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On the stratigraphy of the Last Glaciation in the Dolne Powiśle and the Elbląg Elevation (Northern Poland)

Some results of last studies on stratigraphy of Last Glaciation on Dolne Powiśle and Elbląg Elevation areas were discussed. It is highly probable that glaciotectionic thrust slices have dominated in the Quaternary cover structure in the latter area. They could involve multiple duplication of the same strata which *in situ* had formed on area of recent Baltic bottom. It induces definite consequences in construction of stratigraphic profile of studied deposits and their dating. There are also principal differences in opinions on age and genesis of some intermorainic series, younger than the Eemian Interglacial.

INTRODUCTION

Geological and geomorphological studies of last twenty years on Lower Vistula area supplied a lot of data about stratigraphy of Last Glaciation. This area has been known for a long time as place with many profiles, presenting nearly complete deposits sequences of that age. The well data, coming from there, allowed to precise position of older marine deposits of the Eemian Interglacial. Results of studies in the seventies made possible to organize in 1979 the international symposium "Vistulian Stratigraphy 1979". It was held as workshop of the Subcommittee of European Quaternary Stratigraphy INQUA. There were presented profiles from area between Płock and Sopot and their interpretation particularly from Lower Vistula region, indicated three horizons of glacial deposits, separated mainly with fluvio-glacial and limnoglacial ones (J. Chalain et al., 1980). Scientists, who studied this area, have presented their results also in two issues of *Quaternary Studies in Poland* (E. Drozdowski, 1980; R. Galon,

1982; A. Makowska, 1980; J.E. Mojski, 1980; J. Rzechowski, 1980; T. Wysoczański--Minkowicz, 1982). Next works of E. Drozdowski (1986, 1988, 1989), E. Drozdowski, S. Fedorowicz (1985, 1987), S. Fedorowicz, E. Drozdowski (1986), A. Makowska (1982, 1986, 1989, 1990, 1991), and A. Makowska, W. Rabek (1990), where interpretations of new field and laboratory data as well as datings with ^{14}C and thermoluminescence methods have been presented, led not only to large differentiation of opinions but also to express some too extensive conclusions, discussed here.

For a long time has been known that structure of the Quaternary on Dolne Powiśle and Elbląg Elevation was different. On Dolne Powiśle these deposits have normal sequence but the Elbląg Elevation consisted of the Quaternary sediments with intensive glaciotectionic disturbances. Such situation involved separate descriptions of discussed areas.

DOLNE POWIŚLE

It is generally accepted that within Vistula Stage are three correlatable glacial horizons (Tab. 1). Only A. Makowska distinguished there five such horizons: the additional two being: the one, oldest and forecoming the next other ones and the other — youngest, overlaing them. This first horizon was named by her as Malbork Phase or — after lithostratigraphic division — Malbork Horizon (A. Makowska, 1986). Malbork Phase was taken from terminology of S.Z. Różycki but A. Makowska used the name Malbork Glaciphase (A. Makowska, 1979). Minimal till thickness and occurrence of it only in several borehole profiles do not favour to create a new, separate stratigraphic unit. But it is possible to regard as a working hypothesis the occurrence of BI horizon in northern part of Dolne Powiśle, which horizon was only described by A. Makowska. Nothing was known about accumulation conditions of deposits, separating BI horizon and glacial series BII.

Glacial horizon BV was connected — after A. Makowska — with ice-sheet decline after origin of the Pomeranian end moraines. It could be assumed that in some places have existed conditions favourable for formation of distinct glacial horizon, younger than glacial till of the Leszno Stadial (Main Stadial), but assumption, that both glacial tills have been separated far to north, could lead to conclusion that before the Pomeranian Phase the ice-sheet retreated northward, beyond recent national boundaries. On the Kaszuby border of the Gdańsk Bay lack of such data. Assuming that the deposits of BV horizon should be regarded as originated immediately nearby the Pomeranian marginal zone and they have close genetic and age relations with it. This opinion is connected also with great and controversial problem of age and genesis of all this marginal zone, discussion of which overpasses purposes of this article.

The divergent opinions were about age of BII horizon. A. Makowska (1986) dated it for over 100 ka BP. Similar age range stated the author but it should be pointed out that the principles of such calculations were insufficient (J.E. Mojski, *in press*). They could be documented in some way with such dating of earliest advance of the post-Eemian ice-sheet on the Fennoscandian area (B.G. Andersen, J. Mangerud, 1989) as well as with interpretations of climatic curves, based on various data (H. Flohn, 1985; T.

Table 1

Main division of the Last Glaciation on the Lower Vistula

E. Drozdowski	A. Makowska	J. Rzechowski	J. E. Mojski	
Holocene				
First glacial horizon	Vistulian Glaciation	Upper (Leszno-Pomeranian Stadial) and Late BIV and BV	G3	Main Stadial
Grudziądz Interstadial		Middle	G2	Grudziądz Interstadial
Second and third glacial horizons		Lower (Świecie Stadial) BIII		pre-Grudziądz Stadial
		Krastudy Interglacial		(Konin?)
		Toruń Glaciation BI and BII	G1	Kaszuby Stadial
Eemian				

Wysoczański-Minkowicz, 1982). In the last of mentioned works (T. Wysoczański-Minkowicz, 1985) the so-called criomegastadial was dated between 114 680 and 94 230 years BP. That hundreds or thousands of years could be omitted but still exists the time range, corresponding to calculations and few datings of profiles from Dolne Powiśle except of suggestions of E. Drozdowski (1986, 1988), who dated the oldest glacial horizon of last cold stage for about 58–56 ka BP. These results are merely about 3–4 ka higher than datings of younger horizon, that means — second glacial horizon according to terminology of E. Drozdowski (Tab. 1). It was not so distinct age difference to create two separate glacial horizons, originated during two ice-sheet advances. This dating difference locates within mistake limit of thermoluminescence method used and it could be suspected that was studied one and the same glacial horizon — and the same glacial till level — corresponding to the second glacial horizon. E. Drozdowski, studying only outcrops, has not found the first post-Eemian horizon of glacial till (BII horizon after A. Makowska). Such horizon occurs very low, often at the depth comparable with position of the Vistula valley bottom as documented boreholes data, and mostly covered with thick wash slope and slumped deposits. Only northward, on eastern part of the Kaszuby Upland, this horizon outcropped (J.E. Mojski, 1980).

The middle glacial horizon of the Vistula Glaciation (second glacial horizon, BIII, pre-Grudziądz Stadial) has undoubtful clear stratigraphic position. Also its thermoluminescence dating was unquestionable. Similar opinion exists about upper glacial horizon (BIV, first glacial horizon).

Two intermorainic series, occurring on Dolne Powiśle area and separating three glacial horizons there, should be more detailed studied. Older of these was correlated with the Krastudy Interglacial and named as the Gniew Formation (A. Makowska, 1986), which was an equivalent of the lower fluvio-glacial in older terminology of R. Galon.

The Gniew Formation has no deposits indicating its origin in interglacial conditions. Most of its deposits is of fluvio-glacial type. They occurred in many outcrops along valley borders of Lower Vistula and could be formed partly during decline of older ice-sheet and advancing of the next one. Between these deposits could occur in some places the fluvial sediments. According to preliminary studies of author (J.E. Mojski, 1982) most of described deposits has formed during ice-sheet decline of the Kaszuby Stadial, when the thick covers of kame terrace have originated in eastern part of the Kaszuby Upland (J.E. Mojski, 1980).

The profile in Gniewskie Młyny is one of most significant outcrops, in which deposits of the Gniew Formation are visible. A. Makowska interpreted them as fluvio-glacial with redeposited fauna of Eemian age but after E. Drozdowski they represented the marine cover of the Grudziądz Interstadial, containing shells of *Cardium edule*, *Macoma baltica*, *Cyprina islandica* and *Nassa reticulata*, dated with ^{14}C method for about 40 ka BP (detail values — in work of E. Drozdowski, 1988). The Gniewskie Młyny profile documented large divergences in interpretations and dating of deposits found in various outcrops along the borders of Lower Vistula Valley. It seems that more probable — in light of recent studies results — were datings of E. Drozdowski. Assuming them the intermorainic series from the Gniewskie Młyny profile should be placed between glacial horizons BIII and BIV but its marine genesis

is out of the question. Marine fauna could be there only in secondary place as was documented in many outcrops from western border of Żuławy area. Its primary source were probably marine deposits, which have formed on the southern Baltic area during the Grudziądz Interstadial. They were teared from primary position by last ice-sheet and placed within fluvioglacial deposits, originated on the sheet foreground during its southward advance. Other arguments of E. Drozdowski for marine genesis of described sediments could be explained in similar way. But one important factor should be assumed. It is recent hypsometric position of studied deposits. If they were marine *in situ*, it would indicate that sea level had recent altitude of several tens of meters. In light of our knowledge on sea level changes in the Younger Pleistocene, such assumption should be fantastic. It could be proper if vertical Earth crust movements existed, uplifting all area of Lower Vistula Valley several tens of meters during last 40 ka. But it is also fantastic hypothesis because it was sure that level of supposed sea on Lower Vistula area had not been higher than level of the Eemian sea.

THE ELBLĄG ELEVATION

The area of Lower Vistula Valley supplies many data for stating the stratigraphy of the Vistula Glaciation but the Elbląg Elevation is unuseful for it. It was known times ago that deposits occurring in large outcrops were not *in situ* but were disturbed by glaciotectonic processes of various types. Field studies of A. Makowska, carried for many years, have confirmed this opinion but she thought that nevertheless of such disturbances the reconstruction of primary stratigraphic profile of whole Quaternary sequence, forming the elevation, was possible. She has presented this conception several times and interpreted these glaciotectonic disturbances on many geological cross-sections as broad folds. Amplitude of disturbances achieves 100 m, calculating from outcrop data but their intensity suggests widespread occurrence of other structures as large slices, onlapped one on as other and completely detached from primary depositional place, which was an area of recent Baltic bottom. A. Makowska (1986) has mentioned about slices occurrence but without details and examples. Such problems documented well the borehole profile from Pagórki, most significant for final stratigraphic conclusions of A. Makowska (A. Makowska, W. Rabek, 1990; A. Makowska, 1991). In this profile the deposits of the Krastudy Interglacial laid at the depth from 8 up to 147 m and their thickness was 139 m, including marine sediments 72.0–59.6 m thick. During conference on stratigraphy of the Last Glaciation on the Lower Vistula area, in September 1991 in Sopot, complete core of this profile was presented. Many participants, also author, paid attention to occurrence there of no less than four, macroscopically similar, interlayers of deposit, described by A. Makowska as "red clays", within interval of 200 m, between the altitudes from 94 m b.s.l. up to 115 m a.s.l. Their macroscopic similarity and textural features such as intense fracturing and frequent slickenslides, were described also by A. Makowska (1991). These phenomena indicated the strong stresses, acting within deposits. They also could document the glaciotectonic character of deposits studied and their recurrence at varied depths may suggest the slices occurrences. According to author such interpretation of whole Pleistocene profile from Pagórki

should not be ignored. Occurrence of slices that seems repetition of sequences of defined beds, significantly hinders or excludes possibilities of primary sequence reconstructions, makes that profile unuseful in stratigraphic sense and eliminates it as stratotypical one. Surely, it is only hypothesis but with similar value as other ones, including presented by A. Makowska.

In that situation, according to author, occurrence of deposits of the Krastudy Interglacial, particularly — marine sediments of this age *in situ* — in the Pagórki borehole profile is insufficiently documented.

Similar remarks refer to position and stratigraphic interpretation of deposits of the Krastudy Interglacial nearby Kamionka, located just beyond the Elbląg Elevation (A. Makowska, 1990). These deposits occurred in borehole profiles at the altitudes 15–60 m a.s.l. (these data calculated from geological sections, presented in mentioned article). Deposits thickness is up to 20 m. Their stratigraphic position is debatable because they are glaciotectonically disturbed — as described A. Makowska (*op. cit.*, p. 484) — and covered with no more than one glacial till horizon.

Conclusions of A. Makowska (1986), referring to two marine horizons, dated from 50 to 30 ka BP, were very controversial and had important palaeogeographic implications. These horizons were found in Próchnik II and Łęcze sites and occurred recently very close to ground surface on area of the Elbląg Elevation, at the altitude over 100 m a.s.l. Opinion of A. Makowska is based on founding within these sands very scanty and strongly damaged marine fauna. In marine horizons from Próchnik II site was noted "probable...*Arctica islandica* (?)" (*op. cit.*, p. 40). Assemblage of marine fauna, found in marine horizons from Łęcze site, indicated the cold-water basin.

Proofs of "sea from Próchnik II site", being the nearly unclassified shell fragment, seem very insufficient for creating new marine horizon of the Pleistocene in Poland. Such fact could be ignored in interpretation of all profile, assuming lack of sufficient informations about genesis of deposits, containing mentioned shell. Fauna composition of assemblage from "sea from Łęcze site" documents its marine character but also there was no analysis of sedimentary conditions of deposits, containing it. Lack also of these deposits dating. Two cited values of ^{14}C (34.5 and 35.1 ka BP) referred to fresh-water deposits but not to marine ones.

The fundamental problem is occurrence of deposits with marine fauna not *in situ*. Marine fauna found in deposits, mainly sandy, from Łęcze i Próchnik II sites was redeposited, probably several times. But it provenienced not from area of the Elbląg Elevation, even from its most northern part, but its primary location was on area of recent Baltic Sea. It is possible that also there this fauna was incorporated into deposits of probable fluvio-glacial character. It could be supposed, due to lack of dating, that fauna from "seas" of Próchnik I and II and Łęcze have developed during final stages of the Eemian sea or later, during one of interstadials of the Last Glaciation. But there are no clear proofs for existence of several such seas in general as well as proofs that such seas have existed in any part of recent land. This indicated that opinion about nine marine transgressions in the Pleistocene on area of Dolne Powiśle (A. Makowska, 1989) should not be expressed. Most significant result of A. Makowska studies, in part related to marine deposits of the Last Glaciation, was discussing of possibilities of their occurrence on area of recent Baltic Sea.

Other controversial problem was genesis, age and position of red and grey clays, of the Elbląg Clays type, within the Pleistocene profile. From tens years they have been main point of discussions. In Pagórki such clays formed probably parts of glacioteconic slices and occurred both below and above the marine deposits of the Eemian Interglacial. If slices occurrence is accepted the clays age will be — according to mentioned profile — difficult to define. In outcrops northward from Elbląg such clays occurred together with deposits glacioteconically disturbed and were noted at varying altitude. But it should be pointed out that within the Elbląg Clays was made pollen diagram of the Eemian age, with climatic optimum (B. Halicki, L. Brodniewicz, 1961). This old interpretation was changed with time and last diagram reinterpretation (K. Mamakowa, 1989) indicated that it was not of the Eemian age. Pollen grains were redeposited and also deposit contains many older impurities. Several overlapping of the same bed could not be excluded.

The Elbląg Clays have some features similar to the Late Glaciation – Holocene clays from deeper parts of the Baltic Sea as Gdańsk Deep, Bornholm Deep. These similarities should be regarded in reconstructions of sedimentary conditions of the Elbląg Clays because up till now the attempts to make pollen diagram from recent marine clays have been unsuccessful. It led to conclusion that probably the Elbląg Clays and other clays with marine fauna from the Elbląg Elevation area could be deeper water facies of the Eemian sea. Such facies have formed far before and long after the climatic optimum. But it should be not excluded they were older and for any horizon of such deposits, especially found in the borehole profiles, could not be stated the other age.

Occurrence of the Eemian marine deposits at the depth a little lower than recent sea level, confirmed — it referred at least to the lower part of the Pagórki profile — the interpretation of A. Makowska. At the same level were found those deposits on Dolne Powiśle area, of their nearshore facies type. It could indicate that marine deposits of the Eemian were laid there *in situ*. If it is true, as a consequence it should be assumed that all older deposits have been glacioteconically disturbed before the Eemian, during the Middle Polish Glaciation or earlier, but overlaing deposits were disturbed after the Eemian Interglacial. A. Makowska has mentioned several times about the repetition of the glacioteconic disturbances. Probable occurrence of the marine Eemian deposits *in situ* on disturbed basement in Pagórki site suggests gap existence in the bottom of marine sediments, resulted due, for example, to abrasion. The known rate of the Littorina transgression, in younger part of the Holocene, along Polish coasts indicated that during several thousands years the large upland areas with altitude no less than several tens of meters have been denudated.

FINAL REMARKS

Some final remarks should be added at the end of article. One of them refers to principles of stratigraphic divisions of stage range in the Quaternary — it means: glacial and interglacial. A. Makowska in her last works documented such distinguishing of glacial and later interglacial, younger than the Eemian but older than the Vistula

Glaciation. It is nothing new for Poland and all Europe. Adequate examples are known in literature. But in her last article (A. Makowska, 1991, p. 267) she wrote that "...in glacial zone up till now the equivalents of the Toruń Glaciation and the Krastudy Interglacial have been not found...". It refers to Poland area but is not true. The equivalent of glacial till, which A. Makowska regarded as "indexing" deposit of the Toruń Glaciation, has been known from tens years in the Lower Vistula Valley and mostly it was assumed as stadial counterpart. This till could be regarded as equivalent of other, distinct glaciation, if it is covered with interglacial deposits, documented with palaeontological and — especially — palaeobotanical data. Such deposits have been up till now unknown, at least on the peri-Fennoscandian area. For a long time attempts to define interglacial younger than the Eemian have been taken up but principles for it were insufficiently documented as well as the opinion of the A. Makowska. Her important contribution was the reminder of such principal problems of the Upper Pleistocene stratigraphy. In the light of current studies it could not be successful. In such situation is odd her omission of results of all earlier studies (A. Makowska, 1991). Author of this article, from the beginning of his investigations in the Gdańsk region, has distinguished three glacial horizons over last interglacial, basing among others on the data from Tczew (J.E. Mojski, 1979, 1980). It is clear that such complete deposit sequence is visible on eastern border of the Kaszuby Lake District, in numerous borehole profiles and outcrops, located between Tczew and Gdynia. Westward the situation was less recognized. The correlation of individual glacial horizons resulted not only from mapping in detail scale but also due to glacial tills studies (J.E. Mojski, 1980; J. Rzechowski, 1980). Results of the last ones gave some principles for wider correlations, expanding outside the Dolne Powiśle area.

Names of the lithostratigraphic units not only of the Last Glaciation but of the whole Pleistocene have in all cases the temporary meaning and in that way they should be regarded in current publications, except of serial geological maps. More stable name fixing could result from general discussion and acceptance by the specialistic team, the best will be in the Committee for Quaternary Research of the Polish Academy of Sciences. Then the name, for example, "Kaszubski" could be replaced with "Toruński" or inversely. It should be added that all stratigraphic terminology of the Quaternary in Poland is an example of carelessness and it needs of minimal corrections.

Datings with ^{14}C and thermoluminescence methods were commented by A. Makowska. But it should be pointed out that comparing the such immense amount of presented materials and conclusions the number of datings is insufficient. The profiles with several vertical datings were completely absent. It could suggest that age data, proposed by A. Makowska, will be unimportant for geochronological and correlation applications. But importance of these problems obliges us to make such analysis in earlier selected profiles.

The field and laboratory studies, including defining of diagnostic features for recognition the glacial tills composition, are also necessary. Petrographic composition of selected gravel fractions and direction measurings of longer boulder axes give first informations not only about correlability of various glacial till horizons but also about movement direction of ice-sheet, which left these tills. Such studies were done for areas of Lower Vistula and surroundings of Gdańsk, locally with very positive results (see — J.E. Mojski, 1980). Similar investigations are indispensable in our aims to precise

the stratotype profiles. Complete results of already finished studies of J. Rzechowski and his team should be soon published. They are partly known (see — J. Rzechowski, 1979, 1980) and allow to explain some new aspects of stratigraphy of the Last Glaciation.

The Vistula Stage is very promising object for further studies. There could be applied various methods, various criterions of stratigraphic division. Good outcrops also invite to field studies, but their efficiency strongly depend on properly realized complex works. The last ones, in sense of presented here problems, are still before us. Only such studies could explain numerous doubts about stratigraphy of the Vistula Stage on Dolne Powiśle area.

Translated by Grzegorz Czapowski

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Received: 4.10.1991

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O STRATYGRAFII OSTATNIEGO ZŁODOWACENIA NA DOLNYM POWIŚLU I WZNIESIENIU ELBLĄSKIM

Streszczenie

W ostatnim dziesięcioleciu ukazały się publikacje, w których zostały sprecyzowane nowe poglądy na stratygrafię zlodowacenia wisły na Dolnym Powiślu (E. Drozdowski i A. Makowska) oraz na Wzniesieniu Elbląskim (A. Makowska), a także na wielokrotność transgresji morskich w czasie ostatniego zlodowacenia na tych obszarach.

Na Dolnym Powiślu powyżej morskiego eemu leżą trzy poziomy osadów glacialnych, każdy z nich ma przynajmniej rangę stadiału. Istnieją jednak różne korelacje między poszczególnymi poziomami. Najstabilniej rozpoznany jest najstarszy poziom glacialny.

Wzniesienie Elbląskie zbudowane może być, według autora, z wielkich łusek glacytektonicznych, obejmujących być może cały plejstocen. W budowie tych łusek biorą udział osady plejstocenyjskie egzarowane z dna obecnego Bałtyku. Występujące w tych osadach szczątki fauny i flory są zapewne wielokrotnie redeponowane. Stąd poglądy o wielokrotności transgresji morskich w plejstocenie na Dolnym Powiślu i Wzniesieniu Elbląskim sformułowane przez obu autorów wymagają rewizji.