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$\delta^{18}O$ and $\delta^{13}C$ isotope investigation of the Late Glacial and early Holocene biogenic carbonates from the Lake Lednica sediments, western Poland

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ABSTRACT:

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Stable isotope composition ($\delta^{18}O$ and $\delta^{13}C$) of biogenic carbonates derived from the Lake Lednica sediments at Rybitwy, western Poland, was applied to obtain data on climatic changes during the Late Glacial and early Holocene. A wide range of carbonates occurring in the sediments was analysed for $\delta^{18}O$ and $\delta^{13}C$ records, including shells of several gastropod species, the bivalve genus *Pisidium* and carapaces of ostracods belonging to the subfamily Candoninae.

The $\delta^{18}O$ and $\delta^{13}C$ records reveal changes commonly observed for the Late Glacial and early Holocene with the exception of the low oxygen isotope values of the Bölling and Alleröd Interstadials. The latter is interpreted as a consequence of ^{18}O-depletion of the lake water resulting from gradual melting of the dead ice that still filled the deepest parts of the Lake Lednica valley during the period described. The Younger Dryas Stadial begins with the isotopically lightest values in the sequence; however, due to the ^{18}O-depleted values of the Alleröd Interstadial the Alleröd/Younger Dryas boundary is poorly marked. The Younger Dryas/Preboreal transition is documented by a significant shift in $\delta^{18}O$ values of about 2–3‰, resulting from an increase in the mean annual temperature. The $\delta^{13}C$ record reflects the productivity level in the lake, with ^{13}C-enriched carbonates during the Bölling and Alleröd Interstadials, and the Preboreal and Boreal, when photosynthetic activity of phytoplankton and macrophytes was the most intensive.

Differences in $\delta^{18}O$ and $\delta^{13}C$ values between mollusc shells and ostracod carapaces reflect the specific season and subhabitat of each carbonate secretion.

Key words: Stable isotopes $\delta^{18}O$ and $\delta^{13}C$; Late Glacial; Early Holocene; western Poland.

INTRODUCTION

Oxygen and carbon stable isotope records in lacustrine carbonates are commonly used to reconstruct environment and climate changes during the Quaternary. Numerous papers have presented reliable palaeoecologic and palaeoclimatic reconstructions based on $\delta^{18}O$ and $\delta^{13}C$ records of carbonates precipitated within lakes. Combining oxygen and carbon isotope signatures recorded in bulk carbonates, mollusc shells, ostracod carapaces or *Chara* encrustations offers the possibility of obtaining seasonally specific data. It also allows conclusions to be drawn concerning differences in $\delta^{18}O_{water}$ and $\delta^{13}C_{dic}$ (dissolved inorganic carbon) values between particular environments within a lake (e.g. Hammarlund *et al.* 1999; von Grafenstein *et al.* 2000; Leng and Marshall 2004).

Reconstructions of the Late Glacial and Holocene climate based on $\delta^{18}O$ and $\delta^{13}C$ compositions in carbonates precipitated within a lake have hardly been carried out in Poland. Only a few papers dealing with this problem can be mentioned (e.g. Różański 1987; Różański *et al.* 1988; Kuc *et al.* 1993; Hammarlund 1998; Ralska-Jasiewiczowa *et al.* 2003). In none of them was the isotopic composition of biogenic carbonates described. This contrasts with studies in other European countries, especially Germany (e.g. von Grafenstein *et al.* 1994; Böttger *et al.* 1998; Mayer and Schwark 1999) and Sweden (e.g. Hammarlund and Keen 1994; Hammarlund *et al.* 1999, 2002, 2003), where such analyses are commonly performed.

The main purpose of the study was to reconstruct climatic and environmental conditions during sediment accumulation in Lake Lednica, western Poland, based on isotopic analysis of biogenic carbonates. Secondly, the isotopic record of a variety of biogenically precipitated carbonates was analysed to establish whether the stable isotope signatures of the taxa can be used as environmental tracers with equal success. The third topic was a trial to explain similarities and differences between isotope records in biogenic lacustrine carbonates of different origin.

The palaeoenvironment and palaeoclimate of the Lake Lednica area have been investigated in several previous studies. The geochemical composition of the lake sediments was described by Mazurek (1987, 1988). Mazurek (1988, 1990), Stankowski (1989) and Kolendowicz (1992) reconstructed fluctuations in the water level of Lake Lednica based on changes in the distribution and composition of the lacustrine deposits. The Late Glacial sediments at Imiołki, a site located 3 km to the north of Rybitwy, were extensively studied by a group of scientists lead by Tobolski (1998). Researches included analyses of pollen, plant macrofossils, Cladocera and insects as well as carbon and oxygen stable isotope compositions in bulk carbonates. A detailed description of the mollusc assemblages of the Imiołki and Rybitwy sediment successions and their environmental significance was presented by Apolinarska and Ciszewska (2006).

$\delta^{13}C$ and $\delta^{18}O$ records in biogenic lacustrine carbonates have been already used in palaeoclimatic and palaeoenvironmental studies (e.g. von Grafenstein *et al.* 1994; Tevesz *et al.* 1996; Böttger *et al.* 1998; Hammarlund *et al.* 1999; Leng *et al.* 1999; Jones *et al.* 2002). Each of the papers cited focused on 2–4 different types of carbonates: in particular, ostracods, the bivalve genus *Pisidium* and *Chara* encrustations.

SITE DESCRIPTION

Lake Lednica is situated in the southern part of the Gniezno Lake District about 35 km east of the City of Poznań in west-central Poland (Text-fig. 1). It is an elongated lake with an area of ca. 3.4 km^2 filling the southern part of a tunnel valley extending between Janowiec and Lednogóra. The relief of the study area was formed during the last Pleistocene glaciation. Aspects of the glacial and postglacial history of the area were summarized in Apolinarska and Ciszewska (2006). The Rybitwy sediment sequence was cored on the southwest shore of Lake Lednica, about 300 m south of the village of Rybitwy (Text-fig. 1). The borehole site is situated on the lower accumulative terrace of the lake (Mazurek 1990), approximately one metre above the present water surface.

The study area is influenced by both Atlantic and continental air masses, the influence of the former being more pronounced. The present climate is characterized by a mean annual precipitation of ca. 500 mm and a mean annual temperature of 7.9°C (mean July 17.9°C; mean January –2.4°C). A seasonal precipitation minimum causes water deficit in the summer months (Kondracki 2000).

MATERIALS AND METHODS

Fieldwork and subsampling

Isotope analyses were performed on biogenic carbonates derived from a sediment core, collected in the mid 1980s near the lake shore at Rybitwy using a 0.5 m long Instorf peat borer (Mazurek 1987). The ca. 5.0 m sediment sequence was previously described by Mazurek (1987) and Apolinarska and Ciszewska (2006). Sediment samples, 5 cm thick, were taken at ca. 10 cm intervals (see Apolinarska and Ciszewska 2006).

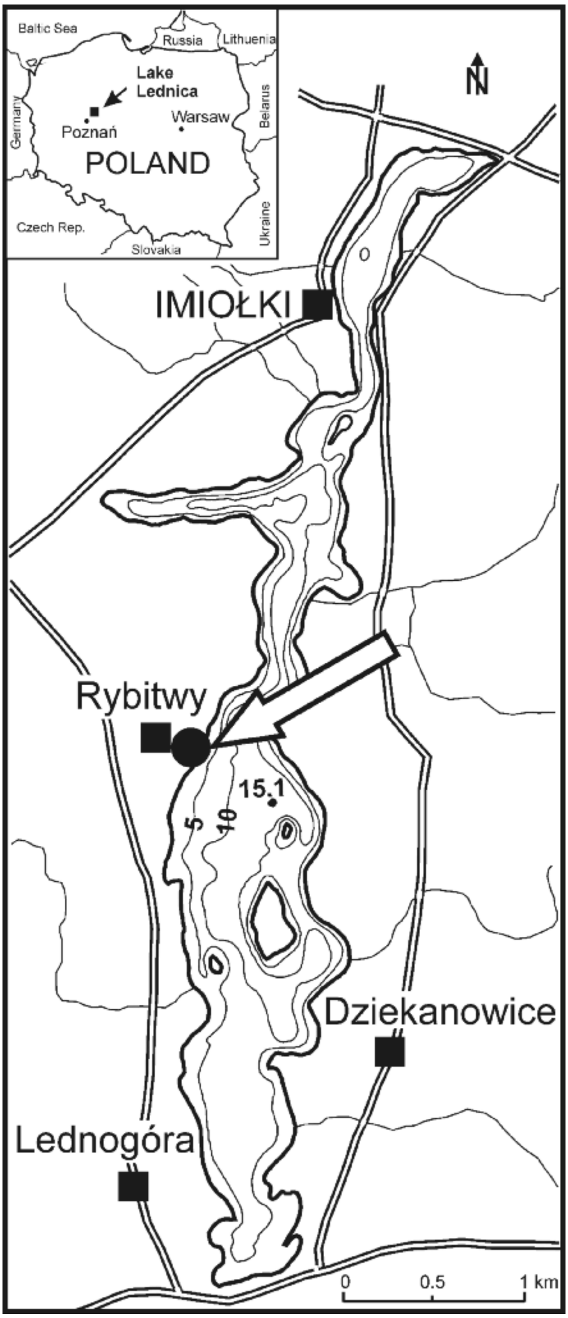
Sample preparation and isotope analysis

Sediment samples were soaked in water to disintegrate the sediments and than gently passed through 2.0, 0.5 and 0.125 mm sieves under running water. Shells and carapaces were hand picked after drying and then sorted and counted under a low-power binocular microscope. The stable isotope analysis was performed on a variety of biogenic carbonates present in the sediments. The main criteria for choosing taxa for the analysis were their possibly most continuous presence in the sequence as well as the abundance of shells and carapaces. Discontinuity of the isotope records (see the isotope profiles, Text-fig. 2) results from the absence of particular taxa in some samples. Isotope analysis was carried out on the shells of the gastropod species *Valvata cristata* Müller, *Valvata pulchella* Studer, *Valvata pisci-*

nalis (Müller), *Gyraulus laevis* Alder, *Armiger crista* (Linnaeus) and *Bithynia tentaculata* (Linnaeus) opercula, the bivalve genus *Pisidium* and carapaces of adult individuals belonging to the ostracod subfamily Candoninae.

Shells for isotope analysis were carefully chosen. Any signs of dissolution eliminated a specimen. Special attention was given to mollusc shells as they are usually composed of aragonite, a mineral prone to diagenetic alteration. The shell microstructure of a few species was examined on polished sections under the scanning microscope (SEM) and compared to the microstructure observed by Falniowski (1989a, b; 1990) in Recent shells of the same species. No differences were noticed. Preservation of original molluscan shell aragonite of chosen individuals was proved by X-ray diffraction analysis performed in the Institute of Geology, University of Poznań, Poland. The results indicate that the gastropod and bivalve shells were exposed to minimal diagenetic alteration and are likely to preserve their primary isotopic signatures.

All the carbonates were cleaned prior to analysis in order to eliminate contaminations that could affect isotope data. Preparation techniques began with gentle cleaning with a soft brush to remove sediment attached to shells, followed by treatment with 30% hydrogen peroxide (H_2O_2) for 24 hours to remove organic remains, mainly periostracum. The specimens were then washed several times in distilled water, dried at room temperature and ground to a fine powder. In order to obtain a mean isotope signal for each sediment layer sampled, samples for isotope analysis comprised 5–6 specimens. Stable isotope analyses were carried out in the Stable Isotope Laboratory at the University of Erlangen, Germany. Carbonate powders were reacted with 100% phosphoric acid at 75ºC using a Kiel III online carbonate preparation line connected to a ThermoFinnigan 252 mass-spectrometer. All values are reported in per mil (‰) relative to V-PDB by assigning a $\delta^{13}C$ value of +1.95‰ and a $\delta^{18}O$ value of –2.20‰ to NBS19. Reproducibility was checked by replicate analyses of laboratory standard and is better than ± 0.07‰.



Text-fig. 1. Topographic map of the study area with an outline map of Poland with inset to show the location of Lake Lednica. The site investigated is indicated by an arrow

Radiocarbon dating

The Late Glacial and Holocene chronology is based on ^{14}C dating of the shells of the bivalve genus *Pisidium*. Radiocarbon analyses were carried out in Poznań Radiocarbon Laboratory, where ^{14}C activities are measured using the technique of accelerator mass spectrometry (AMS). A possible influence of the hard water effect on the dates obtained was estimated by measuring ^{14}C in *Betula* seeds. The hard water effect measured was negligible.

RESULTS AND INTERPRETATION

General tendencies in the stable isotope record allow three main phases during the deposition of the sediment sequence to be distinguished. Isotope phase 1 is characterized by gradually decreasing $\delta^{13}C$ values, with significant sample to sample variations. The $\delta^{18}O$ record remains more stable, with only slight ^{18}O-depletion over time. Isotope phase 2 begins with the minimum $\delta^{18}O$ values in the sequence, followed by a general ^{18}O-enrichment interrupted by isotopically lighter oxygen isotope values, whereas the $\delta^{13}C$ record rises strongly. Isotope phase 3 records the maximum $\delta^{18}O$ and $\delta^{13}C$ values, gradually becoming depleted in ^{18}O and ^{13}C respectively.

Isotope phase 1 – The Oldest Dryas Stadial, the Bölling and Alleröd Interstadials

The Rybitwy lacustrine sequence begins with blue-grey silts overlying fluvioglacial sands (Mazurek 1988). Such sediments occur in the lowermost unit of lake deposits at numerous sites in the littoral of Lake Lednica and the lake surroundings (e.g. Litt 1988; Makohonienko and Tobolski 1991). The age of the silts was determined as Oldest Dryas (e.g. Tobolski 2000). Although lithology on its own cannot be indicative of coeval deposition, it is possible that the blue-grey silts in the study area are synchronous and were deposited after the ice-sheet retreat from the area. However, the Oldest Dryas is not recorded in the isotope data due to an absence of a mollusc fauna from the silts.

Isotope phase 1 is characterized by an overall trend of ^{18}O and ^{13}C depletion in the isotope records (Text-fig. 2). $\delta^{13}C$ values decline from ca. –0.5‰ to ca. –3.5‰ with strong fluctuations between the samples. This contrasts with the increasingly higher temperatures during the Bölling and Alleröd Interstadials, which favoured increased productivity within the lake, resulting in ^{13}C-enriched DIC. $\delta^{18}O$ values show a *c.* 1‰ decrease during the period described.

Isotope phase 2 – The Younger Dryas Stadial

The minimum $\delta^{18}O$ and $\delta^{13}C$ signatures induced by strong cooling and decrease in productivity in the lake reflect the early stage of the Younger Dryas Stadial (Text-fig. 2). ^{18}O-enrichment of the carbonates in the middle unit of that period is a consequence of gradual climate warming, while the subsequent decrease in $\delta^{18}O$ values of *Pisidium* may have resulted from elevated precipitation during the late Younger Dryas, as suggested by Hammarlund *et al.* (1999). ^{13}C-enrichment during the time unit described indicates gradual reestablishment of macrophytes and phytoplankton, preferentially incorporating $H^{12}CO_3^{-}$, in the lake, following their initial retreat in response to climate cooling. The ^{13}C-enrichment noted agrees with the carbon isotope record of the Younger Dryas observed at other European sites (e.g. Hammarlund *et al.* 1999).

The Late Glacial at Rybitwy is characterized by rare, bivalve/dominated mollusc fauna (Apolinarska and Ciszewska 2006). The deep water habitat for which a high bivalve-snail ratio is typical was suggested as a major factor influencing the situation observed (Apolinarska and Ciszewska 2006). The cold climate, especially during the Younger Dryas, is of minor importance here.

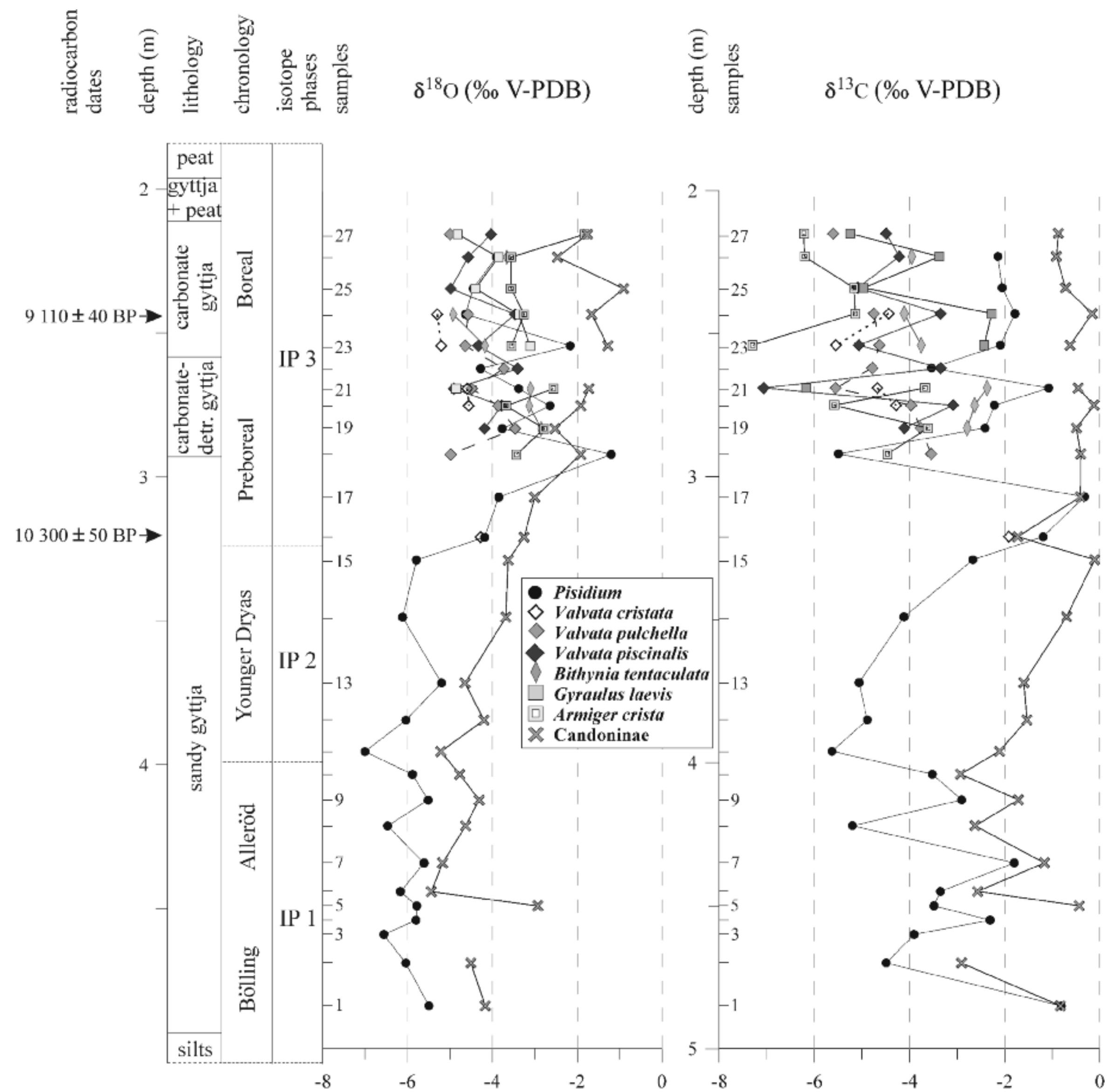
Isotope phase 3 – The Preboreal and Boreal

Holocene climate warming recorded in the upper unit of the sediment sequence is reflected in a positive shift in isotopic composition of carbonates (Text-fig. 2). An increase in $\delta^{18}O$ values by *c.* 2.5‰ at the threshold of the Holocene is in agreement with a change in the oxygen isotope record noted for the Younger Dryas/Preboreal transition at numerous European sites yielding lacustrine deposits (e.g. Schwander *et al.* 2000; von Grafenstein *et al.* 2000). The dry and increasingly warmer climate of the early Holocene (Ralska-Jasiewiczowa and Starkel 1991) might have also influenced $\delta^{18}O$ values by means of evaporative enrichment of water in ^{18}O. ^{13}C-enriched DIC was a consequence of increased productivity in the lake as a consequence of climate amelioration.

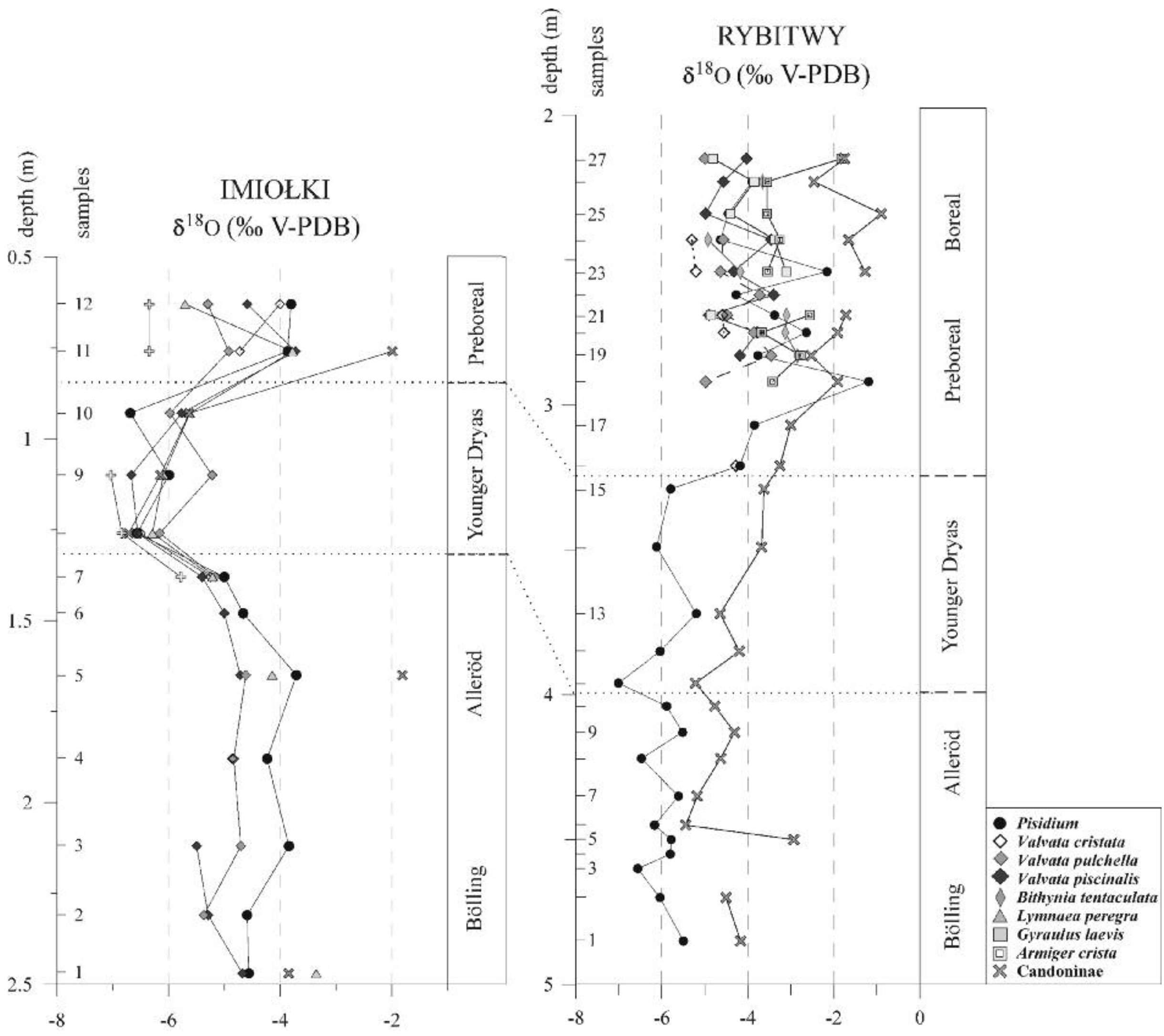
Mean oxygen and carbon stable isotope signatures of water and DIC samples from the Lake Lednica taken in monthly intervals between May and September 2008 (Pełechaty and Apolinarska, unpublished data), were measured as –3.68‰ and –4.22‰, respectively. After correcting $\delta^{18}O$ records of aragonitic mollusc shells and Candoninae carapaces by mineral specific isotope fractionation value and vital effects, –0.6‰ and –2.2‰, respectively (see unit Discrepancies in the $\delta^{18}O$ records), $\delta^{18}O$ values of the biogenically precipitated carbonates are on average 0.3–1.3‰ lower than stable oxygen isotope composition of the recent lake water. $\delta^{13}C$ value of the recent lake water is slightly ^{13}C-enriched in comparison to $\delta^{13}C_{snails}$ considered as precipitating in equilibrium with $\delta^{13}C_{dic}$. $\delta^{13}C_{dic}$ is *c.* 2‰ and *c.* 4‰ lower than mean carbon stable isotope values of *Pisidium* and Candoninae, respectively. Thus $\delta^{18}O$ and $\delta^{13}C$ record in carbonates investigated does not differ significantly from the stable isotope composition of the recent Lake Lednica waters. Discrepancy noted between recent $\delta^{13}C_{dic}$ and $\delta^{13}C_{Pisidium}$ and $\delta^{13}C_{Candoninae}$ is most probably a consequence of site-specific conditions of carbonate precipitation (see unit Discrepancies in the $\delta^{13}C$ records).

Shallowing of the lake recorded as a change in sediment type from sandy gyttja to carbonate-detritus gyttja (Mazurek 1988, 1990; Stankowski 1989) may have been a response to the early Holocene lake-level lowering phase observed in deposits of numerous lakes in central Poland (Ralska-Jasiewiczowa and Starkel 1988; Stankowski 1989; Ralska-Jasiewiczowa *et al.* 1992). Lake shallowing was a consequence of low precipitation and increasing air temperature during the Preboreal (Ralska Jasiewiczowa and Starkel 1991). The change in the lake depth is also reflected in a shift from a poor, bivalve-dominated mollusc assemblage in the sandy gyttja to a diverse gastropod-dominated mollusc fauna in the carbonate-detritus gyttja.

The $\delta^{18}O$ and $\delta^{13}C$ records in snail shells differ considerably (Text-fig. 2). Changes in the isotope values of the taxa are often contradictory. This contrasts with results from other studies, which show great similarity in the isotope values of gastropod shells, e.g. the Imiołki sediment sequence (Apolinarska and Hammarlund, in prep., Text-fig. 3). The isotope record observed may have resulted from shell mixing in the wave zone. Shells may have been transported from different parts of the lake where site-specific conditions, i.e. deeper or shallower habitat, sparse or dense vegetation, influenced their isotopic composition. It is also possible that the $\delta^{18}O$ and $\delta^{13}C$ values of some snails are useless for palaeoenvironmental studies. However, the latter suggestion seems improbable, since a few species from the Rybitwy sequence were also present at Imiołki, where



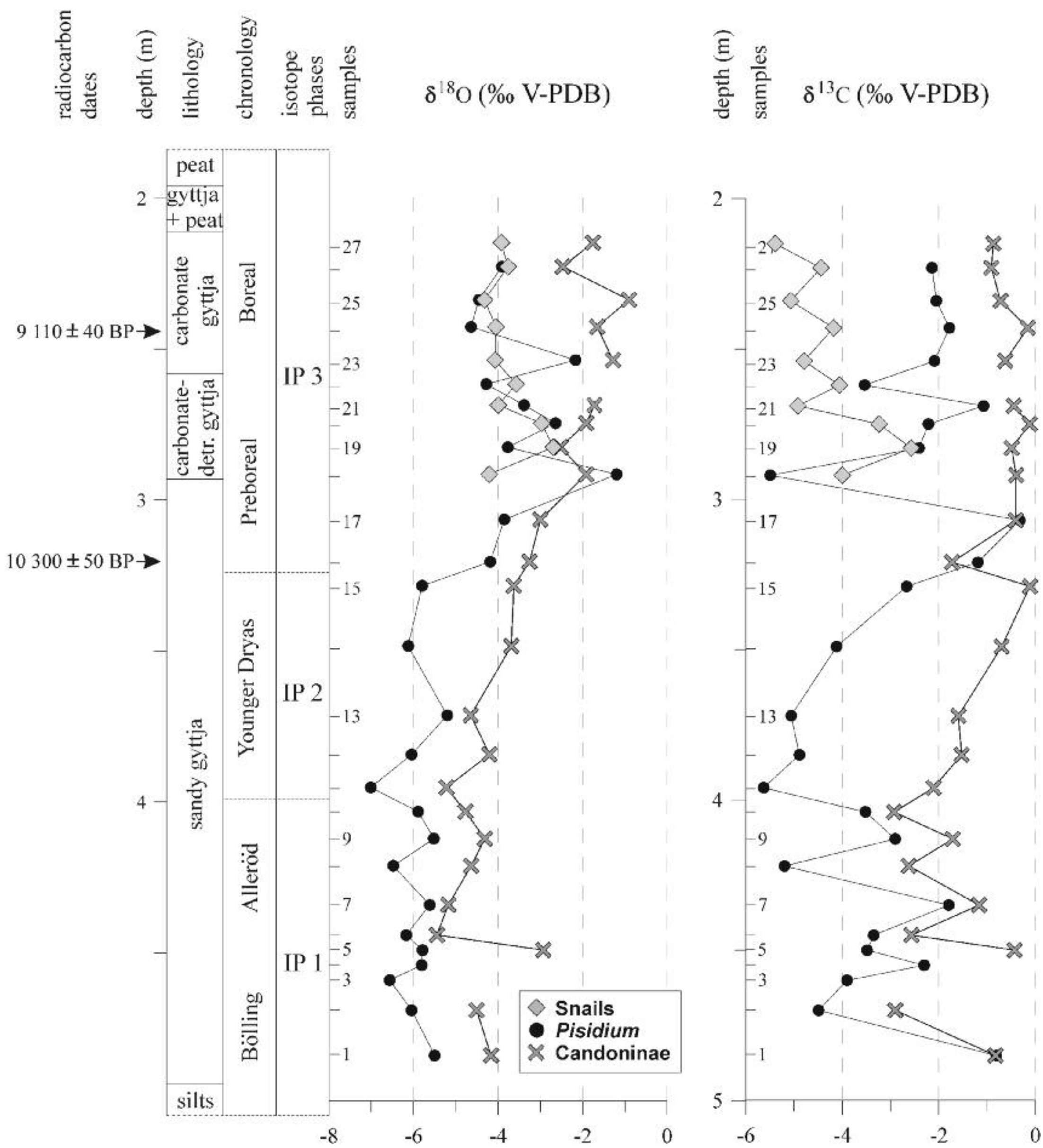
Text-fig. 2. Oxygen and carbon stable isotope records obtained from carbonates of biogenic origin at Rybitwy plotted against depth, lithology and chronology of the sediments and radiocarbon dates obtained (samples 16, 24). Isotope phases (IP) distinguished on the basis of general changes and prevailing trends of $\delta^{18}O$ and $\delta^{13}C$ curves such a conclusion cannot be drawn. Despite the great variability of the isotope record in snail shells (Text-fig. 2, samples 18–27), more detailed studies as well as the mean $\delta^{18}O$ and $\delta^{13}C$ values of the snails (Text-fig. 4) allow the distinction of two units that correspond to changes in lithology. In carbonate-detritus gyttja (Text-fig. 2, samples 18–22) the majority of snail species, i.e. *Armiger crista, Bithynia tentaculata, Valvata pulchella* and *Valvata cristata*, are characterized by ^{13}C-enriched values compared to those in carbonate gyttja (Text-fig. 2, samples 23–27). The $\delta^{18}O$ values of most snail species, i.e. *Bithynia tentaculata, Valvata pulchella, Armiger crista* and *Valvata cristata*, covary with the $\delta^{13}C$ values. $\delta^{18}O_{Pisidium}$ and $\delta^{13}C_{Candoninae}$ reveal similar changes to the $\delta^{18}O_{snails}$ values (Text-figs 2, 4). The isotope record described may be explained by a change in water residence time in the lake and/or fluctuations of the water level. ^{13}C and ^{18}O-enriched isotope values recorded in the carbonate-detritus gyttja may have originated from decreased through-flow and a possible consequent water level drop that resulted in the residence time effects. Gradual decrease of both $\delta^{18}O$ and $\delta^{13}C$ of the carbonates during deposition of carbonate gyttja, may reflect shortening of the water residence time in the lake and/or water level rise, indicating increased humidity of the climate. The ^{18}O and ^{13}C-depletion of the carbonates cannot be explained as a response to climate cooling, since the Preboreal and Boreal are characterized by a gradual rise in mean annual temperature (Ralska-Jasiewiczowa and Starkel 1991). The above conclusions are confirmed by the gastropod and bivalve fauna occurring in the upper unit of the sequence (Apolinarska and Ciszewska 2006).



Text-fig. 3. Comparison of oxygen stable isotope record in the carbonates analysed at Imiołki and Rybitwy. Note the ^{18}O-depletion of the carbonates at Rybitwy during the Bölling and Alleröd interstadials (for explanation see text)

The mollusc assemblage present in the carbonate-detritus gyttja is composed mainly of species inhabiting small, episodic, strongly overgrown reservoirs. Transition to the calcareous gyttja resulted in a general increase in both the number of taxa and specimens, with the majority of aquatic species being typical of stable, stagnating water basins. According to Schubert (2001), the low water level in Lake Lednica persisted during the Preboreal and Boreal, and was caused by low precipitation in conditions of a gradual rise in mean annual temperature.

The increase in $\delta^{18}O_{Candoninae}$ values observed during the early Holocene does not agree with the changes in the $\delta^{18}O_{snails}$ values (Text-figs 2, 4) and originates from rising winter temperatures (late autumn and early winter is the time when adult carapaces are secreted by ostracods belonging to the subfamily Candoninae). Severe winters of the Preboreal, resulting from a continental character of the climate, became distinctly milder during the Boreal as a consequence of the increasing influence of Atlantic air masses (Ralska-Jasiewiczowa and Starkel 1991).



Text-fig. 4. $\delta^{18}O$ and $\delta^{13}C$ signatures derived from shells of the bivalve genus *Pisidium*, carapaces of ostracods belonging to the subfamily Candoninae and mean isotope values of the snail species analysed. The isotope data are plotted against depth, lithology and chronology of the sediments and radiocarbon dates obtained (samples 16, 24)

$\delta^{18}O$ record – discussion

Following the stratigraphy presented above, where samples 1–10 reflect the Bölling and Alleröd Interstadials and samples 11–15 refer to the Younger Dryas Stadial, it occurs that the Rybitwy sediment sequence lacks the changes in the oxygen isotopic record that are typical of the Late Glacial time (Text-fig. 2). The $\delta^{18}O$ values remain relatively constant, ranging from –8‰ to –6‰ and contrast with the record at Imiołki (Apolinarska and Hammarlund, in prep.), a site located 3 km to the north of Rybitwy, where the oxygen isotope values reveal changes typical of the Late Glacial and early Holocene interval (Text-fig. 3). The mean $\delta^{18}O_{Pisidium}$ values for the Younger Dryas at Imiołki and Rybitwy do not differ significantly, ca. –6.4‰ and ca. –6.0‰ respectively. Values recorded for the earliest Holocene are also very similar, *c*. –3.8‰ at Imiołki and *c*. –4.0‰ at Rybitwy (Text-fig. 3). Moreover, the increase in $\delta^{18}O_{Pisidium}$ values on the transition to the Preboreal is much the same in both sections. A strong discrepancy between the isotope records is observed for the Bölling and Alleröd Interstadials. The mean $\delta^{18}O_{Pisidium}$ value at Rybiwy, ca. –5.9‰, is significantly lower than the mean $\delta^{18}O_{Pisidium}$ value at Imiołki, ca. –4.3‰. The data lead to the conclusion that, during the Bölling and Alleröd Interstadials, the $\delta^{18}O$ values of the water in Lake Lednica were lower than expected. Blocks of dead ice, filling the deepest parts of the lake valley might have been a source of isotopically light ^{16}O. $\delta^{18}O_{water}$ from the melting ice was ^{18}O-depleted in comparison to the $\delta^{18}O$ of precipitation during the period described. The presence of ice sheet remnants in the lake after the ice cover retreat from the study area was previously suggested by Stankowski (1989). Confirmation of the suggestion is the fact that the oldest lacustrine sediments found in the littoral zone of Lake Lednica are of Late Glacial origin (Makohonienko and Tobolski 1991; Tobolski *et al.* 1998), whereas the lacustrine sedimentation in central parts of the basin began in the earliest Holocene (Tobolski 1991). The above conclusion allows suggestion that during the Bölling and Alleröd Interstadials, the connection between the Lake Lednica and a small reservoir at Imiołki was lost or limited.

Discrepancies in the $\delta^{13}C$ records

The $\delta^{13}C$ record of the taxa analysed reveals distinct offsets in the carbon isotope values between the carbonates (Text-figs 2, 4). Compared with $\delta^{13}C_{Candoninae}$, the $\delta^{13}C$ record in the snail shells is displaced by *c*. 3–4‰ towards isotopically lighter values. $\delta^{13}C_{Pisidium}$ is *c*. 2‰ decreased in comparison with $\delta^{13}C_{Candoninae}$. During the Younger Dryas Stadial the difference in carbon isotope values between the two taxa increases to 3–4‰. Although all the taxa analysed are benthic organisms, ostracods and bivalves may be both infaunal and epifaunal. The infaunal habitat of the bivalve genus *Pisidium* and the ostracod subfamily Candoninae is considered here as a factor influencing the $\delta^{13}C$ values of their shells. It has been proven that $\delta^{13}C_{dic}$ gradients may exist between bottom waters, interstitial waters close to the sediment surface and waters at greater depths in the sediment (e.g. Lojen *et al.* 1999). The gradient observed is due to different concentrations of the dissolved oxygen in water during the decay of organic matter. Under aerobic conditions organic matter transported to the bottom of a lake is at least partly oxidised. Release of ^{12}C and the formation of isotopically light $\delta^{13}C_{dic}$ is the consequence of that plant decay. Under the anaerobic conditions that occur commonly at greater depth in the sediment, organic remnants may decay in a process of anaerobic degradation that leads to the formation of strongly ^{13}C-depleted methane ($\delta^{13}C_{methane}$ in freshwater = *c*. -60‰, Hoefs 2004) and ^{13}C-enriched CO_2, isotopically heavier in comparison to HCO_3^- in bottom waters. Hence, the increased $\delta^{13}C$ values of *Pisdium* and Candoninae may result from their infaunal mode of life, whereas the ^{13}C-depleted carbon isotope record in snail shells is a consequence of the epifaunal habitat of these molluscs. The intermediate $\delta^{13}C$ signatures in *Pisidium* shells (Text-figs 2, 4) may be explained by differences in the habitat of the bivalve, which, depending on the species composition, may be both infaunal and epifaunal. Also, ostracods belonging to the subfamily Candoninae may sink deeper into the sediment, where the influence of ^{13}C-enriched pore waters on the carapaces will be greater. The results support the findings of von Grafenstein *et al.* (1999) who analyzed stable oxygen and carbon isotope composition of ostracod carapaces of the subfamily Candoninae and shells of the bivalve genus *Pisidium*, inhabiting Lake Ammersee in Germany. A correlation between $\delta^{13}C_{dic}$, $\delta^{13}C_{shell}$ and downward distance from the sediment surface was observed.

Biogenically precipitated carbonates may also be affected by the so called vital effects resulting from physiological activity of the carbonate precipitating organism, shifting isotopic composition of shells out of equilibrium with water or DIC. Snail shells are regarded as precipitating in isotopic equilibrium with ambient lake water (Fritz and Poplawski 1974). $\delta^{13}C$ vital effects in *Pisidium* and Candoninae were estimated –0.2‰ and 0.8‰, respectively (von Grafenstein *et al.* 1999).

Discrepancies in the $\delta^{18}O$ records

Discrepancies in the $\delta^{18}O$ records between those of mollusc shells and ostracod carapaces is a consequence of the time taken for the carbonates to precipitate. In temperate climates mollusc growth is restricted to the warm season, i.e. spring, summer and early autumn. Adult ostracods belonging to the subfamily Candoninae grow and precipitate carapaces during the late autumn and early winter. Hence, the increased $\delta^{18}O_{Candoninae}$ values result from decreased temperatures during the growth of the carapaces. The $\delta^{18}O_{water}$ varies with the temperature of the water by about –0.24‰ per degree C for the temperature range between 10 and 20°C (Kim and O'Neal 1997). Thus, the *c*. 1–2‰ discrepancy in $\delta^{18}O$ values reflects a temperature change of between 4 and 8°C. When discussing the differences in stable oxygen isotope records of the carbonates vital effects and mineralogic composition must be considered. Aragonite precipitated in isotopic equilibrium is 0.6‰ enriched in ^{18}O compared to calcite (Tarutani *et al.* 1969). When accounting this value, the discrepancy in $\delta^{18}O$ values between mollusc shells composed of aragonite and ostracod carapaces with calcitic carapaces, decreases. Physiological processes, i.e. vital effects, in Candoninae have been found to cause 2.2‰ positive shift in $\delta^{18}O$ of carapaces (von Grafenstein *et al.* 1999). The above data suggest smaller temperature difference during snail and ostracod carbonate precipitation than suggested previously. Vital effect influencing $\delta^{18}O_{Pisidium}$ has been estimated to 0.86‰, however the value must be subtracted by 0.6‰, a consequence of aragonitic composition of *Pisidium* shells (von Grafenstein *et al.* 1999, Tarutani *et al.* 1969). Stable oxygen isotope records corrected by the vital effects become more congruent.

SUMMARY AND CONCLUSIONS

Oxygen and carbon stable isotope records in biogenic carbonates were successfully applied in the reconstruction of climatic and ecologic conditions during the accumulation of the Rybitwy sediment sequence.

The $\delta^{18}O$ and $\delta^{13}C$ curves reveal changes commonly observed for the Late Glacial and early Holocene, with the exception of the low oxygen isotope values for the Bölling and Alleröd Interstadials. The ^{18}O-depleted values confirm the earlier suggestion by Stankowski (1989) that the deepest parts of the Lake Lednica tunnel valley remained filled with dead ice during the early Late Glacial time. Gradual melting of the ice decreased $\delta^{18}O_{water}$ in comparison to the expected values resulting from $\delta^{18}O_{precipitation}$ at that time. Due to the decreased $\delta^{18}O$ record during the Bölling and Alleröd interstadials, the drop in $\delta^{18}O$ values at the threshold to the Younger Dryas was insignificant. The maximum $\delta^{18}O$ values for the sediment sequence described are observed for the Preboreal and Boreal and reflect climate amelioration during the early Holocene. The $\delta^{13}C$ record reflects productivity level in the lake, with increased values during the Bölling and Alleröd Interstadials and the Preboreal and Boreal, when phytoplankton and macrophytes were best developed due to the warm climate.

Although Rybitwy and Imiołki are located in proximity to each other and lacustrine sedimentation at both sites covers almost the same stratigraphic unit, their oxygen and carbon isotope records differ. The most pronounced discrepancy occurs in the lower unit of the sequences accumulated during the Bölling and Alleröd Interstadials. The situation observed suggests that $\delta^{18}O$ and $\delta^{13}C$ records must be regarded as unique for each site. Reservoirs occurring in close proximity may be characterized by their own site-specific isotope record due to local conditions that may greatly influence the isotopic composition of water and DIC. Despite these differences, the isotopic curves are usually broadly similar.

Except for the Bölling and Alleröd Interstadials, covariance between the $\delta^{18}O$ and $\delta^{13}C$ curves is generally observed. This results from the interdependence between major factors controlling $\delta^{18}O_{water}$ and $\delta^{13}C_{dic}$. The photosynthetic activity of macrophytes and phytoplankton in response to changes in mean annual temperature and/or changes in water residence time is regarded here as the most important. The $\delta^{18}O$ and $\delta^{13}C$ covariance points to a general slow water exchange in the reservoir.

The $\delta^{18}O$ and $\delta^{13}C$ records in the snail shells at Rybitwy seem strongly chaotic. Closer comparison of the stable isotope signatures, the mean isotope values of the snails in particular, reveals their similarity to the $\delta^{18}O$ and $\delta^{13}C$ values of *Pisidium* and carapaces of ostracods belonging to the subfamily Candoninae. The reason for the strongly differentiated isotope record may be shell mixing in the wave zone of the lake, where shells from different habitats within the lake were accumulated. The assumption that the isotope records of snails may not be used as palaeoclimatic and palaeoenvironmental indicators is opposed by the data at other sites investigated (e.g. the Imiołki site).

A significant discrepancy in the $\delta^{18}O$ and $\delta^{13}C$ values between the carbonates analysed reflects the different isotope conditions in which they were formed. This in turn results from the time and place of precipitation, specific for each type of carbonate. Vital effects influencing isotope composition of biogenically precipitated carbonates must also be considered.

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