S T U D I A G E O M O R P H O L O G I C A C A R P A T H O - B A L C A N I C A
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SEDIMENTATION RATES IN THE HIGH TATRA LAKES DURING THE HOLOCENE — GEOMORPHIC INTERPRETATION

INTRODUCTION

Lake basins occurring in high-mountain areas are excellent sedimentation traps for material originating from denudation of a catchment. Material which is derived from the slopes surrounding a lake or which is delivered by mountain rivers and streams is deposited in the lake and only its small amount is driven outside the lake as suspension (Brune 1953). Therefore, sediments transported by proglacial or pronival waters as well as by water periodically draining the slopes, which are transformed by debris flows and other rapid mass movements (e.g. debris avalanches), are deposited in the lakes. Moreover, in the sediments are imprinted the changes in natural environment since the ice retreat from the lake basins which have been formed by valley and cirque glaciers. Sedimentation structures formed in the lakes point to the character of processes undergoing in the catchment.

In the high-mountain areas, where the glaciers melted completely by the end of the last glaciation or in the early phases of the Holocene, the lake sediments provide evidence of non-glacial changes in the environment which was under the influence of periglacial climate. The evidence is particularly clear in the lakes surrounded by steep rocky and debris slopes. All pronounced changes in the glacial cirque environment, consisting in degradation and wasting of vegetation cover due to natural or anthropogenic morphogenetic processes, are registered in sediments. A lesser stability of the slopes with degraded vegetation covers favours erosion and transportation which supply fine, loose mineral material to the lake basins. The high energy, short-lasting, yet often catastrophic, morphogenetic processes (e.g. debris flows, debris avalanches, rock falls and rock slides) supply to the lake basin coarse material including even block-size chunks. Such material usually accumulates at the lake shoreline and contributes to accretion of submerged and emerged slopes forming the lake basin. Mineral material deposited by debris avalanches on the ice surface is transferred on drifting ice floes as the ice cover wastes and can be plunged into the lake even in the deepest and the most distant sites from the shore (Luckman 1975; Jonasson 1991; Baumgart-Kotarba and Kotarba 1993). Thus, rock pieces, called drop stones, are found in fine, clayey-sandy deposits (Gradziński *et al.* 1986). The drop stones are often stuck in laminated sediments. In such a case, deformation of laminae visible around such stones is associated with their penetration through the deposits (Baumgart-Kotarba *et al.* 1993). The whole packages of unsorted material happen to be deposited in high-mountain lakes (Więckowski 1984). Debris flows reaching the lake shores supply large amount of clastic material in a form of turbidity currents. These currents also reach the deepest parts of the lakes. As a result, laminated structures, characterized by gravitational sorting, are formed.

In cirque lakes located at high elevations, and often having amphitheatre-like shape, there is no supply from one specific direction. A characteristic feature of such lakes is water inflow and delivery of mineral substances from various directions. The source areas of the weathered material are controlled by high energy hydrometeorological phenomena triggering intensive erosion and denudation processes in various parts of a catchment. The studies on temperature pattern of the Tatra waters have indicated that there are suitable conditions for development of benthic density currents which can transfer fine weathered material delivered to the lakes. Therefore, at the bottoms of the lake basins there are suitable conditions for redistribution of the material originating from slope wash (Słup and Garncarz 1985; Baumgart-Kotarba and Kotarba 1993). The above should explain a significant structural similarity of sediments (sequences consisting of interbedded coarser deposits and finer gyttjas) in the cores sampled in sites even distant one from each other (200–300 m apart) in Lake Czarny Staw Gąsienicowy and Lake Morskie Oko. It refers mainly to sedimentation events induced by particularly intensive morphogenetic processes. On the other hand, the sediments sampled from the steep slopes of the lake basins, being the extension of the debris slopes surrounding the lake, in various distances from the shores differ as to the thickness of laminae and layers as well as to the size of fine material even if the rhythm of sedimentation is recurrent here.

There are other commonly known modes of material delivery to the high-mountain lakes besides those presented above. These include: eolian delivery being the result of a long- and short distance wind transportation (Thorn and Darmody 1985; Izmaiłow 1984) and production of mineral and organic matter associated with biological life of water bodies. Organic gyttjas, which have formed in the Tatra lakes during calm sedimentation undisturbed by inputs of the material derived from denudation of the catchment, contain quartz grains usually 20–22 μm in diameter (Baumgart-Kotarba and Kotarba 1993). Such grain size is also typical of the eolian dust deposited on a surface of snow cover at present if the material is blown from remote parts of the northern Africa or Ukraine.

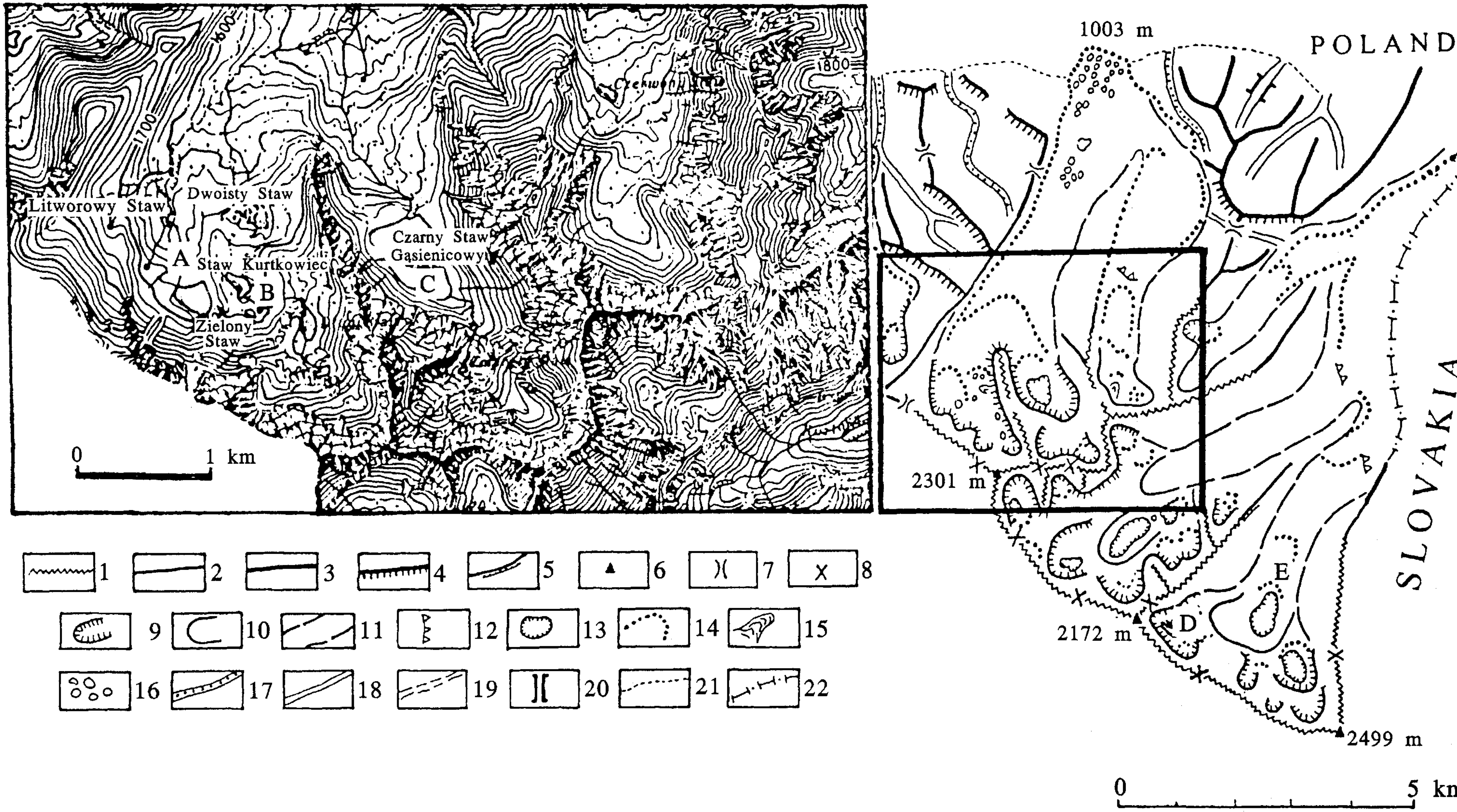

Fig. 1. Location map. The glacial features of the Polish High Tatra (according to Klimaszewski 1962) and location of 5 alpine lakes mentioned in the text. 1 — sharp rocky ridge crest, 2 — narrow rounded ridge crest, 3 — wide rounded ridge crest, 4 — cuesta-like crest, 5 — double ridge, 6 — summit, 7 — pass related to less resistant rocks, 8 — pass related to dislocation zone, 9 — glacial cirque, 10 — trough head, 11 — glacial trough, 12 — valley step, 13 — lake basin of glacial origin, 14 — moraine ridge, 15 — relict rock glacier, 16 — dead-ice hollows, 17 — valley floor with glaciofluvial deposits, 18 — fluvial (non-glaciated) valley, 19 — karst valley, 20 — structural narrowing of valley, 21 — northern margin of the Tatras, 22 — state boundary

A — Zielony Staw, B — Staw Kurtkowiec, C — Czarny Staw Gąsienicowy, D — Stawek na Kopkach, E — Morskie Oko

Ryc. 1. Lokalizacja pięciu jezior alpejskich omawianych w artykule na tle mapy głównych form rzeźby Tatr Wysokich (według Klimaszewskiego 1962). 1 — ostra skalista grań, 2 — wąski zaokrąglony grzbiet, 3 — szeroki zaokrąglony grzbiet, 4 — grzbiet o założeniach strukturalnych (kuesta), 5 — podwójny grzbiet, 6 — wierzchołek, 7 — przełęcz założona na mało odpornych skałach, 8 — przełęcz założona na strefie dyslokacji, 9 — cyrk glacjalny, 10 — zamknięcie żłobu lodowcowego, 11 — żłób lodowcowy, 12 — próg dolinny, 13 — misa jeziorna pochodzenia lodowcowego, 14 — wał morenowy, 15 — reliktowy lodowiec gruzowy, 16 — zagłębienia wytopiskowe, 17 — dno doliny z osadami glacifluwialnymi, 18 — dolina rzeczna, niezlodowacona, 19 — dolina krasowa, 20 — strukturalne zwężenie dolinne, 21 — północna granica Tatr, 22 — granica państwa

A — Zielony Staw, B — Staw Kurtkowiec, C — Czarny Staw Gąsienicowy, D — Stawek na Kopkach, E — Morskie Oko

The purpose of the paper is to present differences in a mode and rate of lake sedimentation in the High Tatras in relation to location of the lakes with respect to the slopes surrounding them (Fig. 1). Moreover, evaluation of the dynamics of these processes in the Holocene is also attempted.

CONDITIONS OF ORGANIC MATTER DELIVERY TO THE TATRA LAKES

Considering the above described mode of material delivery to the lakes, one can distinguish at least three types of lakes within an alpine landscape of the High Tatras.

(1) Lakes lacking any contact with the slopes, located in wide valley floors; these comprise water bodies which fill up depressions between moraine ridges (e.g. Lake Dwoisty Staw and Lake Kurtkowiec) or hollows formed by glacial plucking (e.g. Lake Wielki Staw in the Pięć Stawów Polskich Valley) or tiny ponds on glacially polished terrain (e.g. lakes Mnichowe Stawki and Stawek na Kopkach in the Za Mnichem valley). Here, the only sources of organic matter and mineral material are eolian delivery and organic production within the water bodies. Under the Tatra conditions, the supply of mineral material from the shores due to wave action is almost zero because the shores of the ponds comprise mainly degraded granite bedrock or coarse glacial and glacifluvial deposits in places. The deposits found in the discussed water bodies are usually brown or dark brown organic gyttjas (Wicik 1984; Więckowski 1984). In the lakes of this type (type 1) the content of organic matter in the sediments is high and uniform. For example, in the Holocene core sampled from Lake Kurtkowiec the minimum organic matter content is 32.89% and the maximum 63.73%. In Lake Stawek na Kopkach the values are 37.7% and 56.6%, respectively.

(2) Lakes having a limited contact with active rocky and debris slopes. Here, delivery of the weathered material from the slopes is partially reduced as the lakes are separated by systems of lateral and frontal moraines or by smoothed rocky steps (lakes: Zielony Staw Gąsienicowy, Czarny Staw Gąsienicowy). In such lakes only 50% of the shoreline is in a direct contact with morphogenetically active alpine slopes. Material denuded from the slopes, which are separated from the lakes by the system of moraine ridges, is deposited at the feet of these slopes and does not enter the lake basins but fills up local depressions. The Holocene sediments found in these lakes resemble organic gyttjas interbedded with mineral material of various genesis (laminae and layers, drop stones, layers with gravitational sorting, chaotic avalanche packages). Mineral deposits accumulate in the lake basins only in the periods when high energy morphogenetic processes act. These are periods of climatic instability. Mineral inserts in the gyttja deposits of these lakes are indicators of extreme events when threshold values have been exceeded and when the slope system being in the direct contact with the

lake has been in quasi-stable equilibrium. A specific feature of these sediments is a very variable content of organic matter; from 3–5% in the mineral inserts to 25–30% in the gyttja deposits.

(3) Lakes having a full contact with the slopes at three sides at least (e.g. Lake Morskie Oko, Lake Czarny Staw pod Rysami) (Fig. 2). Here, the structure of the sediments is very diversified as all the events occurring in the catchment are registered in the lake sediments. Deposition of various mineral material predominates in such lakes and gyttjas, which mark periods of calm sedimentation, amount to a merely few percent of the total thickness of the Holocene

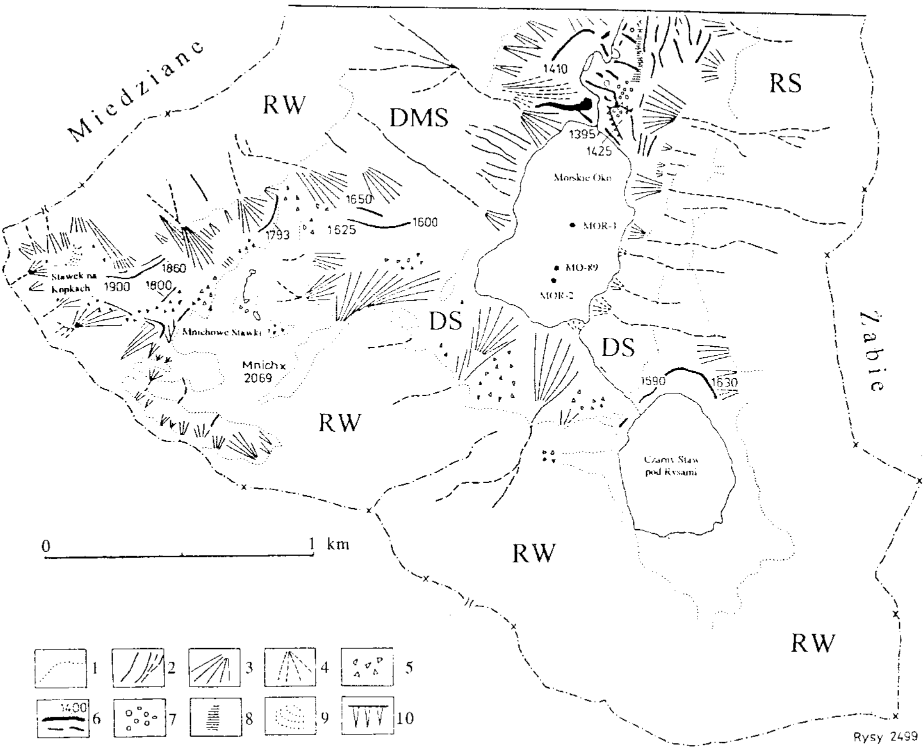

Fig. 2 . Geomorphological scheme of the upper reach of the Rybi Potok valley, High Tatra. Location of lake sediment cores sampling (MOR-1, MOR-2, MO-89) is shown. 1 — limit of main slope units, 2 — gullies, 3 — gravitational talus cone, 4 — gravitational/alluvial cone, 5 — talus heap, 6 — moraine ridge, 7 — dead-ice hollows, 8 — glaciofluvial terrace, 9 — relict rock glacier, 10 — erosion scarp, RW — rockwall, RS — rocky slope, DMS — debris-mantled slope, DS — debris slope

Ryc. 2. Szkic geomorfologiczny zamknięcia Doliny Rybiego Potoku. Pokazana lokalizacja miejsc pobrania rdzeni jeziornych (MOR-1, MOR-2, MO-89). 1 — granica głównych rodzajów stoków, 2 — system rynien korazyjnych i żlebów, 3 — stożek usypiskowy, 4 — stożek usypiskowo-napływowy, 5 — hałda gruzowa, 6 — wał morenowy, 7 — zagłębienie wytopiskowe, 8 — terasa glacifluwialna, 9 — reliktowy lodowiec gruzowy, 10 — krawędź erozyjna, RW — ściana skalna, RS — stok skalny, DMS — stok skalno-pokrywowy, DS — stok gruzowy sediments. Gyttjas form in short spans of the Holocene and the organic content does not exceed 25%.

All three types of the Tatra lakes discussed above occur in a cryogenic system comprising the area above the timberline. A generally low biological productivity in the lakes and small content of autochtonic matter in sediments coincide with a supply of allochtonic matter derived from the lake catchments, and especially from the slopes being in the direct contact with these lakes. Then, massive mineral layers are formed which represent denudation events in the catchments. Therefore, the amount of organic matter can be used as an indicator of relief dynamics. Fig. 3 illustrates this problem with the studied lakes in the High Tatras as examples.

It should be emphasized here again that the above discussion refers to the lakes located in the cryonival morphogenetic domain (as defined by Kotarba and Starkel 1972). In the temperate forest domain the mean organic matter

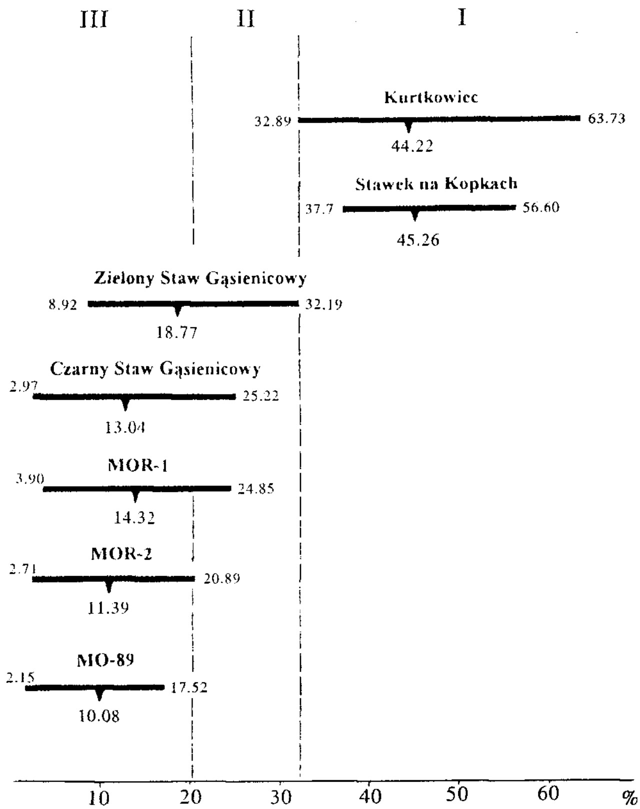

Fig. 3. Organic matter content (minimum, maximum and mean) in various Tatra lakes (I–III) described in the text

Ryc. 3. Zawartość substancji organicznej (minimalna, maksymalna i średnia) w trzech różnych kategoriach jezior wyróżnionych w tekście content is much higher. According to Bogumił Wicik (1984) the mean values of the loss of ignition in the youngest, 0.0–0.5 m thick parts of the cores from lakes Toporowy Staw, Smreczyński Staw and Štrbske Pleso (Slovakia) are 55.2, 72.0, 72.9%, respectively.

SEDIMENTATION RATE IN THE TATRA LAKES

The studies on the Tatra lakes have shown that sedimentation rates in the Holocene depend on a type of lake as well as on a size and a shape of lake basin. According to B. Wicik (1984) the mean Holocene rate of sedimentation in Lake Czarny Staw Gąsienicowy is 0.2 mm/year. Yet the sedimentation rates in the lakes of type (2) and (3) depend on the dynamics of morphometric processes on the slopes surrounding these lakes, so sedimentation rates differ significantly on a scale of particular phases of the Holocene. The mean Holocene rate of sedimentation in Lake Kurtkowiec (type 1) is 0.15 mm/year. The rates, even lower than that, have been stated in tiny ponds in the alpine zone. Basinal depressions between roche moutonne in the valley Za Mnichem, where lateral delivery of material is lacking, are filled up with dark brown organic gyttjas. The sample taken from the depth of 70 cm below the water surface in pond Stawek na Kopkach was dated at 6460 ± 70 BP by ^{14}C. It means that the sedimentation rate during the recent c. 6.5 thousand years was 0.10 mm/year.

The analysis of the Holocene cores sampled in Lake Czarny Staw Gąsienicowy showed (Baumgart-Kotarba and Kotarba 1993) that calm, slow sedimentation of organic silts predominated in the first phase of the Holocene, i.e. in the Preboreal and Boreal. Massive mineral sediments were formed in the period preceding the radiocarbon date c. 8300 BP. The high sedimentation rate was correlated by the authors with very important events on a global climate scale, i.e. with the Joux phase (8700–8300 BP). During the Atlantic period, lasting until c. 5000 BP, sedimentation was calm. This sedimentation imprinted in the deposits as not numerous and rather thin mineral interbedding with the gyttjas. The Subboreal period manifested again in a more vigorous dynamics of the Tatra environment, so in the sediments of Lake Czarny Staw Gąsienicowy mineral, gravel-sandy inserts predominated. They were deposited in the lake by turbidity currents triggered by large debris flows on the slopes. The younger part of the Subboreal period (4000– –2500 BP) was calm again. The next, large scale re-activation of the processes occurred fairly recently, in so called Little Ice Age, i.e. from 1400 to 1860 AD (Kotarba 1993–1994).

The analogous sediment core sampled from Lake Zielony Staw provided very important evidence of sedimentation rates. If the mean Holocene sedimentation rate was 0.21 mm/year, the highest sedimentation rates would be characteristic of the Little Ice Age (0.36 mm/year) and of the early Subboreal

(0.20 mm/year) while the lowest rates would take place in the early Subatlantic (0.13 mm/year) and in the Atlantic (0.18 mm/year) (Kotarba 1992).

A much higher sedimentation rate was found in Lake Morskie Oko (Fig. 4). An active contact of the lake basin with the slopes surrounding it makes this lake to stand out from other lakes in the Polish part of the High Tatras. The total length of Lake Morskie Oko shoreline is 2640 m (Sawicki 1929) while that of the non-active shoreline, the shoreline formed by moraine material in the northern part of the lake, is only 380 m (15.4%). The debris-mantled slopes, surrounding the lake from the east and west, are dissected by a system of active, 800–1000 m long gullies which start directly below the rocky ridge of Żabia Grań and Miedziane. The southern slopes are high (up to 850 m) rockwalls and active gravitational/alluvial cones (300–400 m long) of Zielony, Skalnisty and Szeroki Piarg (Fig. 2). From these slopes, whose base is c. 2000 m long, weathered material is delivered either by a system of gullies or by areal and linear debris flows. Additional factors transforming the slopes on Lake Morskie Oko are snow avalanches entering an ice cover in winter periods (Chomicz 1957, Paryski 1948, Hajdukiewicz 1948, Kłapowa 1969). The mean sedimentation rate in Lake Morskie Oko was c. 0.5 mm/year during the last 7000 years. The radiocarbon date obtained from the sediments sampled at the depth of 350 cm below the lake bottom and 45.8 m down the water surface (core MOR-2, Fig. 4) was only 6920 ± 160 BP (Gd-9301). It should be emphasized here that the sediments in Lake Zielony Staw Gąsienicowy, which were dated at the beginning of the Holocene (10 040 ± 150 BP, Ua-1446), are only 250 cm thick (Baumgart-Kotarba *et al.* 1990, Baumgart-Kotarba and Kotarba 1993). Five radiocarbon dates from the core MOR-2 helped in evaluation of the sedimentation rate in Lake Morskie Oko. The rate was 0.51 mm/year in the Atlantic period and increased to 0.58 mm/year in the Subboreal and then decreased to 0.47 mm/year (by the end of the Subboreal). In the Subatlantic the sedimentation rate increased even to 1.29 mm/year, which was undoubtedly associated with a large delivery of weathered mineral material to the lake in the period following the dates 2120 and 2390 BP (Fig. 4). This delivery manifested in massive sedimentation of structureless, coarse sands. The organic matter content decreased to minimum values of the order of 5% (4.56% in core MOR-1) and even 2.71% in core MOR-2. Unquestionably, it was the most dramatic period of a high instability of the slopes of the Morskie Oko glacial cirque.

The data presented above indicate that the lake sedimentation rates differ significantly from c. 0.1 mm/year to 1.29 mm/year and that these rates depend, first of all, on configuration of slopes surrounding the lake and on the degree to which the slopes are stabilized by vegetation. The latter features control activity of morphogenetic processes. Moreover, the size of the source catchment is very important. Thus, the sedimentation rate is a reliable measure of variability of relief dynamics in longer periods.

In the light of the sedimentation rates presented above, the opinion that the large water reservoirs fill up more slowly than the small ones is not

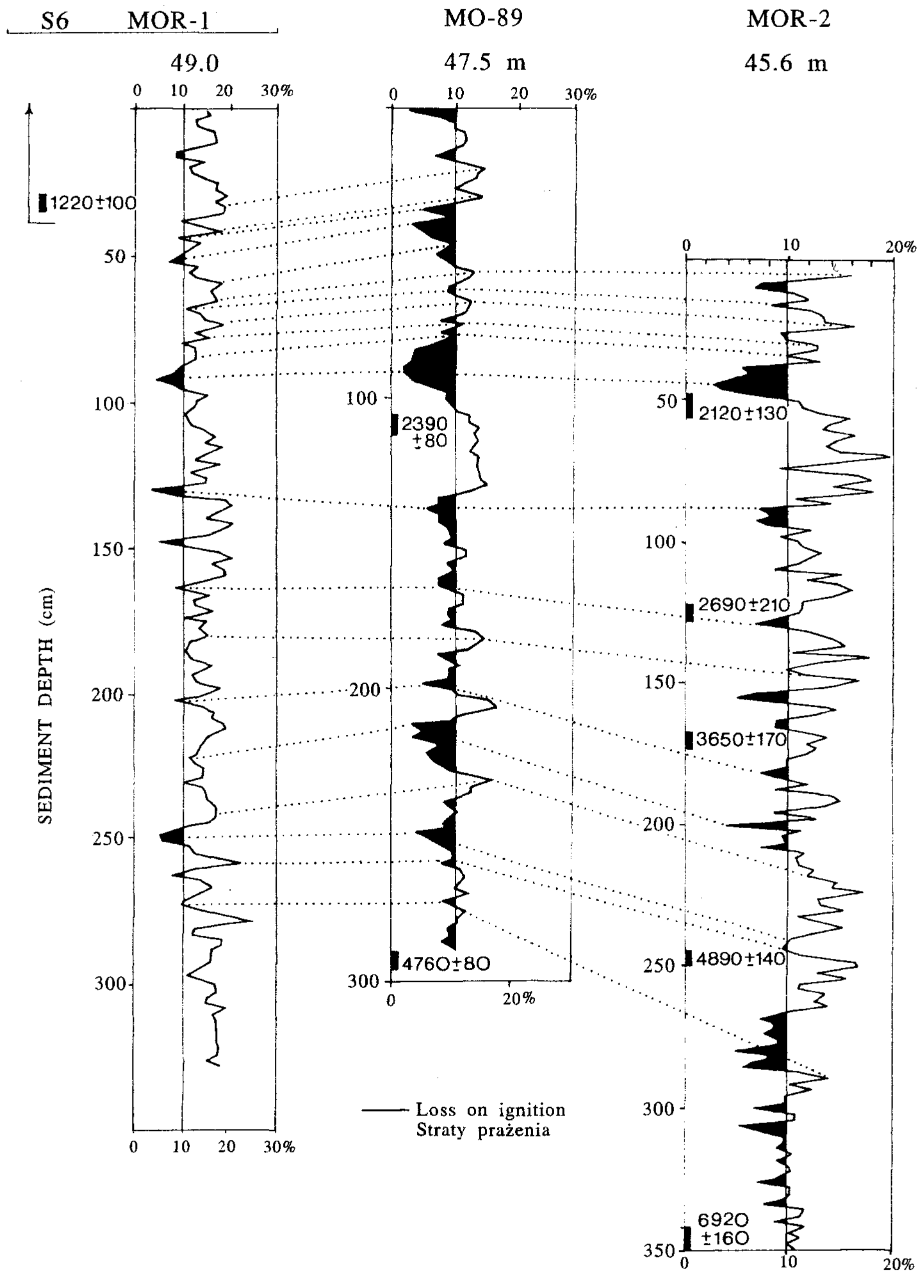

Fig. 4. Organic matter content in the cores recovered from the Lake Morskie Oko, determined by measuring the loss of ignition at 550°C. Correlation of three independent cores due to radiocarbon dating

Fig. 4. Zawartość substancji organicznej w rdzeniach z Morskiego Oka określona poprzez straty prażenia w temperaturze 550°C. Korelacja krzywych wyprażania udokumentowana datowaniami radiowęglowymi

confirmed. The sedimentation rate in Lake Morskie Oko is the highest among the studied lakes and the factors affecting this rate are numerous routes (sources) of material supply and the mode of material delivery. The dense system of gullies and a very important role of snow avalanches bearing mineral and organic substances cause this lake to be characterized by the highest sedimentation rates. The latter statement is not in disagreement with observation on a faster silting of small lakes located in the highest geoecological vertical zones of the Tatras. Lake sedimentation *sensu stricto* has to be distinguished from filling up the small water bodies by mass movements, mainly rockfalls and debris flows triggered on rockwalls and on debris slopes, decreasing the water surface of tiny lakes on a measurable scale.

Wicik (1984) quotes, after Simonow (1971), that "the rate of sediment accumulation in the lakes of Antarctic is estimated for 0.08 mm/year". Not only is it important to determine climatic conditions in the surrounding of the lakes yet to learn thoroughly the slope relief in the vicinity of the lakes as well as the conditions of weathered material delivery to the lake basins.

CONCLUDING REMARK

The characteristics of the lake sediments presented in this discussion has indicated that the lake sedimentation pattern differs significantly even in such small, high-mountain massif as the Tatras. Therefore, any conclusions of paleogeographical character drawn on the basis of sediments sampled from one lake only may be misleading or even leading towards false generalization on a regional scale as well as on a scale of the Tatra massif. Thus, learning all the lake environments of this region is a must.

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REFERENCES

Baumgart-Kotarba M., Jonasson C., Kotarba A., 1990. *Studies of youngest lacustrine sediments in the High Tatra Mountains, Poland.* Studia Geomorph. Carpatho-Balcanica, 24, 161–177.

Baumgart-Kotarba M., Kotarba A., 1993. *Późnoglacjalne i holoceńskie osady z Czarnego Stawu Gąsienicowego w Tatrach.* Dokumentacja Geogr. IG i PZ PAN, Z badań fizyczno-geograficznych w Tatrach, 4–5, 9–30.

Baumgart-Kotarba M., Kotarba A., Wachniew P., 1993. *Młodoholoceńskie osady jeziorne Morskiego Oka w Tatrach Wysokich oraz ich datowanie radioizotopami ^{210}Pb i ^{14}C.* Dokumentacja Geogr. IG i PZ PAN, Z badań fizyczno-geograficznych w Tatrach, 4–5, 45–61.

Brune G. M., 1953. *Trap efficiency of reservoirs.* Transactions of American Geophysical Society, 34, 407–418.

Chomicz K., 1957. *Les avalanches dans la montagnes de Tatra. Méthodes de mesures.* Extract de la publication no 69 de l'A.I.H.S. Symposium Intern. sur les Aspects Scientifiques des Avalanches de Neige.

Gradziński R., Kostecka A., Radomski A., Unrug R., 1986. *Zarys sedymentologii.* Wyd. Geol., 1–628.

Hajdukiewicz J., 1948. *Wielka lawina przy Morskim Oku w dniu 8 kwietnia 1948 r.* Taternik, 30, 1–2, 57–58.

Izmaiłow B., 1984. *Eolian deposition above the upper timber line in the Gąsienicowa valley in the Tatra Mts.* Zesz. Nauk. UJ, Prace Geogr., 43–59.

Jonasson C., 1991. *Holocene slope processes of periglacial mountain areas in Scandinavia and Poland.* UNGI Raport 79, Uppsala University, 1–156.

Klimaszewski M., 1962. *Zarys rozwoju rzeźby Tatr Polskich,* [in:] *Tatrzański Park Narodowy.* 105–124.

Kłapowa M., 1969. *Obserwacje lawin śnieżnych w Tatrach.* Wierchy, 38.

Kotarba A., 1992. *Mountain slope dynamics due to debris-flow activity in the High Tatra Mountains. Poland,* Bull. Asoc. Géogr. Franç., 257–259.

Kotarba A., 1993–1994. *Zapis małej epoki lodowej w osadach jeziornych Morskiego Oka w Tatrach Wysokich.* Studia Geomorph. Carpatho-Balcanica, 27–28, 61–69.

Kotarba A., Starkel L., 1972. *Holocene Morphogenetic Altitudinal Zones in the Carpathians.* Studia Geomorph. Carpatho-Balcanica, 6, 21–35.

Luckman B. H., 1975. *Drop stones resulting from snow-avalanche deposition on lake ice.* Journal of Glaciology, 14, 70, 186–188.

Paryski W. H., 1948. *Lawiny przy Morskim Oku.* Taternik, 30, 1–2, 54–57.

Sawicki L., 1929. *Atlas jezior tatrzańskich.* Mapy. Prace Komisji Geograficznej nr 2 PAU.

Simonow I. M., 1971. *Oazisy Wostocznoj Antarktidy.* [in Russian], Gidrometizdat.

Słup Z., Garncarz S., 1985. *Możliwości śledzenia przypowierzchniowej filtracji w zbiornikach wodnych w Tatrach w oparciu o przestrzenne badania termiczne.* Praca dyplomowa, Wydz. Geol.-Poszukiwawczy AGH, Międzyresortowy Instytut Geofiz., (unpublished), 1–54.

Thorn C. E., Darmody R. G., 1985. *Grain-size distribution of the insoluble component of contemporary eolian deposits in the alpine zone, Front Range, Colorado, U.S.A.,* Arctic and Alpine Research, 17, 4, 433–442.

Wicik B., 1984. *Osady jezior tatrzańskich i etapy ich akumulacji.* Prace i Studia Geogr. UW, 5, 55–69.

Więckowski K., 1984. *Makroskalowa charakterystyka osadów dennych jezior tatrzańskich.* Prace i Studia Geogr. UW, 5, 39–54.

STRESZCZENIE

A. Kotarba

PORÓWNANIE TEMPA HOLOCEŃSKIEJ SEDYMENTACJI W JEZIORACH TATR WYSOKICH — INTERPRETACJA GEOMORFOLOGICZNA

Misy jeziorne występujące w obszarach wysokogórskich są pułapkami sedymentacyjnymi dla osadów pochodzących z denudacji zlewni. Materiał dostarczany do jeziora z otaczających stoków lub poprzez górskie rzeki i strumienie jest deponowany w jeziorach i tylko nieznaczna jego część jest odprowadzana poza misę w postaci zawiesiny. Osady składane w jeziorach stanowią więc

zapis procesów zachodzących w środowisku wysokogórskim od momentu ustąpienia lodu z mis jeziornych. Biorąc pod uwagę sposoby dostawy substancji mineralnej do pięciu jezior tatrzańskich wyróżniono trzy typy jezior w obrębie rzeźby alpejskiej Tatr Wysokich, scharakteryzowanych poprzez zmienność zawartości substancji organicznej w osadach holoceńskich, tempo sedymentacji i struktury sedymentacyjnej przeanalizowane na zdjęciach rentgenowskich. Tempo holoceńskiej sedymentacji jeziornej jest bardzo zróżnicowane, od około 0,1 mm/rok do 1,29 mm/rok i zależy od konfiguracji stoków otaczających jeziora i stopnia utrwalenia roślinnością. Zmienność tempa sedymentacji w każdym z jezior jest również zróżnicowana w czasie i nawiązuje do aktywności morfogenetycznej stoków warunkowanej zmiennością klimatyczną w okresie holocenu.