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Late Pleistocene and Holocene Climatic Variability in the Carpathian-Balkan Region

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Regional distribution and relevance in paleonvironmental studies of lakes in the Tatra Mts. (Western Carpathians)

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Introduction

Scientific limnological research in the Tatra Mountains were initiated by Stanislaw Staszic in the early XIX century. After the World War II, the evolution of Tatra lakes was investigated by Kondracki, Klimaszewski, Baumgart-Kotarba and. Extensive paleolimnological investigations in the Tatra Mountains were started by the group of scientists led by K. Starmach in the beginning of the second half of the 20th century.

There has been not much research concerned to the regional distribution of lakes and their properties in the Tatra Mountains (Pociask-Karteczka 2013). Very early division of lakes presented A. Gadomski (1922), which distinguished four types of lakes: a) tarns (cirque lake or corrie loch), b) bedrock-dammed lakes, c) moraine lakes. This division was concerned in subsequent publications (Choiński 2007). M. Lukniš (1973, 1985) recognized additional types: kettles and landslide-dammed lakes and M. Klimaszewski (1988) – inter-sheepback lakes. J. Pacl and K. Wit-Jóźwik in Klima Tatier (Pacl, Wit-Jóźwik 1974) were focused on the temperature of water in lakes in Polish and Slovak parts and M. Borowiak (2000a,b) provided a comprehensive analysis of types, dimensions, temperature and chemical composition of water in lakes in the Tatra Mountains.

According to present day state of knowledge, one may distinguish following genetic types of lakes: I) glacial, II) not-glacial. There are four types of the glacial origin lakes in the Tatra Mountains (Fig. 1): a) tarns (cirque lakes or corrie loch), b) bedrock-moraine dammed lakes, c) inter-sheepback lakes, d) moraine lakes, e) kettles.

Most of lakes in the Tatra Mountains are tarns and bedrock-moraine dammed lakes, and they are located at the elevation over 1400 m a.s.l. in the Western Tatra Mountains, and over 1600 m a.s.l. in the High Tatra Mountains. Some of them are paternoster lakes – a series of stair-stepped lakes formed in individual rock basins aligned down the course of a glaciated valley. Lakes in the Five Polish Lakes Valley is an example of such type. The inter-sheepback lakes occur at higher elevations (e.g. Wyżnie Mnichowe Stawki, Zamrznuté oká). There is a little number of moraine lakes in the Tatra Mountains (e.g. Smreczyński, Toporowy Niżni) and kettles (e.g. Štrbské Pleso, Kotlinowy Stawek). Some lakes are located among rock debris or rock debris and moraine material (Dwoisty Staw Gąsienicowy, Anitino očko) – they are of polygenetic origin.

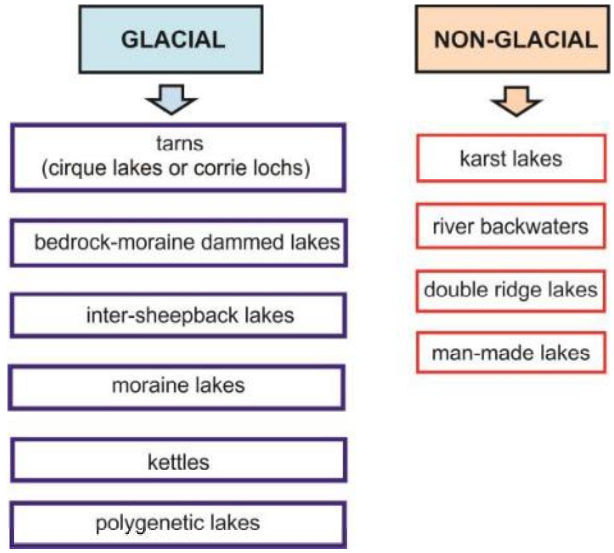

Fig. 1 Types of lakes in the Tatra Mountains

There is a diversity of not-glacial lakes in the Tatra Mountains, as follows: karst lakes (Mokra Jama, Tiché pleso), river backwaters (Rybie Stawki), lake at double ridge (the Kasne Pass) and man-made lakes (Nové Štrbské pleso, the reservoir on the Bystra Creek, ponds at the outlet of the Olczyska valley).

The aim and methods

The aim of the paper is to contribute to regional characteristics of glacial lakes, which are prevailing in the Tatra Mountains – the highest part of the Carpathian Mountain chain – and to gather information about paleoenvironmental studies of their sediments. The Tatra Mountains are divided into Western Tatra and High Tatra Mountains (Fig. 2). The presented topic constitutes a background for further research aiming at use sediments of lakes as paleoenvironmental research.

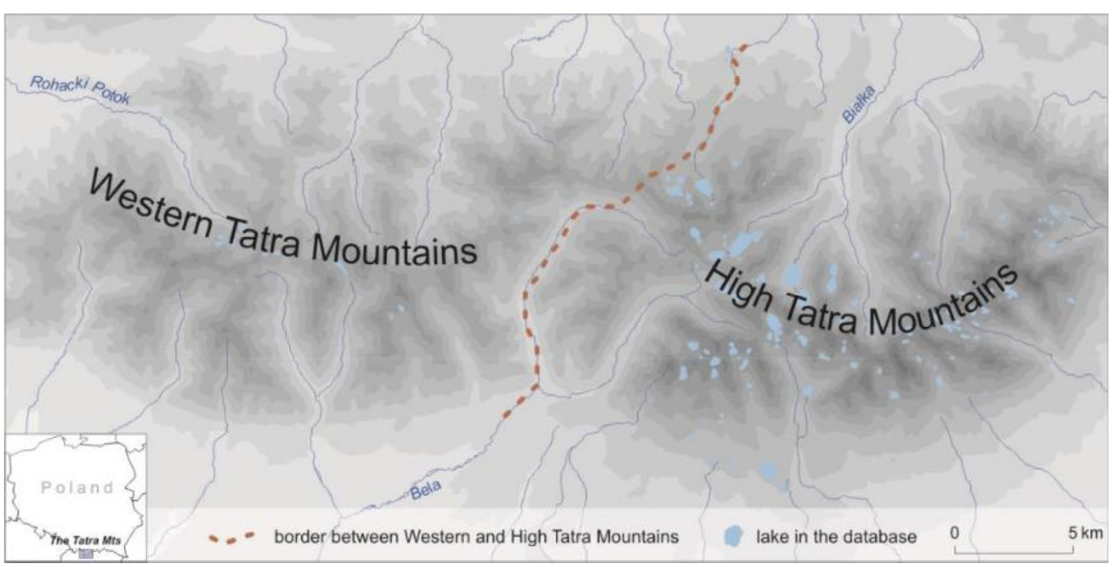

Fig. 2 The investigation area

There is a scarce of papers about entire Tatra region, which had been divided into Polish and Slovak parts for many years and these parts were treated separately in most of scientific projects. Five types of lakes were taken into consideration in the Western Tatra Mountains and the High Tatra Mountains: 1a) major glacial lakes, 1b) minor glacial lakes, 2) shallow glacial lakes, and 3) peat bogs with pool.

The created lake-geodatabase contains various physiographic characteristics, as altitude, depth, area, aspect, geology, rocks as well as geometry (polygons) saved in UTM Zone 34N projection. On the basis of the database, the shares of lakes in river catchments and 500x500 m grid cells were calculated. The watersheds in the Polish Tatra Mountains were delineated according to the Map of Hydrographic Division of Poland (Czarnecka 2005), and in the Slovaks part of the mountains – was delineated on the basis of the SRTM using Hydrology toolbox in ArcGIS 10.2.2. (Jarvis et al. 2008).

Regional analysis – spatial and vertical distribution of lakes

The Tatra Mountains occupy an area of 785 square kilometres, of which about 610 square kilometres (77.7%) occur within Slovakia and the rest – on the territory of Poland. There are 298 lakes; eight of them exceed area of 0.1 square kilometr and most of them lie in Polish Tatras. Lakes occupy the area of about 3.23 square kilometres (0.41%). The lake-geodatabase considered in the paper includes 188 lakes (3.22 square kilometres). There is no data for about 30% of very small lakes, so they have been omitted in the lake-geodatabase; most of them are seasonal, undersized water bodies with the area of no more than of 0,01 square kilometr.

There is a significant difference in spatial lakes' distribution in the Tatra Mountains (Fig. 3). Great majority of lakes is located in the High Tatra Mountains (156 out of 188 in total) whereas only 32 are located in the Western Tatra Mountains (Table 1). The share of lakes in the upper part of the Białka River amounts 2.7-5.0% (the High Tatra Mountains), whereas there are no lakes in most of river catchments in the Western Tatra Mountains (Fig. 1). Majority of lakes in the High Tatra Mountains (64%) splits into two altitudinal zones between 1600-1799 and 1800-1999 m a.s.l. (Table 1). Most of them represents shallow glacial lake type (54.5%) likewise in the Western Tatra Mountains.

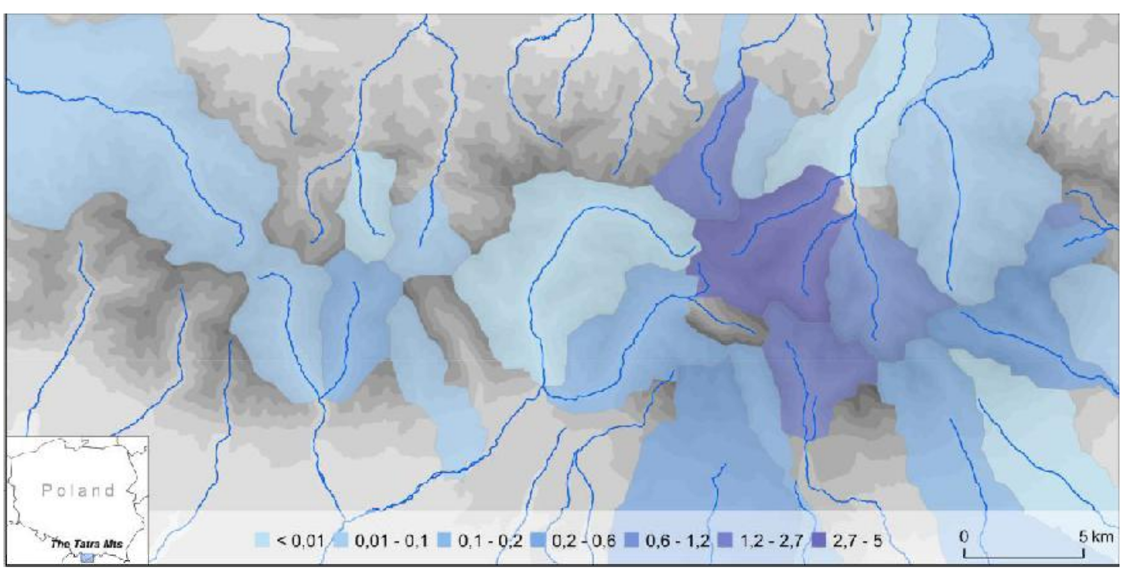

Fig. 3 Share of lakes [%] in river catchments in the Tatra Mountains

Table 1 Number of lakes in altitudinal zones in the Tatra Mountains

Altitude [m a.s.l.]	800-999	1000-1199	1200-1399	1400-1599	1600-1799	1800-1999	2000-2199	≥2200	Total
High Tatra Mts.		**2**	**9**	**12**	**48**	**51**	**33**	**1**	**156**
Major glacial lake			1	3	10	3	3		20
Minor glacial lake		1	1	3	6	14	11		36
Shallow glacial lake			2	4	26	33	19	1	85
Peat bog with pool		1	5	2	6	1			15
Western Tatra Mts.	**1**		**2**	**8**	**14**	**7**			**32**
Major glacial lake									
Minor glacial lake				1	3	1			5
Shallow glacial lake	1		2	5	8	5			21
Peat bog with pool				2	3	1			6
Total	**1**	**2**	**11**	**19**	**62**	**59**	**33**	**1**	**188**

There are no major glacial lakes in the Western Tatra Mountains. The number of minor and shallow glacial lakes equals respectively 5 and 21, i.e. 81.25% of all lakes in this part of the mountains. Most of them lies in 1600-1799 m a.s.l. altitudinal zone.

The number of grid cells (500x500 m) containing surface of a lake reaches 179 (of 2117 total) in the High Tatra Mountains and merely 29 (2489 of total) in the Western Tatra Mountains. The maximal share of lakes in the Western Tatra Mountains does not exceed 5%, whereas it may reach even about 65% in the High Tatra Mountains.

Sediments in lakes – as paleoclimate indicators

Lake sediments provide a useful means of monitoring and tracking pollutants and the long-term evolution of the environment in local and regional scale. K. Pasternak (1965) presented chemical composition of sediments in some Tatra lakes and primary comments on their origin. In the years 1974-1978 a team of Warsaw geographers conducted paleolimnological investigations (Kondracki 1984). Bottom sediments of twelve lakes were sampled. The sickness of lacustrine deposits in the investigated lakes amounts 1-3 m, and the accumulation rate is diminished with the increasing elevation (Więckowski 1984). Palynologic analyses and the radiocarbon dating revealed that the lakes located in cirque lakes were formed in the oldest Dryas (or earlier) whereas moraine lakes located at lower altitudes emerged at Boreal and the early Atlantic period (Skierski 1984, Stasiak 1984, Wicik 1984). The *Cladocera* remnants in the lacustrine sediments indicate their oligotrophic type (Szeroczyńska 1984).

In the 90. of the 20th century, a team of Cracow geomorphologists and geophysicists used geophysical methods to determine the thickness of sediments in the Morskie Oko Lake. They found the maximum thickness 7.5 m of postglacial sediments (Baumgart-Kotarba et al., 1996). The thickness of sediments accumulated in other lakes does not exceed 2.5 m (Baumgart-Kotarba, Kotarba 1993). The smaller thickness of bottom sediments in the Morskie Oko Lake (less than 4 m) were identified in the northern part of it. It has been caused probably by intensive delivery of mineral material from slightly forested slopes (Baumgart-Kotarba et al. 2003).

The role of the slopes in the transport of mineral material to the lake was investigated by A. Kotarba (1996). He distinguished three types of lakes: i) lakes without contact with active slopes, ii) lakes with limited direct contact with active rock slopes, and iii) lakes with contact with the active slopes. The rate of sedimentation in the first type of lake reaches 0.10 mm per year, and in the lakes of the third may reach even 0.50 mm per year. Furthermore the rate of sedimentation in the Holocene has been varied from 0.13 mm per year during the early phase of the Subatlantic phase to 0.36 mm per year during the Little Ice Age in the Zielony Staw Lake (Kotarba 1992). The greater variability can be observed in the Morskie Oko Lake, where the rate of sedimentation has been ranging from 0.10 to 1.29 mm per year (Kotarba 1996).

Research focused on acidification and eutrophication of the Tatra lake ecosystems was conducted within international environment projects of the European Commission: AL:PE2, MOLAR and EMERGE in the 90. of 20th and in the beginning of the 21st centuries. As a part of these research bottom sediments of the lakes were studied also. Sediment cores from nine lakes were dated radiometrically by ^{210}Pb and ^{137}Cs. Cores from all lakes had good records of the fallout radionuclides from which it was possible to construct reliable chronologies of the recent sediments. Radionuclide inventories and sedimentation rates may vary significantly over even small areas of the lake. At most study sites there were significant discrepancies between the atmospheric fluxes of fallout radionuclides and their supply rates to the lake sediments; these discrepancies are not clear, but are presumably related to predominant fallout during the winter as snow when it is liable to substantial redistribution by the strong winds experienced in these environments (Appley, Piliposian 2006). As far bottom sediments of forty selected alpine and forest lakes were examined to determine their chemistry, correlates with lake water composition, and to provide data on changes under elevated atmospheric pollution in the second half of the 20nd century. Sediments in alpine lakes reflect more closely soil composition than more productive forest lakes. The chemical composition of modern sediments (0-1 cm) differ from deeper ones due to elevated input of atmospheric pollutants during the second half of the 20th century, especially in oligotrophic alpine lakes (Kopáček et al. 2006, Stuchlík et al. 2006). Analysis of the post-glacial environmental change on the base of the lake sediments presented A. Obidowicz (1996), K. Wołowski et al. (2002), Stuchlík et al. (2002) and Bitušík et al. (2009).

Conclusions

There are about 300 lakes in the Tatra Mountains and they have a glacial origin. The vast majority of them (83%) occur in the High Tatra Mountains. This area is supposed to represent at least disturbed environment in Europe, and lake sediments allow investigate long-term climate and environmental variability and change. The results of limnological research in the Tatra Mountains are of great importance to reveal the paleogeography of the Carpathian Mountains.

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