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Late Glacial and Holocene paleoenvironmental records in the Tatra Mountains, East-Central Europe, based on lake, peat bog and colluvial sedimentary data: A summary review

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ABSTRACT

The Tatra Mountains are the highest massif in the Carpathian mountain arc (2655 m) and represent a typical alpine landscape developed in the course of Pleistocene glaciations, but are not glacierized today. The glacial relief of the massif offers an abundance of topographic depressions (cirque overdeepenings, morainic closed depressions) where sedimentary sequences may potentially reveal paleoenvironmental changes that may have occurred since the glaciers' retreat from the Last Glacial Maximum position (~26–18 ka). We present a review of Late Glacial and Holocene sedimentary archives from the Tatra Mountains collected in the Polish and non-Polish literature. The data sets (40 sites) included 21 lake, 13 peat bog, and 6 colluvial sediment sites. The entire listed sediment sequence features radiometric datings or at the very least a chronological framework is inferred from the biostratigraphy. The oldest sampled sedimentary sequences were dated back to the Oldest Dryas and were obtained from the deepest glacial lakes located in the subalpine zone (up to 1700 m). Shallow lakes (<10 m) and morainic closed depressions do not reveal sediments older than the Holocene. This can be linked with dry climate conditions and unfavorable hydrologic regimes during the Late Glacial when the studied depressions remained dry over the long term following deglaciation, irrespective of elevation and position in the glaciated valley system. For the Holocene, several millennial-scale phases of climate humidity and increased debris flow activity were identified. The intensification of debris flows is indicated at 9–7.5 ka and during the mid- to late Holocene (at ca. 6 ka, 3.5 ka, 2 ka, after 300 AD, 800–1000 AD, and LIA), separated by relatively stable climate conditions during the 'Holocene thermal optimum' (7.5–6 ka). The LIA in the Tatra Mountains was a relatively long (1220–1925 AD) and climatically unstable period, with a cold and dry first phase (1220–1540 AD), followed by a cold and humid phase (1540–1925 AD). During the modern warm period, renewed intensification of extreme slope processes has been recorded after 1970 AD.

1. Introduction

The high mountain environment is very sensitive to regional and local climate variability (Messerli and Ives, 1997; Beniston, 2000; Slaymaker and Owens, 2004). An alpine type of landscape developed in the course of Quaternary mountain glaciation offers an abundance of natural sedimentary traps (topographic sinks), inherited from erosional and accumulation glacial action including large cirque and trough overdeepenings, small basins in glacially scoured bedrock, and various inter-morainic closed depressions, where sedimentary sequences are recorded (Fig. 1). Before the widespread use of the terrestrial cosmogenic nuclide dating method, a combination of morphostratigraphy, palynology, and radiocarbon dating of organic material found in morainic closed depressions or glacial lakes constituted the only means of establishing the age of glacier retreat as well as the construction of deglaciation chronologies (Patzelt and Bortenschlager, 1973; Ivy-Ochs et al., 2009).

Sedimentary records of mountain lake, peat bog, and slope colluvia deposits are a valuable source of paleoclimate data. In high

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mountain areas, sedimentation is controlled by long-lasting, low energy accumulation of autochthonous material (organic gyttja, peat), punctuated by short-lasting, high energy episodes of allochthonous material delivery caused by rapid mass movement processes. Changes between organic and minerogenic sedimentary units reflect the alternating stable and unstable hillslope phases, respectively (Kotarba, 1992; Jonasson, 1993; Matthews et al., 1997, 2009). Minerogenic sediments with intercalations rich in coarse clastic material are a distinct indicator of high-energy geomorphic processes such as debris flows, slope wash, meltwater transport, and debris avalanches. Debris-flows exert the greatest effect on lake sediment transport and accumulation of terrestrial material across the lake floor, leading to the final disappearance of shallow alpine lakes (Hreško et al., 2012). Sandy and/or silty mineral layers could be interpreted as distal debris-flows facies, which are deposited: (i) at the base of the slope by fluid in the latter stage of each flow (Matthews et al. 1997, 2009), or (ii) in lake depressions, where subaquatic turbidity currents cause gravitational sorting of debris flow sediments (Sletten et al., 2003; Kotarba, 1996a,b). These sedimentologic records have potential as a source of paleoclimate information related to extreme rainfalls and climate humidity (Kotarba, 1996a,b; Sletten and Blikra, 2007). The material transported by slope processes (colluvial sediments, as defined by Matthews, 2001) can also be trapped in various types of closed depressions located in valleys and cirques. Moreover, colluvia resulting from rapid mass movement provide complementary paleoenvironmental information concerning debris flow frequency and landscape instability recorded by sandy and silty layers altered with loamy sediments with higher organic content.

The Tatra Mountains, located in the Western Carpathians on the Slovak-Polish border, are the highest massif in the Carpathians and provide some of the best developed alpine type relief in the entire Carpathian mountain arc (Lukniš, 1973; Klimaszewski, 1988). Pleistocene mountain glaciers, which had strongly reshaped the Tatra massif, also produced topographic sinks, which are today occupied by about 300 lakes and numerous peat bogs. Preliminary studies on lake sediments began in the region in the second half of the 20th century (Pociask-Karteczka, 2013 and references therein). Detailed scientific research on lakes and peat bogs began about 40 years ago with a major paleolimnological research effort in the years 1974–1978 by Kondracki (1984). During this research project, the bottom sediments of twelve lakes were sampled both in the Polish and Slovak Tatras. The obtained results cast a new light on the Tatras' deglaciation chronology, as they showed that glacial cirque lakes located at higher elevations had become ice-free surprisingly early in the Oldest Dryas. In contrast, morainic lakes located at lower elevations emerged as late as the Boreal and the early Atlantic periods (Skierski, 1984; Stasiak, 1984; Wicik, 1984). Further lake drilling in the Polish part of the High Tatra Mountains, led by M. Baumgart-Kotarba and A. Kotarba (Baumgart-Kotarba et al., 1990, 1993, 1996, 2001; Baumgart-Kotarba and Kotarba, 1993) confirmed early deglaciation of cirques at high elevations and additionally supported this finding with the oldest radiocarbon datings (12.5 ka) in Lake Czarny Staw Gąsienicowy. The authors along with a number of coworkers conducted comprehensive multidisciplinary studies on glacial and periglacial geomorphology, active slope processes, paleobotany, geophysics, and lichenometry, with the aim of understanding Late Glacial, Holocene, Little Ice Age (LIA), and modern Tatra environmental evolution. In contrast to the Polish part of the High Tatra Mountains, where most lake sediment drilling was designed to obtain full sedimentary sequences in the Slovak High Tatras; only two lakes were drilled with this purpose in mind (Štrbskė pleso and Popradskė pleso; Stasiak, 1984; Rybničkova and Rybniček, 1998, 2006). Apart from lake research, numerous studies also focused on peat bogs and colluvial sediments in the Tatra massif, which complemented paleoenvironmental information obtained using lake data.

It has been stressed that there is a need for the collection of data and evidence in order to attempt a major paleoenvironmental synthesis for the Carpathian–Balkan region for the late Pleistocene and Holocene (Batterbee et al. 2007, 2009; Buczkó et al. 2009). A comprehensive review of key quantitative paleorecord data from

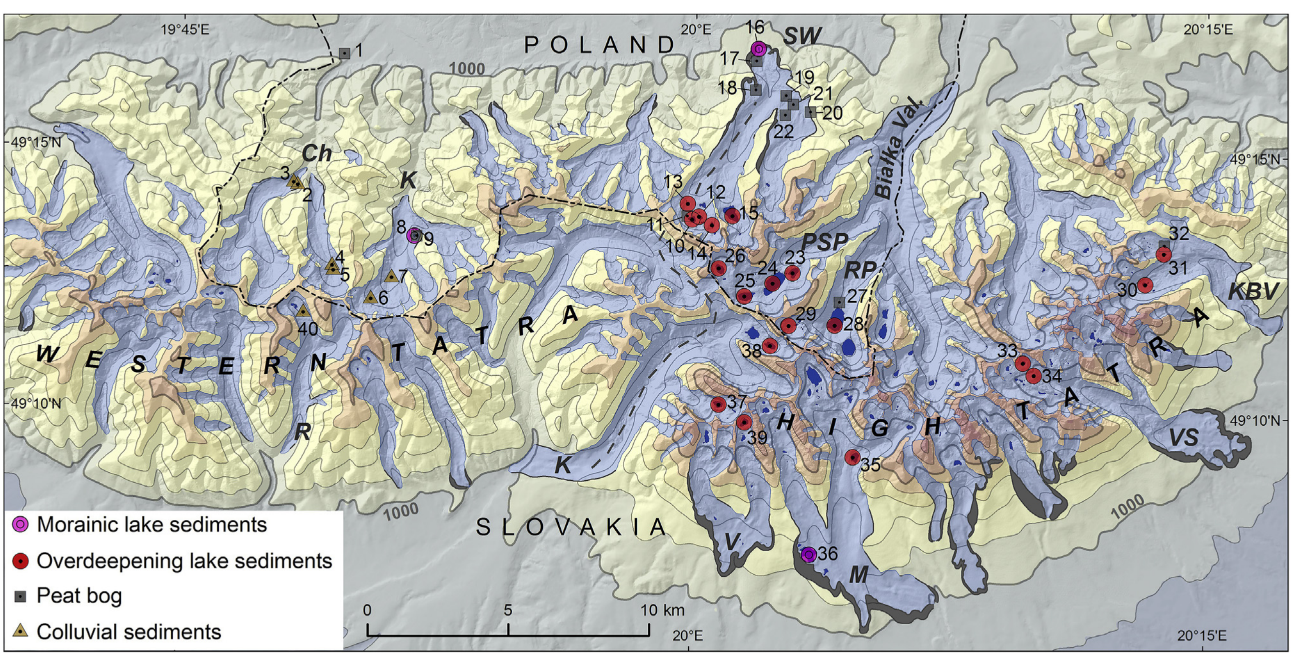

Fig. 1. Late Glacial and Holocene sedimentary sequence sites in the Tatra Mountains on the background of the Last Glacial Maximum glacier extent (after Zasadni and Kłapyta, 2014). Site code numbers refer to Table 1. Contours are in 200 m intervals. Topographic names: Ch – Chochołowska Val., K – Kościeliska Val., SW – Sucha Woda Val., PSP – Pięć Stawów Polskich Val., RP – Rybi Potok Val., R – Račkova Val., K – Kôprová Val., V – Važecká Val., M – Mengusovská Val., VS – Vel'ká Studená Val., KBV – Kežmarskej Bielej vody Val.

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