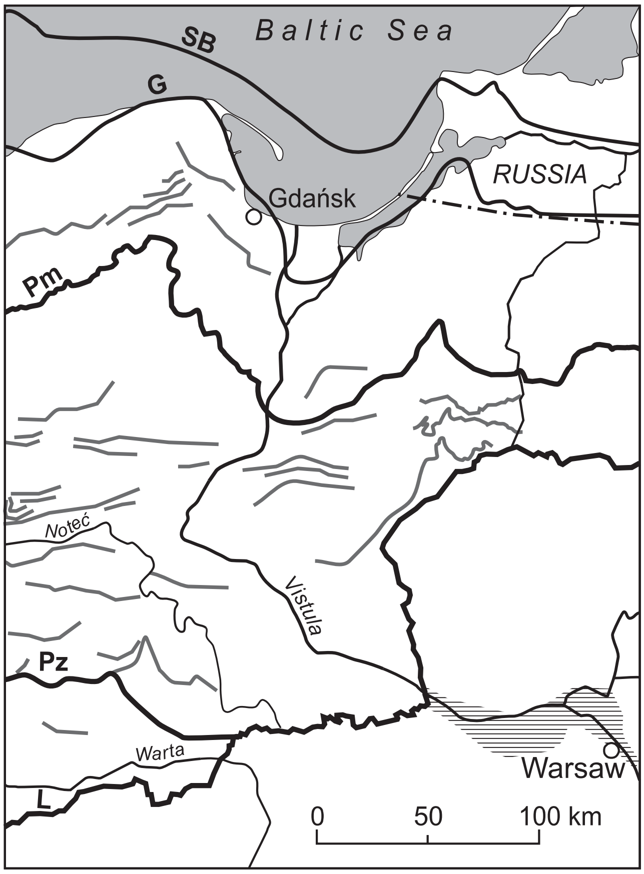


Fig. 5. Major glacial phases during the Late Vistulian in the Lower Vistula Region, compiled from different authors. Indicated are ice sheet limits during Leszno (L), Poznań (Pz), Pomeranian (Pm), Gardno (G) and Słupsk Bank (SB) glacial phases and also of minor local glacial oscillations. In the Warsaw region the area occupied by the ice-dam lake during the Last Glacial Maximum is presented

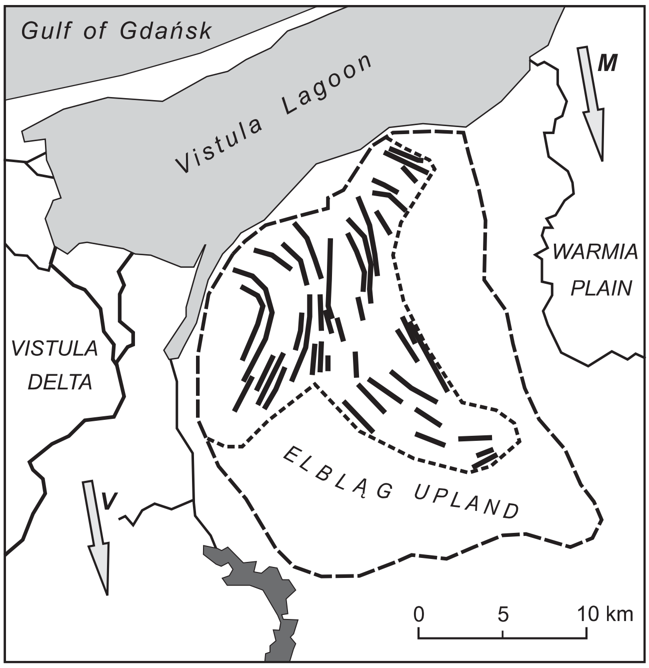


Fig. 6. Ice sheet dynamics during LGM: Vistula (V) and Mazury (M) Palaeo-ice streams around the Elbląg Upland (197 m a.s.l.) during the Last Glacial Maximum (LGM) after Aber and Ruszczyńska-Szenajch (1997), modified

interpreted to be glaciotectonic thrusts features (Aber, Ruszczyńska-Szenajch, 1997), created by the fast-moving ice streams as they flowed around and over the plateau (Fig. 6). At the Lubawa Elevation and the Elbląg Upland but also in the cliffs of the Gdańsk area (Kaulbarsz, 2005), there is much evidence for extensive glaciotectonic deformations.

To the south of the Pomeranian limit there are several discontinuous marginal zones that represent the earlier, post--LGM ice sheet limits; however, age of none of these has been strictly defined and it is also possible that the Pomeranian ice sheet limit was further to the south (cf. Roszko, 1956; Gałązka, 2004).

LATE GLACIAL AND HOLOCENE PALAEOGEOGRAPHY

The Lower Vistula Valley has developed after the Pomeranian Phase when drainage along the Toruń-Eberswalde ice--marginal streamway was ceased and the river turned to the north. Numerous proglacial lakes were formed in front of the retreating ice sheet and among them, the ice-dam lake at Gniew was the most extensive. The Vistula Palaeo-ice Stream that was still active after the Pomeranian Phase, discharged its huge ice flux, among others by calving into the proglacial lake of Gniew.

River terraces of the Lower Vistula were formed during Late Glacial and Holocene. The Holocene marine sediments occur at the bottom of the Gulf of Gdańsk and in the Vistula Lagoon.

CONCLUSIONS

- The Lower Vistula Region was a main route for Pleistocene ice sheets advancing into the Polish Lowland.
- Vast ice-dam lakes were formed in the Lower Vistula Valley at the end of the Elsterian Glaciation.
- An extensive sea bay existed in the Lower Vistula Region during the Eemian Interglacial.
- The Lower Vistula Region is a stratotype area of the Vistulian Glaciation (Weichselian).
- There were several ice sheet advances in the Lower Vistula Region during the last Scandinavian glaciation.

REFERENCES

ABER J., RUSZCZYŃSKA-SZENAJCH H., 1997 – Glaciotectonic origin of Elbląg Upland, northern Poland, and glacial dynamics in the southern Baltic region. *Sedim. Geol.*, **111**: 119–134.

BER A., 1988 – Quaternary stratigraphy of the Suwałki Lakeland, based on recent data. *Quatern. Stud. Poland*, **8**: 7–13.

GALON R., 1934 – Dolina dolnej Wisły, jej kształt i rozwój na tle budowy dolnego Powiśla. *Bad. Geogr.,* **12/13**: 1–12. Poznań.

GAŁĄZKA D., 2004 – Investigation of Scandinavian erratics from tills in the interlobate zone, Iława region, northern Poland. International Field Symposium on Quaternary Geology and Modern Terrestrial Processes. Abstracts: 15–16. Riga.

GAŁĄZKA D., KUSIŃSKI J., MARKS L., 1998 – New approach to a maximum extent of the Vistulian Glaciation in the southwestern Mazury Lakeland, northern Poland. The Peribaltic Group, INQUA Commission on Glaciation, Field Symposium on glacial geology at the Baltic Sea coast in northern Poland. Abstracts of papers and posters: 11–12. Szczecin.

GAŁĄZKA D., MARKS L., ZABIELSKI R., 1999 – Czy litostratygrafia glin lodowcowych może być przydatna dla stratygrafii czwartorzędu Polski? *Prz. Geol*., **47**, 2: 261–265.

HEAD M.J., SEIDENKRANTZ M.-J., JANCZYK-KOPIKOWA Z., MARKS L., GIBBARD P.L., 2005 – Last Interglacial (Eemian) hydrographic conditions in the southeastern Baltic Sea, NE Europe, based on dinoflagellate cysts. *Quatern. Intern.,* **130**: 3–30.

HOUMARK-NIELSEN M., 2008 – Testing OSL failures against regional Weichselian glaciation chronology from southern Scandinavia. *Boreas*, **37**: 660–677.

KAULBARSZ D., 2005 – Geology and glaciotectonics of the Orłowo Cliff in Gdynia, northern Poland. *Prz. Geol*., **53**, 7: 572–581. [in Polish with English summary].

KEILHACK K., 1899 – Die Stillstandslagen des letzten Inlandeises und die hydrographische Entwicklung des pommerschen Küstengebietes. *Jahrbuch der Königl. Preuss. geologischen Landesanstalt und Bergakademie zu Berlin für das Jahr 1898*, **19**: 90–152.

KONDRATIENE O., GUDELIS W., 1983 – Pleistocene marine sediments in the Pribaltica area. *Prz. Geol.,* **31**, 5: 497–502.

LINDNER L., MARKS L., 1995 – Zarys paleogeomorfologii obszaru Polski podczas zlodowaceń skandynawskich. *Prz. Geol.,* **43**, 7: 591–594.

LISICKI S., 1997 – Pleistocene of the Mrągowo Lakeland. *Geol. Quart*., **41**, 3: 327–346.

MAKOWSKA A., 1974 – Mapa geologiczna Polski w skali 1:200 000, ark. Grudziądz. Wyd. B. Inst. Geol., Warszawa.

MAKOWSKA A., 1976 – Stratigraphy of tills exposed along the valley of the Lower Vistula area. *Geografia UAM*, **12**: 239–242.

MAKOWSKA A., 1977 – Poziom interglacjalny wśród osadów zlodowacenia środkowopolskiego w dolinie dolnej Wisły. *Kwart. Geol*., **31**, 4: 769–787.

MAKOWSKA A., 1978 – Mapa geologiczna Polski w skali 1:200 000, ark. Elbląg. Wyd. B. Państw. Inst. Geol., Warszawa.

MAKOWSKA A., 1979 – Mapa geologiczna Polski w skali 1:200 000, ark. Iława. Wyd. B. Państw. Inst. Geol., Warszawa.

MAKOWSKA A., 1984 – Osady morskie i rzeczne w rejonie doliny dolnej Wisły. In: Budowa geologiczna Polski, 1: stratygrafia, 3b, kenozoik, czwartorzęd: 197–208. Wyd. Geol., Warszawa.

MAKOWSKA A., 1986 – Pleistocene seas in Poland sediments, age and palaeogeography. *Pr. Inst. Geol.,* **120**: 1–74.

MAKOWSKA A., 1991 – Profil geologiczny otworu w Pagórkach koło Elbląga oraz znaczenie wyników badań pyłkowych jego osadów dla stratygrafii młodszego plejstocenu w Polsce. *Prz. Geol*., **39**, 5/6: 262–269.

MAKOWSKA A., 2001 – Palaeogeography of the Prabuty–Susz area (Lower Vistula Region) prior to, to time and after the Tychnowy Sea transgression, and malacological fauna of the deposits. *Biul. Państw. Inst. Geol.*, **398**: 25–67. [in Polish with English summary].

MARKS L., 1988 – Relation of substrate to the Quaternary paleorelief and sediments, western Mazury and Warmia (northern Poland). *Kwart. AGH, Geologia*, **14**, 1: 1–76.

MARKS L., 1991 – Zasięgi lądolodów zlodowacenia Wisły w środkowej i wschodniej Polsce. *Geografia UAM*, **50**: 531–538.

MARKS L., 1995 – Correlation of the Middle Pleistocene ice-dam lacustrine sediments in the Lower Vistula and the Lower Elbe regions. *Acta Geol. Pol.*, **45**, 1/2: 143–152.

MARKS L., 2002 – Last Glacial Maximum in Poland. *Quatern. Sc. Rev.,* **21**, 1: 103–110.

MARKS L., PIOTROWSKI J.A., STEPHAN H.-J., FEDOROWICZ S., BUTRYM J. 1995 – Thermoluminescence indications of the Middle Weichselian (Vistulian) Glaciation in northwest Germany. *Meyniana*, **47**: 69–82. Kiel.

MOJSKI J.E., 1979 – Outline of the stratigraphy of the Pleistocene and the structure of its basement in the Gdańsk Region. *Biul. Państw. Inst. Geol*., **22**: 5–50.

MOJSKI J.E., 1985 – Quaternary. *In*: Geology of Poland, 1 (3b). Wyd. Geol., Warszawa.

MOJSKI J.E., SYLWESTRZAK J., 1978 – Mapa geologiczna Polski w skali 1:200 000, ark. Gdańsk. Wyd. B. Państw. Inst. Geol., Warszawa.

NIEWIAROWSKI W., OLSZEWSKI A., WYSOTA W., 1995 – The role of subglacial features in glacial morphogenesis of the Kujawy–Dobrzyń Subphase area in the southern and eastern part of the Chełmno–Dobrzyń Lakeland. *Quatern. Stud. Poland*, **13**: 65–76.

ROSZKO, L., 1955 – End moraines of the western Mazurian lake country. *Stud. Soc. Sc. Torunensis*, **2**, 2, 35–245.

ROSZKO L., 1956 – The question of the limits of the Pomeranian Stage on the Lower Vistula. *Stud. Soc. Sc. Torunensis*, **3**, 1: 1–22.

SATKŪNAS J., GRIGIENĖ A., ROBERTSSON A.-M., 1998 – An Eemian – Middle Weichselian sequence from the Jonionys site, southern Lithuania. *Geologija*, **25**: 82–91.

SONNTAG P., 1919 – Geologie von Westpreussen. Berlin.

TORNQUIST A., 1910 – Geologie von Ostpreussen. Berlin.

WYSOTA W., 2002 – Stratigraphy and sedimentary environments of the Weichselian Glaciation in the southern part of the Lower Vistula Region. Wyd. UMK, Toruń. [in Polish with English summary].

WYSOTA W., LANKAUF K.R., MOLEWSKI P., SZMAŃDA J., 1996 – Sedymentologia interstadialnej serii rzecznej (Rzęczkowo) zlodowacenia Wisły (Vistulian) odsłoniętej w południowo-zachodniej krawędzi Wysoczyzny Chełmińskiej. *Acta Univ. N. Copernici*, **97**, *Geogr.*, 28: 39–63.