

Quaternary research in Poland: selected achievements and prospects

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Abstract. During the last thirty years there were several turnouts in Quaternary studies that increasingly accelerated our understanding of natural processes and opened new research fields. Among others, they included complex reconstruction of palaeoclimatic phenomena, studies of deep-sea and long-term continental record, and extensive application of reliable dating methods. In Poland considerable progress was gained in studies of stratigraphy and palaeogeography of the Eemian Interglacial, last Pleistocene glaciation and Holocene, regional loess stratigraphy, key palynologic interglacial sections and standard varve chronology in Lake Gościąg, as well as in complex and systematic studies in polar areas. Priorities in Quaternary studies suggest that particularly quick progress is to be expected in studies of climate change, evolution of natural environment and in monitoring of natural and human-induced hazards.

Key words: Quaternary, research, achievements, priorities

The main feature of the Quaternary studies is their complexity and interdisciplinary character. The idea of integration of interdisciplinary studies of the Quaternary, far beyond a clear geological aspect, has been developed already in the 19th century. In Poland the first institutional Quaternary organisation was created by the Committee for Starunia Research, established by the Polish Academy of Arts and Sciences in June 1929. But already in 1928 at the International Geological Congress in Paris, a new Quaternary organisation was initiated, named the International Union for Quaternary Research (INQUA). Polish Quaternary researcher Mieczysław Limanowski played a significant role in this activity.

After the Second World War, an interdisciplinary spectrum of Quaternary scientists in Poland has been grouped in the Committee for Quaternary Research, established by the Polish Academy of Sciences on 30th June, 1964. Within this Committee, the National Committee of INQUA was founded.

The Committee initiated and supported the studies of the Quaternary in Poland. This activity succeeded in development of the Geochronological Laboratory in Gliwice (Upper Silesia) and supported a wide program of dating of sediments. Activity of the Committee backed up considerable progress and intensified international cooperation and participation in multilateral programs.

Quaternary research during the last thirty years

It has focused mostly within the Earth sciences, with vast participation of biology, also physics, archaeology and agricultural sciences. The Quaternary studies play predominant role in reconstruction of previous events, forecast future changes in natural environment and climate and also monitor the natural hazards. It does seem obvious that demands of the authorities and the society made distinct and quick progress in these studies possible during the last thirty years. The four fundamental points has backed up these achievements:

- application of precise and reliable dating methods;
- vast cooperation with non-Earth scientists in collecting and elaboration of data;
- introduction of new research techniques;

- appearance of theoretical models, tested with collected geological data.

The retrospective view indicates that the last thirty years witnessed a distinct quantitative change in the methods applied. It was firstly due to wide use of computer programs that made possible common introduction of modeling and forecasting to Quaternary research. And although our knowledge is at present much more profound than several dozen years ago, there are still numerous questions without any reasonable answer yet. There are now many new research perspectives that call for undertaking innovatory approaches in the coming years.

New methods applied in the Quaternary research considerably increased the possibilities to find the solution in this sector of science. Among these new methods, or new application of the older methods, there are:

- wide introduction of sedimentology to determination of the sedimentary environment of the Quaternary sediments;
- reconstruction of palaeotemperatures on the basis of oxygen isotopes — this method is considered universal in studies of deep-sea sediments and ice cores, and can be also applied to inland deposits;
- dating of Quaternary sediments;
- measurement of palaeoclimate parameters;
- application of biology (e.g., palynology) as a source of information on environmental changes;
- palaeomagnetism.

Among achievements in Quaternary studies in the world during the last thirty years there are several turnouts that increasingly accelerated our understanding of natural processes and opened new research fields. They include (Porter, 1999):

- identification of climatic cycles of varying duration and attempt of their correlation with definite astronomical and geological phenomena;
- linking the palaeoclimatic signal from deep-sea sediments with changes of ice volume on land;
- complex and interdisciplinary studies of long continental sequences, enabling correlation of changes in vegetation during several intervals of the Quaternary with a record of climatic changes in deep-sea sediments;
- correlation of results of palaeoclimatic studies of deep-sea sediments and ice cores with the palaeomagnetic scale and loess-palaeosol sequences, which demonstrated the occurrence of several dozen inter-

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glacial-glacial cycles throughout the Quaternary — it located the lower boundary of the Quaternary at least at 1.8 mln years ago, but more probably, this boundary should be moved even further back to 2.6 mln years ago;

- calibration of radiocarbon time scale and wider use of uranium-thorium dating;
- introduction of palaeoclimatic modeling based on primary role played by ocean circulation;
- attempt of determination of the role of greenhouse gases in climate development.

Achievements of Quaternary studies in Poland

Studies of the Quaternary in Poland during the last several decades had two aspects: regional and more general. In both, the main role was played by applicative factors, resulting from the fact that most of the country is mantled with thick Quaternary sediments. They contain also most natural deposits and groundwater intakes; this cover is most susceptible to degradation caused by the activity of man.

Among the most significant achievements of the Polish Quaternary scientists during the last thirty years there are:

- studies of stratigraphy and palaeogeography of the Eemian Interglacial, last Pleistocene glaciation and Holocene on the basis of complex lithological, palaeopedologic, chronometric and palaeontological investigations;
- development of regional loess stratigraphy on the basis of lithological, palaeopedologic, chronometric, palaeontological and palaeomagnetic data;
- revealing key palynologic interglacial sections in Poland;
- complex examination of Quaternary sediments in the brown coal mine at Bełchatów, what enabled to establish para-stratotypes for the European stratigraphy;
- elaboration of standard varve chronology on the basis of lithological, chronometric and palaeontological studies of sediments in the Lake Gościąg, what enabled to make it a global reference, especially for calibration of radiocarbon data;
- scheme of changes in a fluvial environment during the last 15 ka, based on complex examination of numerous sections;
- preparation and publication of the principles of classification and stratigraphic terminology for the Quaternary (Zasady..., 1988);
- complex and systematic studies in polar areas.

Significant role on scope and progress in studies of the Quaternary in Poland was played by mapping for the *Detailed Geological Map of Poland*, 1 : 50,000 scale, a project coordinated by the Polish Geological Institute (cf. Ber, 2004). Initiating and stimulating complex studies, the project yielded immense amount of new data and was backed with suitable funds.

All these research achievements were partly gained in cooperation with international boards and foreign organisations, particularly European ones. Worth mentioning is a very fruitful bilateral cooperation with scientific centres in neighbouring countries, particularly in Ukraine, Belarus, Lithuania, Czech Republic and Germany.

Integration of Quaternary research exemplified by some achievements in central Europe

During the last dozen years, an immense progress has been noted in studies of the Quaternary, carried through in cooperation with scientists from different European countries. Easier international contacts and application of new research methods favoured development of the knowledge and intensive exchange of ideas, particularly among the scientists from Central and Eastern Europe.

The main tasks that have been the subject to extensive investigation included selection of basic stratotype sections and defining formal, semi-formal and informal units in the stratigraphic schemes of the Quaternary. It calls for definition of precisely dated chronostratigraphic boundaries. Much in this scope is still to be done, as evidenced by the complex stratigraphic subdivision of the Lower Quaternary in Central Europe, as well as by uncertainties about the exact position of the Neogene/Quaternary boundary (cf. Fig. 1). This task, as well as of the status and definition of the Quaternary itself, has been lately many a time the subject of extensive discussion within the International Commission on Stratigraphy of the International Union of Geological Sciences (IUGS).

Trans-border mapping is another important field of international co-operation. Geologic maps in different scale have been prepared lately for the Polish regions along the border with Czech Republic, Lithuania, Germany, Slovakia, and Ukraine. The most spectacular recent example is a series of geologic maps in 1 : 200,000 scale for the border zone region of Poland and Germany, published in 2003 (Fig. 2).

There are numerous less or more formal groups that cooperate within the scope of the Quaternary research. In Europe one of these is the Peribaltic Group of the International Union for Quaternary Research (INQUA). Within the activities of this Group, eleven field symposiums were organised in 1996–2004 in the southern Peribaltic region (Fig. 3). Presented field material laid foundations for cooperation and played important role in selection of further research topics, such as those briefly outlined below:

- Pleistocene evolution of the Baltic Sea;
- development of river systems;
- distribution and classification of glaciotectonic features;
- dynamics of ice sheet of the last Scandinavian glaciation;
- chronology of the last glaciation.

Pleistocene evolution of the Baltic Sea. Evolution of the Baltic Sea basin has constituted for long a fascinating story for many Quaternary geologists. Intensive erosion resulted in considerable reduction in thickness of the Quaternary cover in this area, if compared with the regions farther south. For this reason, reconstruction of successive events during the Pleistocene, and particularly during its older part, faces numerous difficulties.

At the beginning of the Pleistocene, the central part of the present Baltic basin was occupied by the so-called Baltic Stream, flowing from northeast towards southwest (cf. Gibbard, 1988). We know very little about this Baltic Stream, because the Elsterian ice sheet removed all its sedi-

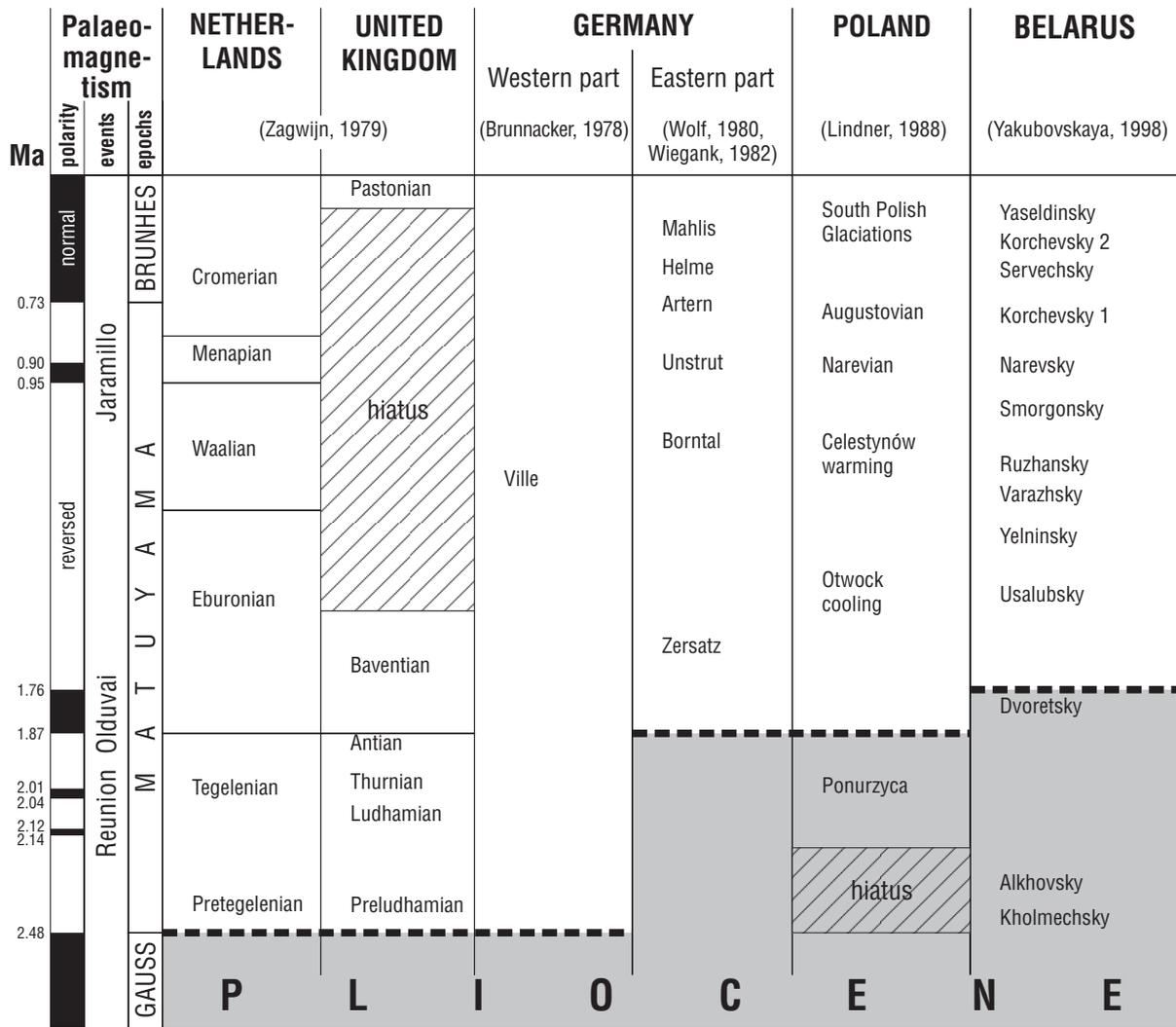


Fig. 1. Attempt of correlation of stratigraphic units of the Lower Quaternary in Europe, after Lindner (1992), modified



Fig. 2. Trans-border sheets of geological map, scale 1 : 200,000 published in 2003; result of co-operation of Polish and German geological surveys

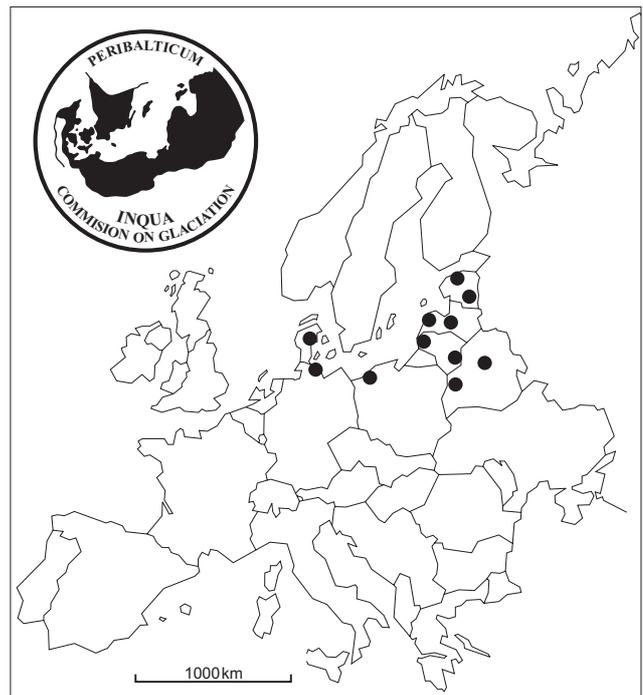


Fig. 3. Field symposiums of INQUA Peribaltic Group in 1996–2004

ments, eroded a deep depression and, therefore, changed completely the topography of this area. Since that time this area has been occasionally occupied by sea incursions (cf. Lindner & Marks, 1994). The first one occurred during the Holstein Interglacial when a sea occupied most of Denmark and northern Germany, and reached at least as far east as the Kaliningrad District of Russia (Fig. 4; Marks, 1988; Marks & Pavlovskaya, 1999, 2003a, b).

There is much more information about the sea incursion that entered the Baltic basin during the Eemian Interglacial (Fig. 4). New data have been collected lately within the project *BALTEEM: Palaeoenvironmental and palaeoclimatic evolution of the Baltic Sea basin during the Last Interglacial (Eemian, Mikulino)*, funded by the European Union and led by P.L. Gibbard (University of Cambridge), with coordinators from Denmark (K.-L. Knudsen), Norway (H.P. Sejrup), and Finland (M. Eronen), and with co-operation of 22 other scientists from Denmark, Estonia, Finland, Latvia, Norway, Poland, Russia, and United Kingdom. The aim of this project focused on reconstruction of evolution of the Baltic basin during the Eemian Interglacial (130–115 thousand years ago), determination of the type and chronology of sea transgressions and regressions starting from the Late Saalian deglaciation until cooling at the beginning of Vistulian, and also on climatic connection of the Baltic basin with the White Sea through the Karelian Isthmus (Gibbard, 2002). This aim was reached with presentation of the palaeogeographical transect from southern Denmark, through northern Poland (Head et al., 2004) to Arkhangelsk area. It called for comparable data along the transect, received with a use of uniform methodology and also supported by suitable documentation from key sedimentary sequences and supplemented with modelling of water circulation and palaeo-tides in the reservoir.

Development of river systems. The framework of the present river system in Central and Eastern Europe has developed already at the start of the Holstein Interglacial,

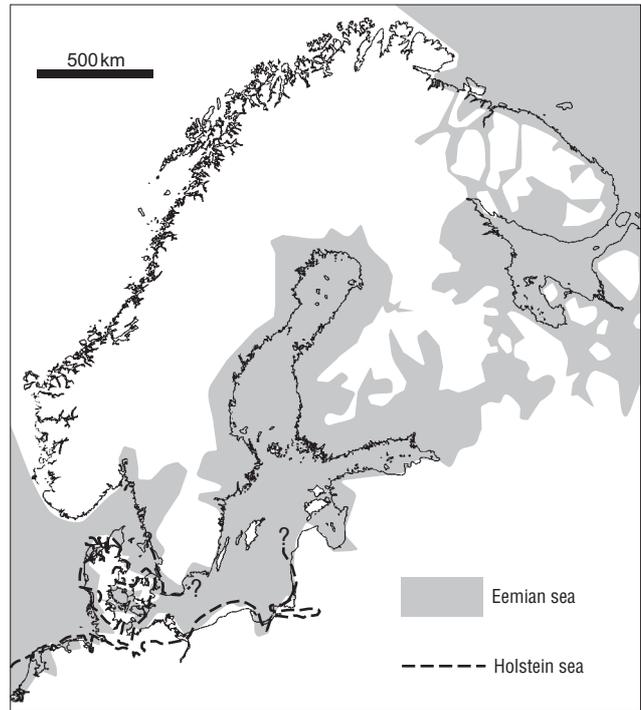


Fig. 4. Sea incursions in the Baltic basin during Holstein and Eemian Interglacials, partly after Funder et al. (2002)

just after a catastrophic runoff of the Late Elsterian ice-dam lakes (Marks et al., 1998; Marks & Pavlovskaya, 1999, 2003a, b; Fig. 5). In spite of occupation of this area by ice sheet of the Middle Polish Glaciations (Saalian) and the following transformation of the landscape during deglaciation, similar river system was established during the Eemian Interglacial, although it resembled partly a fluvio-periglacial network that appeared there at the end of the Wartanian Glaciation (Marks, 2004a). During the last gla-



Fig. 5. River system and main watershed during Holstein Interglacial in mid-eastern Poland and western Belarus against Late Elsterian ice-dam lakes; after Marks & Pavlovskaya (2003b), modified

ciation the northern part of the Middle Vistula Valley was an area of glaciolacustrine sedimentation and water runoff occurred along the ice margin westwards, within the ice marginal streamways. Reconstruction of the Middle and Late Pleistocene river system in Poland indicates that sea level during the Holstein and Eemian interglacials played a driving role in its development (Marks, 2004b). As a result, the modern river system inherits the ancient features and that the main watersheds have been only slightly modified since that time. Water level of the Holstein sea was slightly below and the level of the Eemian sea at similar altitude as the present sea level. However, a more southward extension of the sea during the Holstein and Eemian interglacials caused that buried bottoms of river valleys occur at present considerably deep beneath the alluvia of the Holocene rivers. To the north of Warsaw an important hydrographical junction of Central Europe has been formed already during the Holstein Interglacial (cf. Fig. 5; Marks & Pavlovskaya, 2003b).

Distribution and classification of glaciotectonic features. The main aim of the *Glaciotectonic Map of Central and Eastern Europe* was to prepare the first regional presentation of types and occurrence of glaciotectonic features, collected within a GIS database (Ber & Krzyszkowski, 2004). This work was started in 1995 by the working group GAGE (acting within the INQUA Commission on Glaciation), led by J. Aber (Emporia State University, USA) and A. Ber (Polish Geological Institute, Warsaw). The first stage ended with compilation of the national glaciotectonic maps of Belarus, Czech Republic, Denmark, Estonia, Germany, Latvia, Lithuania, Poland, Russia (Kaliningrad District) and Ukraine. Glaciotectonic structures were subdivided into four main classes, i.e., expressed by modern landforms, fossil landforms, deformed Quaternary sediments and deformed older (pre-Quaternary) deposits (*in situ* and in glacial rafts). The second stage included preparation of numerical glaciotectonic maps in 1 : 250,000 and 1 : 500,000 scale, followed by their compilation in GIS database. Finally, a map of Central and Eastern Europe was prepared in 1 : 3,000,000 scale.

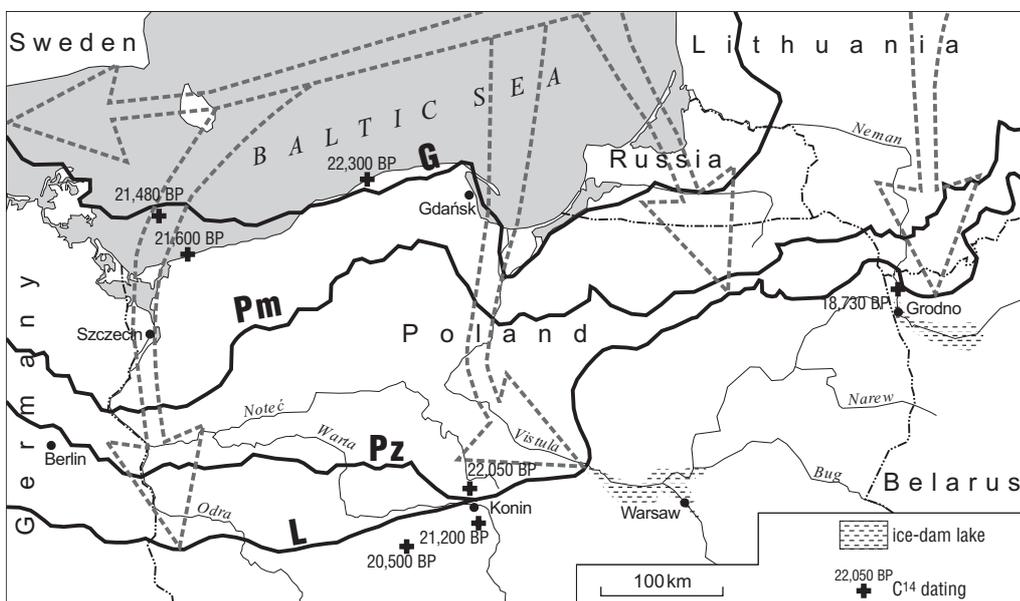
Dynamics of the ice sheet of the last Scandinavian glaciation. Many years of studies in the region to the south of the Baltic basin yielded abundant data that can be used to

determine the ice sheet flow direction. The project *ICEFLOW directions in the Peribaltic area during the Weichselian Glaciation* resulted in collection of all published and unpublished directional data, among others also those presented at symposiums of the INQUA Peribaltic Group.

Ice sheet movement could be determined on the basis of linear landforms and sediment structure. Among them there are indirect (striations, till fabric, local glaciotectonic deformations and streamlined landforms) and direct (tunnel valleys, eskers, kame chains and end moraines) features. Their distribution indicates radial structure in the ice sheet marginal zone and location of interlobe areas.

The project ended with creation of a database and set of national maps in 1 : 500,000 scale, presenting the area of Belarus, Estonia, Germany, Latvia, Lithuania, and Poland. The maps were prepared in 2002–2004 using *ArcInfo* software. These maps were then combined into a complex *Map of Weichselian Directional Ice-flow Features of Central and Eastern Europe*, scale 1 : 1,000,000, compiled by L. Marks (Polish Geological Institute, Warsaw), R. Guobyte (Geological Survey of Lithuania), I. Pavlovskaya (National Academy of Sciences of Belarus), V. Kalm and M. Rattas (University of Tartu, Estonia), H.-J. Stephan (Geological Survey of Schleswig-Holstein, Germany), V. Zelčs (University of Riga, Latvia), W. Gogołek, T. Bielecki and J. Kocyła (Polish Geological Institute, Warsaw). The map presents a uniform picture of glacial directional features that make reconstruction of ice flow direction during the last glaciation possible. Certainly, it provides a sound basis for 3-D palaeoglaciologic modelling of palaeo-ice streams in central Europe.

Chronology of the last glaciation. Recent results of studies of the Antarctic ice sheet introduced palaeo-ice streams to palaeogeographic reconstructions of the Pleistocene glaciations (Andrews & MacLean, 2003; Sejrup et al., 2003), and also resulted in a more dynamic approach to limits and structure of ice sheet in the Central European Lowland (cf. Ringberg, 1988; Stephan, 2001; Marks, 2002; Wysota, 2002; and others; Fig. 6). This picture is enriched by new dating methods applied to ice sheet limits, particu-



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Fig. 6. Ice sheet limits of Leszno (L), Poznań (Pz), Pomeranian (Pm) and Gardno (G) phases of the last glaciation in Poland with limiting maximum non-calibrated radiocarbon data for the Last Glacial Maximum (after Marks, 2002, modified); arrows indicate directions of main palaeo-ice streams

ly dating with cosmogenic ^{10}Be . This method was applied to date the exposure time of surfaces of large erratic boulders, occurring on end moraines at the main ice sheet limits of the last glaciation in Belarus, Estonia, Finland, Latvia, Lithuania and Poland. In Poland, the ^{10}Be age of the Pomeranian Phase was defined at 14.2 ± 1.8 ka (Rinterknecht et al., 2003, 2004 in print), and it is also recommended to locally move this limit southwards.

Priorities in the Quaternary studies for the next 20 years

Application of new methods and development of new research paradigms, combined with inflow of new data, result in systematic recognition of the Quaternary in Poland. On the other hand, the priorities in Quaternary studies in the world suggest that there are three main domains where a particularly quick progress is to be expected:

□ Mechanism of climate change and its forecasting

Magnitude of the present warming is similar to the natural climatic changes. The latter could be, however, masked by human activity, anthropogenic "greenhouse effect" included. The main aim of the future studies will focus on separation of the natural climatic rhythms from those arising from the activity of man. It will make possible preventing or at least limiting the influence of natural phenomena that can be dangerous for the achieved civilisation level.

□ Evolution of natural environment

Interdisciplinary studies of the Quaternary enable complex diagnosis of the state of natural environment on the basis of examination of the changes that occurred in the past. This approach can provide the foundations for sustainable development.

□ Diagnosis and monitoring of natural and human-induced hazards

They include, among others, the effects of earthquakes and volcanic eruptions, soil and seashore erosion, desertification, floods, earth mass movements, water and soil pollution. They are caused by natural and human-induced processes occurring in the natural environment. Studies will put significant input into elaboration of complex monitoring systems, applied for preventing and limiting the effects of hazards as well as for formulating proposals for alternative use of a given area.

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