Carpathian Journal of Earth and Environmental Sciences, February 2016, Vol. 11, No. 1, p. 37 - 54

MOLLUSCAN ASSEMBLAGES FROM HOLOCENE CALCAREOUS TUFA AND THEIR SIGNIFICANCE FOR PALAEOENVIRONMENTAL RECONSTRUCTIONS. A STUDY IN THE PIENINY MOUNTAINS (CARPATHIANS, SOUTHERN POLAND)

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Abstract: The molluscan assemblages occurring in profiles of calcareous tufa in the Pieniny Mountains (the Carpathians, Southern Poland) were subject to a detailed malacological analysis. The study included 27 sites of these deposits. Three of them represent the Early and Middle Holocene, and the remaining is tufa deposited in the Subatlantic Phase, mainly in the historical period. The conducted analyses enabled recognition of several types of calcareous tufa formed under different morphological conditions and containing various molluscan assemblages. On the basis of the gathered material, defining nine types of malacocenoses was possible. Each of them strictly corresponds to the conditions prevailing in time and place of deposits deposition and represents a specified climatic phase of the Holocene. The observed sequences of molluscan assemblags were the basis for paleoenvironmental reconstruction, determining the main phases of climatic changes and the human impact on the natural environment. The results of malacological analysis were complemented with determination of the age of deposits by means of radiocarbon dating and the results of palynological analyses conducted in the sites of peatbogs occurring in Podhale. The carried out reconstruction indicates similarities and differences in the paleogeographic development of mountain and upland areas of Central Europe.

Key words: calcareous tufa, molluscan assemblages, environmental changes, Holocene, Pieniny Mts, Carpathians, Southern Poland

1. INTRODUCTION

The Pieniny Mountains are the range contained in the Pieniny Klippen Belt, stretching along the arc of the Carpathians from Romania to the vicinity of Vienna. The main role in the formation of this range is played by Mesozoic limestone formations. Significant content of calcium carbonate in bedrocks create particularly favourable conditions for the precipitation of calcareous tufa. During geological studies in the Pieniny Mountains, being conducted for over 100 years, many occurrences of these deposits were located. More detailed analyses of calcareous tufa, mainly for the presence of subfossil molluscan shells in it, were, however, taken up during last 30 years. Over the past several decades, over a dozen sites of these deposits were determined, and the results of these studies were the subject of several publications. These works concerned, among others, the occurrence of calcareous tufa in landslides zones (Alexandrowicz, 1993a, 1996a, 1997a, 2013a), the spread of tufa precipitated contemporarily (Alexandrowicz, 2004, 2010), and also tufa cones (Alexandrowicz, 2004, 2014). The collected large amount of malacological data can be the basis of general considerations concerning changes of environment generated by climatic changes and human activity. The objective of the paper is to present environmental changes and paleogeographic evolution of the Pieniny Mts on the basis of diversity and sequences of molluscan assemblages occurring in profiles of Holocene calcareous tufa. This is simultaneously the recapitulation of the previous malacological research in the Pieniny Mts.

Molluscan assemblages occurring in calcareous tufa are an important indicator of paleoenvironment features. Their taxonomical composition and ecological structure are strictly dependent on the depositional conditions. It enables reconstructions with regional character. Simultaneously, limited possibilities of the shell material redeposition cause that molluscan assemblages reflect local conditions prevailing in place and time of the sedimentation, in which they are found. This second aspect is particularly important and valuable. While regional reconstructions can and are conducted by many methods, analyses of the local type, especially in relation to terrestrial environments, encounter major difficulties. They can be to some extent solved thanks to malacological research.

Calcareous tufa can be formed in different environmental types and are characterised by significant diversity of lithological features. This diversity is the basis of the discussed deposits division. These issues were the subject of numerous elaborations, and the results of these studies became the basis to determine the age of calcareous tufa classifications taking their lithological, genetic, morphological and other features into account (e.g. Ložek, 1961; Chafetz & Folk, 1984; Viles & Goudie, 1990; Goudie et al., 1993; Pentecost, 1995; Ford & Pedley, 1996; Pedley, 1990, 2009; Gradziński et al., 2013). Significant diversity of calcareous tufa is also observed in the Pieniny Mts.

2. MATERIAL AND METHOD

The results of malacological analyses conducted in 27 sites of calcareous tufa occurring in the Pieniny Mts were the basis for the presented study (Fig. 1). In total, 56 profiles of these deposits were determined. From this profiles, samples for malacological analysis were taken. Quantitative data for particular localities: number of profiles, samples and the total number of appointed in each locality species and individuals as well as GPS location are presented on Table 1. In the obtained material, rich and diverse malacofauna with predominance of terrestrial species occurred. Water forms occurred less frequently and usually except *Bythinella austriaca* and *Pisidium personatum* they were not numerous. Contemporarily, 115 molluscan species occur in the area of the Pieniny Mts (Urbański, 1939; Riedel, 1988) which constitutes about 65% of all taxa occurring in Poland. In the analysed material, 96 molluscan species (83% species occurring contemporarily in the Pieniny Mts.) represented by over 100 000 specimens were recognised. In some sites, forms unknown from the recent fauna of this area appeared. They are mainly cold-loving species (e.g. *Vertigo genesii*, *Vertigo geyeri*, *Semilimax kotulae*) and water forms, particularly taxa inhabiting small water bodies (e.g. *Pisidium subtruncatum*, *Pisidium obtusale*, *Pisidium amnicum*). Laboratory treatment of materials consisted of elutriation of rocks, and selection of all complete shells and determinable fragments of shells. The number of species and specimens was determined in each sample. Fragments of shells were converted into complete specimens in accordance with the scheme proposed by Alexandrowicz & Alexandrowicz (2011).

Thanks to such rich material, it was possible to separate and characterise faunistic assemblages, whose composition and structure strictly refer to the features of the sedimentary environment. The basis of assemblages differentiation were: the presence of taxa with strictly specified ecological requirements and occurrences of taxa characteristic of climatic phases. Assemblages were highlighted in accordance with the method described by Alexandrowicz (2004) and Alexandrowicz & Alexandrowicz (2011). On this basis, nine types of malacocenoses were separated. The features of assemblages and constituted the basis for the paleogeographic and paleoenvironmental reconstruction.

The age of calcareous tufa was established indirectly and directly. In the first case, the basis for concluding was the comparison of the malacocenoses features with other well-documented stratigraphically profiles of deposits described from the Polish part of the Carpathians (e.g. Alexandrowicz & Alexandrowicz, 1995a, b; Alexandrowicz & Chmielowiec, 1992; Alexandrowicz, 1997b, 2004; Alexandrowicz et al., 2014). The direct determination of the age of deposits was possible due to radiocarbon dating of 19 samples. The basis for dating were either shells of molluscs or remains of plants occurring within deposits. The radiocarbon analyses were conducted in the Radiocarbon Laboratory in Skała near Cracow (the laboratory code: MKL) and at the Department of Radioisotopes of the Institute of Physics of the Silesian University of Technology in Gliwice (the laboratory code: Gd). The results of the radiocarbon analyses were calibrated on the basis of the calibration curve (Stuiver et al., 1998), using OxCal V 3.9 software (Bronk Ramsey, 2001).

Table 1. Localities, malacofauna and types (described in text) of calcareous tufa in Pieniny Mountains

Locality		GPS	Number of profiles	Number of samples	Number of species	Number of specimens	Type
Sg	Sobczański Gorge	49°24’41"N 20°24’24"E	3	18	43	3624	IA; IB
Zw	Zawiasy	49°25'36"N 20°26'25"E	3	16	69	4548	IC
Li	Limbargowy Gorge	49°24′59.3″N 20°21′51.5″E	2	10	53	4491	IA; IB
Gg	Gorczyński Gorge	49°24’32"N 20°23’19"E	2	8	52	1997	IA; IB
Tl	Tylka	49° 25′ 56″ N 20° 23′ 39″ E	4	25	74	15557	IV
Pl	Płaśnie	49° 26′ 01″ N 20° 22′ 18″ E	3	11	57	2972	IV
Oc	Ociemny Stream	49° 25' 53”N 20° 26' 7”E	1	9	70	11096	III
Ss	Skalski Stream	49˚23’58” N 20˚33’49” E	10	59	78	20508	IIA; III
Ja	Jaworki	49° 24' 29”N 20° 32' 44”E	3	22	62	5292	IIB
Kl	Klimontowski Stream	49° 24' 59”N 20° 29' 6”E	2	10	54	1050	IV
Kz	Kozłecki Stream	49° 26' 43”N 20° 26' 16”E	3	12	58	1647	IV
So	Ścigocki Stream	49° 26' 26”N 20° 26' 30”E	2	11	57	8390	IV
Hg	Homole Gorge	49° 23' 56”N 20° 33' 1”E	1	16	59	7212	IV
St	Skotnicki Stream	49° 26' 30”N 20° 28' 2”E	2	7	32	2334	IV
Ma	Macelowy Stream	49° 24' 31”N 20° 24' 33”E	1	8	45	4013	III
Kt	Kąty	49° 24' 37”N 20° 22' 24”E	1	2	34	424	IIB
Kg	Kotłowy Gorge	49° 24' 40”N 20° 24' 38”E	1	2	13	151	IIA
Pn	Pieniński Stream	49° 25' 6”N 20° 25' 52”E	2	4	24	408	IIA
Kr	Krościenko	49° 26' 36”N 20° 25' 55”E	2	4	17	135	IIB
Dg	Długi Gronik	49° 25' 18”N 20° 26' 58”E	1	2	22	228	IIB
Sz	Szczawny Stream	49° 27' 6”N 20° 26' 55”E	1	2	11	237	Vc
Zs	Zakijowski Stream	49° 26' 6”N 20° 26' 53”E	1	2	23	256	IIA
Cs	Czarny Skotnicki Stream	49° 26' 26”N 20° 28' 30”E	1	3	30	3766	IV
Gr	Grajcarek	49° 25' 12”N 20° 30' 33”E	2	4	31	221	IIB
Ku	Krupianka Stream	49° 24' 14”N 20° 31' 57”E	1	2	27	133	IIA
Jh	Jaworki-Homole	49° 24' 18”N 20° 32' 51”E	1	2	29	308	IIB
Bw	Biała Woda Gorge	49° 23' 53”N 20° 35' 1”E	1	1	14	364	Vc

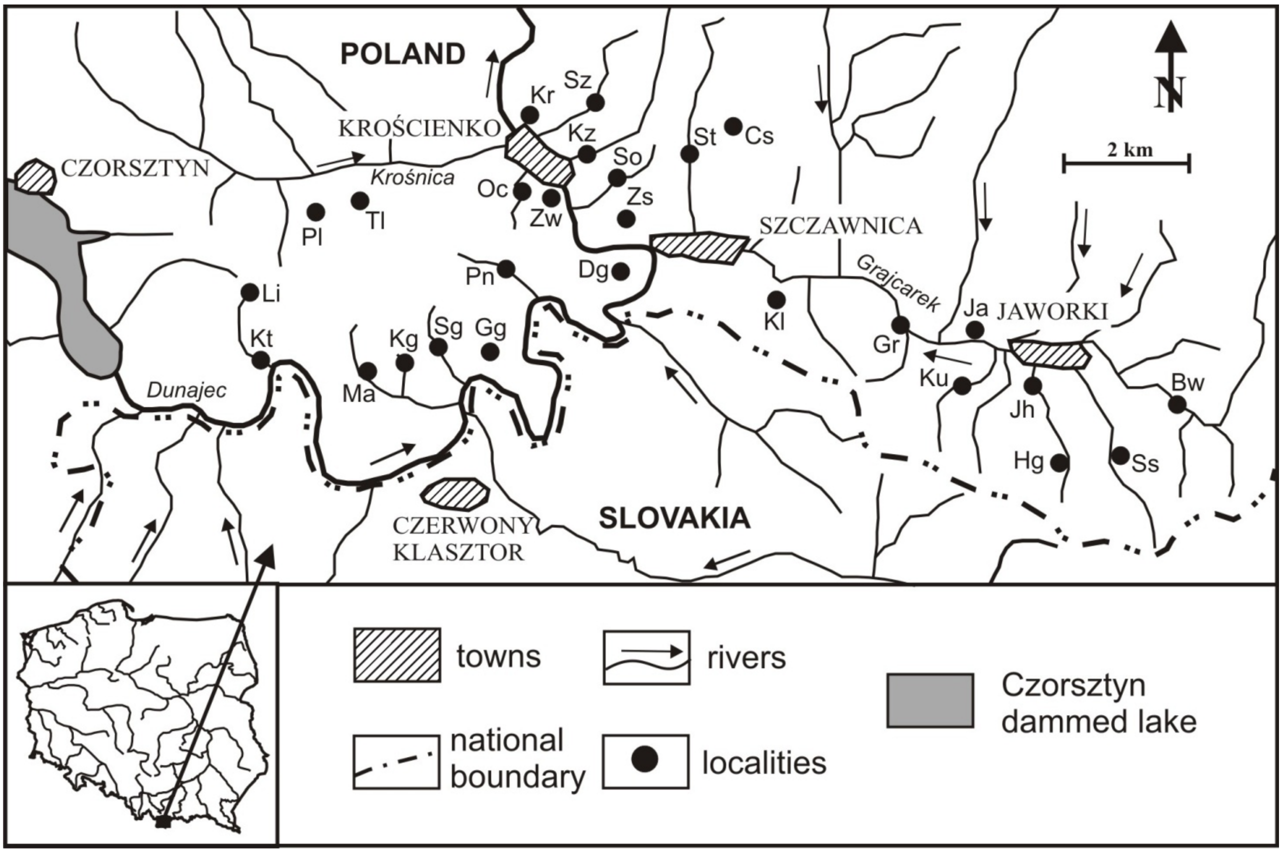

Figure 1. Location of profiles of calcareous tufa in the Pieniny Mountains. Signatures of localities are explained in table 1

3. RESULTS

Calcareous tufa is formed as a result of precipitation of calcium carbonate from water. This process occurs either as a result of physical and chemical phenomena or as a result of the activity of living organisms, mainly plants. Both these factors lead to lowering the content of CO_2 dissolved in water and calcium carbonate precipitation. For the needs of the presented studies, the basis of tufa types differentiation is the morphological criterion which takes mainly their place of deposition into account. In accordance with this point of view it is possible to separate five types of calcareous tufa occurring in the Pieniny Mountains (Fig. 2, Tab. 1).

Type I - calcareous tufa forms cones accumulating under vertical or overhung rocky walls (Fig. 2; Ia, Ib), or fills in niches and depressions within inclined rocky slopes (Fig. 2; Ic). Such habitats are called hygropetric zones (Alexandrowicz, 1988, 2014). They are characterised by good exposure and rapid evaporation of water and large temperature fluctuations. Precipitated $CaCO_3$ forms crusts on rocks which become more thick in time and fall under gravity accumulating at the foot of rocky walls or in depressions as tufa cones. In such cones, loose, fine-grained and silty varieties of tufa containing numerous rock fragments dominate (Ložek, 1961, 1964; Alexandrowicz, 1988, 2004, 2014). Thickness of the discussed cones usually does not exceed 1 m and frequently it is subject to significant, periodic fluctuations. In these deposits, there usually occurs rich malacofauna. Its main component are petrophilous forms. Depending on exposure of rocky wall and on the degree of the sediment supply area shading, either shade-loving species (*Cochlodina orthostoma*, *Pseudalinda stabilis*, *Argna bielzi*), or calciphilous taxa of open environments (*Chondrina clienta*, *Pyramidula pusilla*, *Truncatellina cylindrica*) prevail. A stenotopic species inhabiting sources zones – *Bythinella austriaca* is usually common. Mesophilous taxa and forms typical of dry grassy open habitats (*Vallonia pulchella*, *Vallonia costata*, *Pupilla muscorum*) constitute a complement. Snails preferring wet environments appear rarely.

Tufa with such character were found in: Sobczański Gorge, Zawiasy, Limbargowy Gorge and Gorczynski Gorge (Fig. 1, Table 1) (Alexandrowicz, 2014). Similar tufa occurs also in the Tatra Mountains (Alexandrowicz, 1988, 2001a, 2004). Tufa cones are very susceptible to erosion processes and rapidly undergo destruction (Alexandrowicz, 2014).

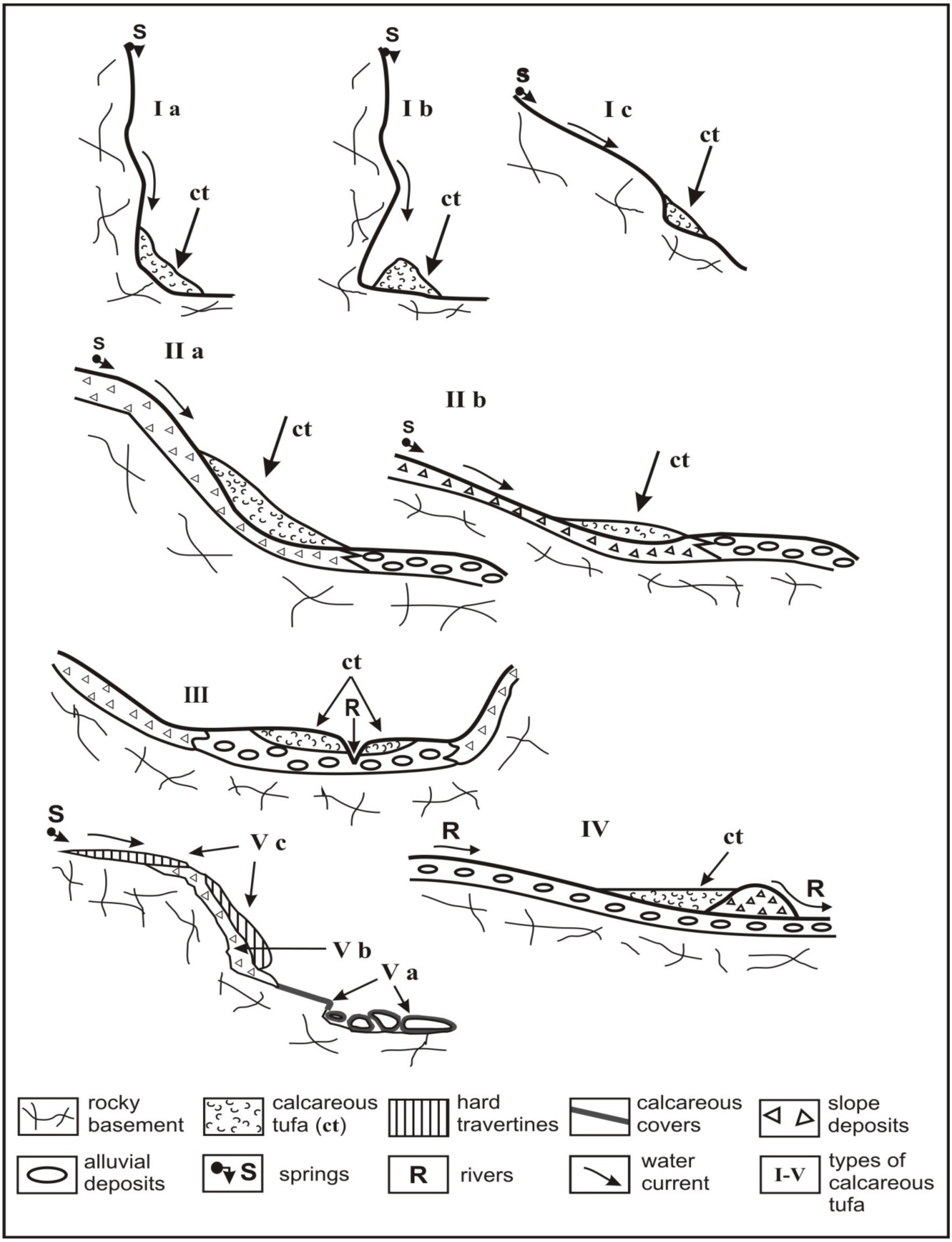

Figure 2. Morphological types of calcareous tufa occurring in the Pieniny Mountains, I – V. types of calcareous tufa described in text

Hence, they represent only the historical period which is confirmed by the results of radiocarbon method of age determination performed in: Sobczański Gorge: 620±80 years BP (1253 – 1431 cal AD; MKL 1352) and 60±30 years BP (1697 – 1916 cal AD; MKL 1350), Zawiasy: 320±40 years BP (1496 – 1646 cal AD; MKL 1353), and Gorczyński Gorge: 140±70 years BP (1650 – 1937 cal AD; MKL

1351) (Fig. 3, Table 2) (Alexandrowicz, 2014).

Type II - includes tufa forming in the vicinity of sources. It is a very commonly occurring type of deposits. They are formed both on relatively steep slopes, usually in narrow valleys of deeply cut streams (Fig. 2; IIa) and in broad valleys, on flattenings in the vicinity of water outflows (Fig. 2; IIb). Precipitation of tufa is most intensive in the distance of several to over a dozen meters from the exact outflow (Pazdur, 1987). Carbonate sediments usually form small, flat cones. Different varieties of calcareous tufa occur in these cones. Most often occur hard, porous travertines. Also loose, grained tufa varieties forming layers and pockets with small thickness appear or fill in niches within layers of travertines. Thickness of the discussed deposits does not exceed 1 m, and usually reaches barely several or over a dozen cm.

Table 2. Radiocarbon datings and startigraphical range of profiles of calcareous tufa Pieniny Mountains

Locality		Age	Stratigraphical data			References
			M	C14 (BP)	Cal C14 (cal BC/AD)	
Sg	Sobczański Gorge	SA	+	620±80 60±30	1253 – 1431 cal AD 1697 – 1916 cal AD	Alexandrowicz, 2004, 2010, 2014
Zw	Zawiasy	SA	+	320±40	1496 – 1646 cal AD	Alexandrowicz, 2004, 2010, 2014
Li	Limbargowy Gorge	SA	+	-	-	Alexandrowicz, 2004, 2010, 2014
Gg	Gorczyński Gorge	SA	+	140±70	1650 – 1937 cal AD	Alexandrowicz 2004, 2010, 2014
Tl	Tylka	SA	+	3330±70 535±30	1772 – 1851 cal BC 1330 – 1430 cal AD	Alexandrowicz, 1996a, 1997a, 2004, 2009b, 2013a
Pl	Płaśnie	SA	+	680±80	1206 – 1423 cal AD	Alexandrowicz, 1996a, 1997a, 2004, 2013a
Oc	Ociemny Stream	BO – AT	+	-	-	Alexandrowicz, 2004
Ss	Skalski Stream	AT; SA	+	6500±270	5924 – 4847 cal BC	Alexandrowicz, 2004
Ja	Jaworki	SA	+	450±50	1398 – 1523 cal AD	Alexandrowicz, 2004, 2010
Kl	Klimontowski Stream	SA	+	-	-	Alexandrowicz, 2004, 2010
Kz	Kozłecki Stream	SA	+	140±50	1670 – 1950 cal AD	Alexandrowicz, 1993a, 1996a, 1997a
So	Ścigocki Stream	SA	+	640±50 250±40	1275 – 1404 cal AD 1515 – 1805 cal AD	Alexandrowicz, 1993a, 1996a, 1997a
Hg	Homole Gorge	PB – SA	+	9940±100 480±40	9857 – 9246 cal BC 1298 – 1527 cal AD	Alexandrowicz, 1996a, b, 1997a
Cs	Skotnicki Stream	SB – SA	+	3170±100	1686 – 1195 cal BC	Alexandrowicz 1993a, 1996a, 1997a
Ma	Macelowy Stream	SA	+	1460±30 900±50	444 – 661 cal AD 1032 – 1235 cal AD	Alexandrowicz, 1990
Kt	Kąty	SA	+	-	-	Alexandrowicz, 2004, 2010
Kg	Kotłowy Gorge	SA	+	-	-	Alexandrowicz, 2004, 2010
Pn	Pieniński Stream	SA	+	-	-	Alexandrowicz, 2004, 2010
Kr	Krościenko	SA	+	-	-	Alexandrowicz, 2004, 2010
Dg	Długi Gronik	SA	+	480±50	1388 – 1499 cal AD	Alexandrowicz, 2004, 2010
Sz	Szczawny Stream	SA	+	-	-	Alexandrowicz, 2004, 2010
Zs	Zakijowski Stream	SA	+	-	-	Alexandrowicz, 2004, 2010
Cs	Czarny Skotnicki Stream	SA	+	-	-	Alexandrowicz, 1996a, 1997a, 2010
Gr	Grajcarek	SA	+	450±35	1410 – 1491 cal AD	Alexandrowicz, 2004, 2010
Ku	Krupianka Stream	SA	+	-	-	Alexandrowicz, 2004, 2010
Jh	Jaworki-Homole	SA	+	-	-	Alexandrowicz, 2004, 2010
Bw	Biała Woda Gorge	SA	+	-	-	Alexandrowicz, 2004, 2010

ST. Stratigraphy (after: Mangerud et al., 1974): PB. Preboreal, BO. Boreal, AT. Atlantic, SB. Subboreal, SA. Subatlantic; M. malacofauna

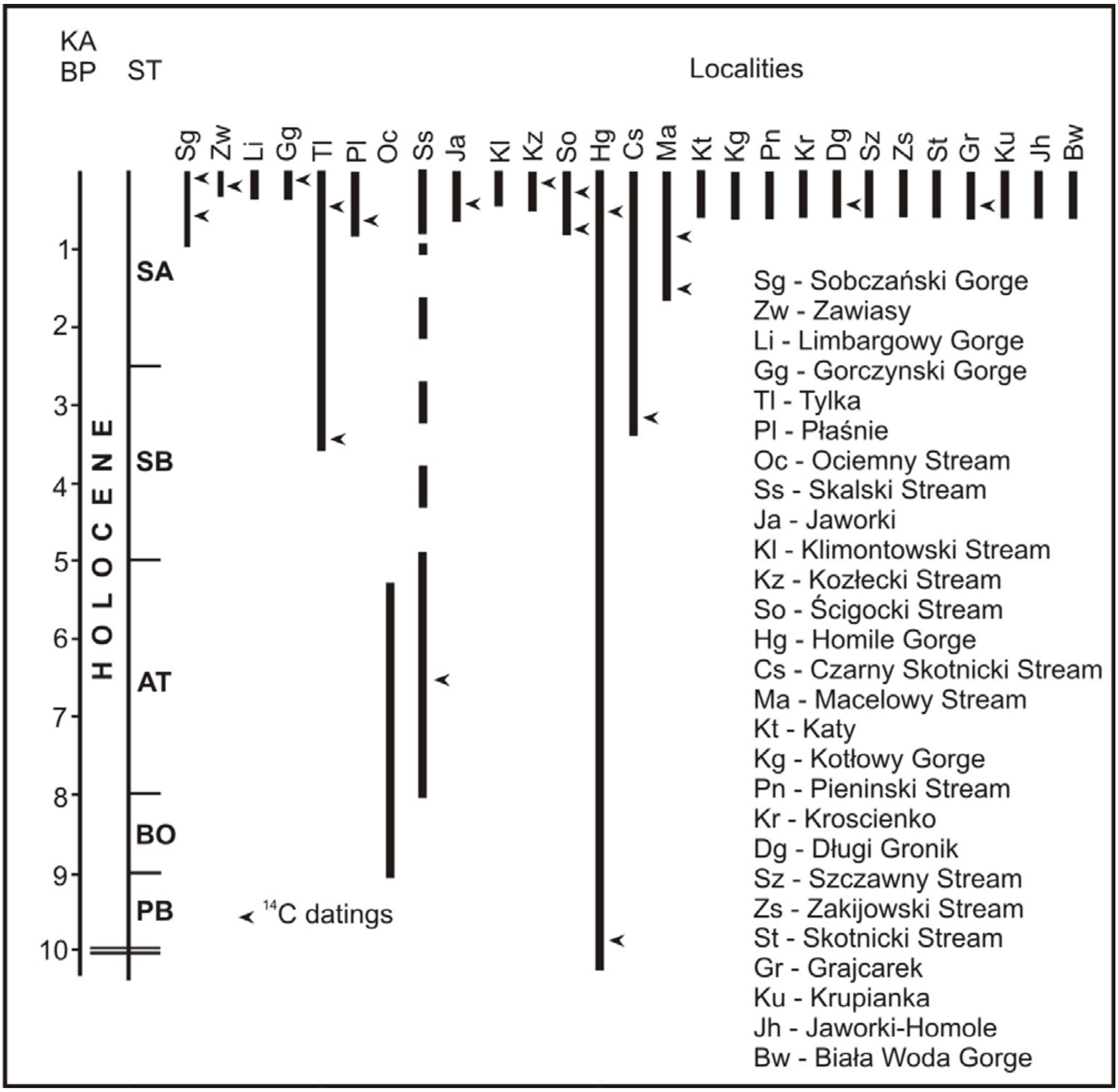

Figure 3. Startigraphical range of profiles of calcareous tufa in the Pieniny Mountains; ST. stratigraphical subdivision (after: Mangerud et al., 1974); for explanations see Figure 2

Malacofauna of tufa precipitated in the direct vicinity of sources is characterised by poor species composition. On the other hand, diversification of fauna types at separate sites of such tufa changes within very wide limits and is strictly dependent on local conditions. The dominant species is usually *Bythinella austriaca*, whose share in assemblages sometimes reaches up to 90%. Malacofauna of tufa accumulated in shaded zones usually contains a significant addition of shade-loving species, particularly preferring wet ground (*Monachoides vivinus*, *Vestia turgida*, *Vestia gulo*) and hygrophilous forms (*Carychium minimum*, *Zonitoides nitidus*). In open areas, a significant role is played by meadow taxa: *Vallonia pulchella*, *Vallonia costata*, *Pupilla muscorum*. In both cases, mesophilous forms constitute a complement of assemblages.

The discussed type of tufa was found in: Skalski Stream, Pieniński Stream, Kotłowy Gorge, Zakijowski Stream, Krupianka Stream (subtype IIa) and in profiles: Jaworki, Katy, Krościenko, Długi Gronik, Grajcarek and Jaworki-Homole (subtype IIb) (Fig. 1, Table 1).

The described type, like tufa accumulated at rocky walls is easily eroded and represents only the historical period: Jaworki: 450±50 years BP (1398 – 1523 cal AD; Gd 5107); Długi Gronik: 480±50 years BP (1388 – 1499 cal AD; Gd 4253) and Grajcarek: 450±35 years BP (1410 – 1491 cal AD; Gd 5287) (Fig. 3, Table 2).

Similar sites of calcareous tufa were described from many outcrops in the neighbouring areas: the Podhale Basin (Mastella, 1975; Alexandrowicz, 1997b, 2004, 2010; Mastella & Rybak-Ostrowska, 2012; Alexandrowicz et al., 2014) and the Flysch Carpathians (Alexandrowicz, 2004, 2009a).

Type III - tufa included in it occurs within the valleys of streams within alluvial deposits or form independent tufa terraces (Fig. 2, III). Different varieties of loose tufa with variable grain size dominate here. Both coarse grained deposits and silty varieties and calcareous silts. Layers of hard travertines occur rarely. Thickness of carbonate deposits ranges from tens of centimeters to 1 meter and maximally can be up to 2 m. In the discussed type, very rich and varied malacofauna assemblages occur, and a number of taxa in particular samples frequently exceed 50. Usually, the dominating fauna components are shade-loving species complemented by mesophilous forms. Taxa belonging to these groups usually constitute 60-70% of the assemblage. The addition of other ecological groups (snails of open environments, hygrophilous and water forms) is usually small.

The presented type of tufa was recognised in: Ociemny Stream, Skalski Stream, and Macelowy Stream (Fig. 1, Table 1).

Tufa occurring within river terraces is much more resistant for destructive factors than the types discussed above. Consequently, they represent longer time intervals encompassing not only the Late, but also Middle and even Early Holocene: Skalski Stream: 6500±270 years BP (5924 – 4847 cal BC: Gd 9977); Macelowy Stream: 1460±30 years BP (444 – 661 cal AD; Gd 5112) and 900±50 years BP (1032 – 1235 cal AD; Gd 5259) (Alexandrowicz, 1990) (Fig. 3, Table 2). They also enable to trace changes in the composition and structure of molluscan assemblages in vertical profiles corresponding to environmental conditions and climate features in particular phases of the Holocene.

Tufa occurring within river terraces is relatively rarely encountered in the Carpathians (Alexandrowicz, 2004). They were, however, described from many sites in the Central Polish Uplands (e.g. Alexandrowicz, 1983, 2004, 2012).

Type IV – calcareous tufa constituting fillings of lakes formed as a result of damming a valley by landslides belong here. As a result of damming the outflow, a small and shallow body of water with rich plant vegetation is usually formed at the back of the dam. It is gradually filled with deposits – fine-grained and silty calcareous tufa interfingering with fluvial deposits – sands and gravels. In the final stage of the small landslide lake development, breaking of the coluvial barrier occurs and the body drainage. Then, terrace strips, whose deposits constituting the filling of the small lake are exposed, are formed. Their thickness is varied and ranges from over a dozen centimeters to maximally several meters (Fig. 2, IV). In calcareous tufa, there usually occurs rich fauna, whose characteristic feature is the presence of water species, typical of shallow, temporary bodies of water (*Galba truncatula*, *Anisus calculiformis*). A common component is also water forms related to fast-flowing streams (*Bythinella austriaca*, *Pisidium personatum*). Typically, there are many forms of open or shaded habitats with high humidity. Mesophilous snails constitute a complement. Species of open environments appear most numerously in bottom parts of profiles marking the phase of plant coverage destruction in connection to landslide forming and in the top part corresponding to the phase of cutting the landslide barrier and draining of the water body. There often occur remains of plants, sometimes even tree trunks, in the discussed deposits. They are particularly numerous in the bottom intervals of profiles. Their dating enables to determine the time of the landslide development. The discussed type of tufa is particularly characteristic of the Pieniny Mountains (Alexandrowicz 1993a, 1996a, b, 1997a, 2004, 2009b, 2013a). Such deposits are also known from the Podhale Basin (Alexandrowicz 1997b, 2003; Alexandrowicz et al., 2014) and the Flysch Carpathians (Alexandrowicz 1996a, 1997a, 2004; Alexandrowicz & Alexandrowicz, 1999). Similar formations also occur in the zone of the Central Polish Uplands. However, travertine dams are usually responsible for forming small water bodies within valleys in this area (Alexandrowicz, 1983, 2004, 2012; Alexandrowicz & Gołas-Siarzewska, 2013). In the Pieniny Mountains, tufa of the discussed type occurs in: Tylka, Płaśnie, Klimontowski Stream, Kozłecki Stream, Ścigocki Stream, Homole Gorge, Skotnicki Stream and Czarny Skotnicki Stream (Fig. 1, Table 1). Although, in terms of age, they represent the whole Holocene (Homole Gorge – 9940±100 years P (9857 – 9246 cal BC; Gd 5272; Alexandrowicz 1996a, b, 1997a), but they most often correspond to the phases of intensity of mass movements during the Subboreal and Subatlantic Phases: Tylka: 3330±70 years BP (1772 – 1851 cal BC; Gd 5701); 535±30 years BP (1330 – 1430 cal AD; Gd 3197); Płaśnie: 680±80 years BP (1206 – 1423 cal AD; Gd 6268); Kozłecki Stream: 140±50 years BP (1670 – 1950 cal AD; Gd 5754); Ścigocki Stream: 640±50 years BP (1275 – 1404 cal AD; Gd 1807; 250±40 years BP

(1515 – 1805 cal AD; Gd 3095); Homole Gorge: 480±40 years BP (1298 – 1527 cal AD; Gd 5268); Skotnicki Stream: 3170±100 years BP (1686 – 1195 cal BC; Gd 2946) (Alexandrowicz, 1993a, 1996a, b, 1997a, 2004, 2009b, 2013a) (Fig. 3, Table. 2).

Type V – is the most common type of calcareous tufa occurrences both in the area of the Pieniny Mountains and in other terrains of the Polish part of the Carpathians (Mastella, 1975; Alexandrowicz, 1997b, 2004, 2009a, 2010; Mastella & Rybak-Ostrowska, 2012; Alexandrowicz et al., 2014). It includes tufa crusts and encrustations precipitated on pebbles and rocky outcrops within stream valleys (subtype Va), deposits of breccia type composed of rocky blocks held together by calcareous tufa (subtype Vb) and travertine covers (subtype Vc) (Fig. 2). From the malacological research point of view, the discussed type is not very interesting and prospective. The main reason is small thickness of deposits (several milimeter to maximum 10 cm) and the dominance of hard strongly lithified travertines, which practically makes the separation of shell material impossible. The only exception are small niches filled with loose varieties of tufa occurring sometimes within subtype Vc. Such deposits contain poor fauna and the dominating species and sometimes the only one is *Bythinella austriaca*. The discussed tufa is precipitated contemporarily and are found in: Szczawny Stream and Biała Woda Gorge (Figs 1, 3, Table 2).

4. DISCUSSION

4.1. Molluscan assemblages

On the basis of the conducted malacological analyses of material from calcareous tufa in the Pieniny Mountains, defining nine types of faunistic assemblages was possible. Separate assemblage types differ among each other in species composition and ecological structure. These features of them indicate environmental conditions prevailingin areas of calcareous tufa deposition and sometimes also stratigraphical position of deposits.

Assemblage with Vertigo substriata – is varied and rich malacocenosis, the characteristic feature is numerous occurrence of *Vertigo substraiata* along with other species with high ecological tolerance: *Perpolita hammonis*, *Punctum pygmaeum* and *Euconulus fulvus*. Also *Discus ruderatus* – a taxon typical of coniferous forests of the taiga type, usually occurs numerously. The occurrence of cold-loving forms such as: *Semilimax kotulae*, *Vertigo genesii*, *Vertigo geyeri*, and *Columella columella* being glacial relicts is also interesting. Assemblage with Vertigo substriata developed in slightly shaded habitats with high humidity in the conditions of cool, continental climate (Figs 4, 5). The discussed assemblage is characteristic of the Early Holocene, mainly for the Preboreal Phase and early part of the Boreal Phase (Fig. 6). Malacocenoses with similar composition and structure were noted in this stratigraphical position in many the Early Holocene profiles of calcareous tufa in the western and central Europe (e.g. Alexandrowicz, 1983, 1997c, 2004; Limondin-Lozouet & Rousseau 1991; Rousseau et al., 1994; Gedda, 2001, 2006; Meyrick, 2001, 2002; Meyrick & Precce, 2001; Limondin-Lozouet, 2011). This fauna is particularly frequently encountered in tufa in the area of the Podhale Basin (Alexandrowicz, 1997b, 2001b, 2003, 2004, 2013b; Alexandrowicz & Rybska, 2013; Alexandrowicz et al., 2014) Fauna with Vertigo substriata was recognised in: Homole Gorge: 9940±100 years BP; 9857 – 9246 cal BC; Gd 5272; Alexandrowicz (1996a, b, 1997a) and Ociemny Stream (Figs 3, 6 Table 3).

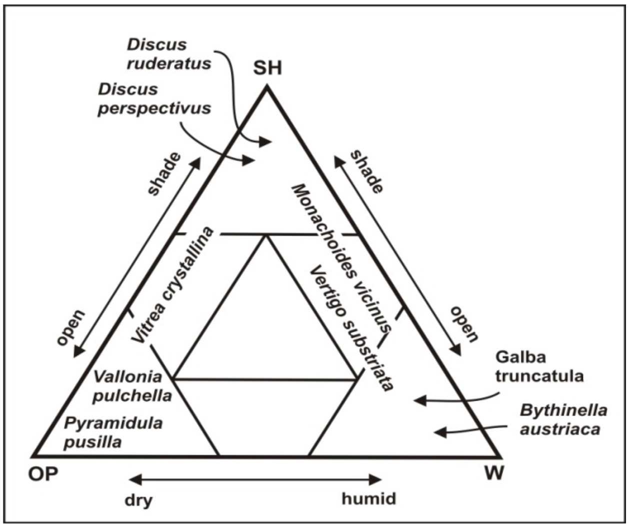

Figure 4. Ecological requirements of molluscan assemblages from profiles of calcareous tufa in Pieniny Mountains; Environments: SH. shade, OP. open, W. water.

Assemblage with Discus ruderatus – is rich malacocenosis with a large share of shade-loving species. Taxa preferring the relatively cool climate with evident continental influences: *Discus ruderatus*, *Eucobresia nivalis*, *Arianta arbustorum* accompanied by forms with higher ecological requirements: *Aegopinella pura*, *Discus rotundatus* occur commonly. The assemblage is completed with mesophilous species: *Vertigo substriata*, *Perpolita hammonis*, *Euconulus fulvus*. There are no cold-loving snails, except *Semilimax kotulae*, which is glacial relict. Fauna with Discus ruderatus represents forests areas, mainly coniferous forests with varied ground humidity (Figs 4, 5). The discussed fauna is characteristic of the Early Holocene and is connected mainly to the Boreal Phase and the beginning of the Atlantic Phase (Fig. 6). Fauna with Discus ruderatus was recognised in: Homole Gorge and Ociemny Stream (Table 3). Assemblage with Discus ruderatus corresponds to the characteristic of the Early Holocene *Ruderatus*-fauna (Dehm, 1967) and was described from many sites in the whole Europe (e.g. Ložek, 1964, 2000; Alexandrowicz, 1983, 1997c, 2004, 2015; Preece & Day, 1994; Alexandrowicz & Alexandrowicz, 1995a, b; Preece, 1998; Preece & Bridgland, 1999; Gedda, 2001, 2006; Žak et.al., 2002; Meyrick, 2002; Limondin-Lozouet & Preece, 2004; Limondin-Lozouet 2011; Alexandrowicz et al., 2014).

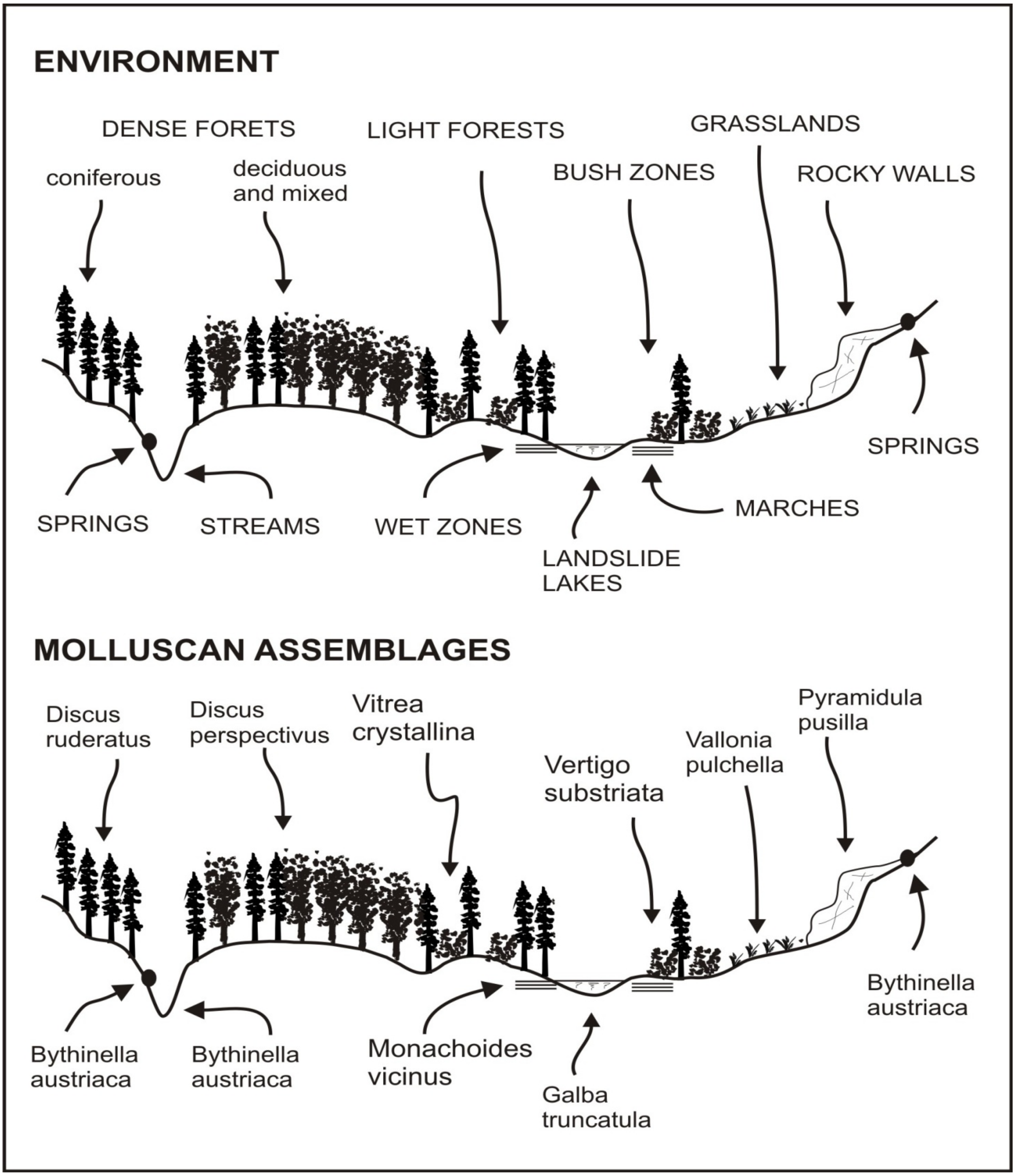

Figure 5. Habitats and molluscan assemblages from calcareous tufa in the Pieniny Mountains

Table 3. Environmental changes in Pieniny Mountains during Holocene

Molluscan assemblage	Climate	Environment	Stratigraphy	Radiocarbon datings	Locality
Galba truncatula	Moderate – recent	temporary water bodies	Subatlantic	1330 – 1430 cal AD; 1275 – 1404 cal AD; 1206 – 1423 cal AD	Tylka Płaśnie Ścigocki Stream
Bythinella austriaca		springs and sterams	Subatlantic	1496 – 1646 cal AD; 1515 – 1805 cal AD; 1670 – 1950 cal AD	Zawiasy Limbargowy Stream Tylka Płaśnie Skalski Stream Kozłecki stream Ścigocki Stream Kotłowy Gorge Pieniński Stream Krościenko Szczawny Stream Zakijowski Stream Krupianka Stream Jaworki-Homole Biała Woda Gorge
Vallonia pulchella		grasslands and cultivated areas	Subatlantic	1298 – 1527 cal AD; 1388 – 1499 cal AD; 1410 – 1491 cal AD	Skalski Stream Jaworki Homole Gorge Kąty Długi Gronik Grajcarek
Pyramidula pusilla		open rocky walls	Subatlantic	1697 – 1916 cal AD 1253 – 1431 cal AD;	Sobczański Gorge Limbargowy Gorge
Monachoides vicinus		humid forests, bush zones	Subatlantic	1650 – 1937 cal AD; 1398 – 1523 cal AD;	Zawiasy Gorczyński Gorge Jaworki Scigocki Stream Homole Gorge
Vitrea crystallina		dry light forests, bush zones	Subatlantic-Subboreal	1772 – 1851 cal BC; 1686 – 1195 cal BC; 1032 – 1235 cal AD; 444 – 661 cal AD	Tylka Płaśnie Klimontowski Stream Skotnicki Stream Macelowy Stream Pieniński Stream Czarny Skornicki Stream
Discus perspectivus	Warm, wet oceanic	dense mixed and deciduous forests	Altantic	5924 – 4847 cal BC	Homole Gorge Ociemny Stream Skalski Stream
Discus ruderatus	Moderate continental	dense coniferous forests	Boreal	-	Homole Gorge Ociemny Stream
Vartigo substriata		humid bush zones and marches	Preboreal-Boreal	9857 – 9246 cal BC	Homole Gorge Ociemny Stream

Assemblage with Discus perspectivus – is very rich malacocenosis characterised by very high share of shade-loving species which can constitute even 70% of the fauna. The most numerous are snails with high thermal and ecological requirements such as: *Discus perspectivus*, *Discus rotundatus*, *Aegopinella pura*, *Ruthenica filograna*. Mesophilous snails constitute a complement while forms typical of open and wet environments occur rarely. The discussed assemblage occurs in mixed or deciduous forests and indicates significant influences of oceanic air masses (Figs 4, 5). The discussed malacofauna represents the period of the Atlantic Phase (Fig. 6) and corresponds to the characteristic of the climatic optimum of the Holocene *Perspectivus*-Fauna (Dehm, 1987). Its presence was noted in: Skalski Stream, Homole Gorge and Ociemny Stream (Table 3). In the first one of the enumerated, deposits containing fauna with Discus perspectivus were dated: 6500±270 years BP (5924 – 4847 cal BC; Gd 9977) (Alexandrowicz, 2004) (Figs. 3, 6, Table 2). Similar malacocenoses related to the Atlantic Phase were described from many other sites of calcareous tufa (e.g. Ložek, 1964, 1972, 1982; Alexandrowicz, 1983, 1997c, 2004; Dehm, 1987; Füköh, 1995; Alexandrowicz & Alexandrowicz, 1995a, b; Meyrick, 2002; Alexandrowicz et al., 2014).

Assemblage with Vitrea crystallina – is malacocenosis in which shade-loving species occur, usually typical of sparse light-saturated forests and bushes. Numerous mesophilous snails, and also species of wet and open environments, constitute a complement. The discussed fauna represents relatively dry habitats with forest and bush patches (Figs 4, 5). This assemblage appears in deposits representing the Subboreal Phase: Tylka: 3330±70 years BP (1772 – 1851 cal BC; Gd 5701); Alexandrowicz, 2004, 2009b, 2013a) and Skotnicki Stream: 3170±100 years BP (1686 – 1195 cal BC; Gd 2946) (Alexandrowicz, 1993a, 1996a, b, 1997a) and the Subatlantic Phase: Macelowy Stream: 1460±30 years BP (444 – 661 cal AD; Gd 5112) and 900±50 years BP (1032 – 1235 cal AD; Gd 5259) (Alexandrowicz, 1990) (Fig. 6, Tab. 2). Apart from the enumerated, it was also found in: Płaśnie, Klimontowski Stream, Skotnicki Stream, Pieniński Stream and Czarny Skotnicki Stream: (Fig. 1, Table 3). Faunas with similar composition, structure and stratigraphical position are known from profiles of calcareous tufa in Podhale (Alexandrowicz, 1997b, 2001b, 2003; Alexandrowicz et al., 2014).

Assemblage with Monachoides vicinus – is malacocenosis characterised by frequent occurrence of shade-loving snails, preferring humid habitats (*Monachoides vicinus*, *Perforatella bidentata*). Numerous mesophilous (*Vertigo angustior*, *Carychium tridentatum*, *Cochlicopa lundica*) and hygrophilous (*Succinea putris*, *Zonitoides nitidus*, *Carychium minimum*), and sometimes also water taxa (*Galba truncatula*, *Bithinella austriaca*) constitute a complement of the assemblage. The discussed fauna is typical of shaded and wet bottoms of valleys (Figs. 4, 5) and appears in deposits of the Subatlantic Phase, mainly in areas with unfavourable from the human activity's perspective terrain conditions (Fig. 6, Tabs 2, 3). Assemblage with Monachoides vicinus was recognised in: Zawiasy, Gorczyński Gorge 140±70 years BP (1650 – 1937 cal AD; MKL 1351), Jaworki (450±50 years BP (1398 – 1523 cal AD; Gd 5107); Ścigocki Stream and Homole Gorge (Alexandrowicz, 2014) (Fig. 1, Tables 2, 3). Similar assemblages were repeatedly described from sites contemporarily precipitated calcareous tufa from the Carpathians area (Alexandrowicz, 1997b, 2004, 2009a, 2010; Alexandrowicz et al., 2014), as well as from fluvial deposits described from the terrain of the Podhale Basin (Alexandrowicz, 2013c).

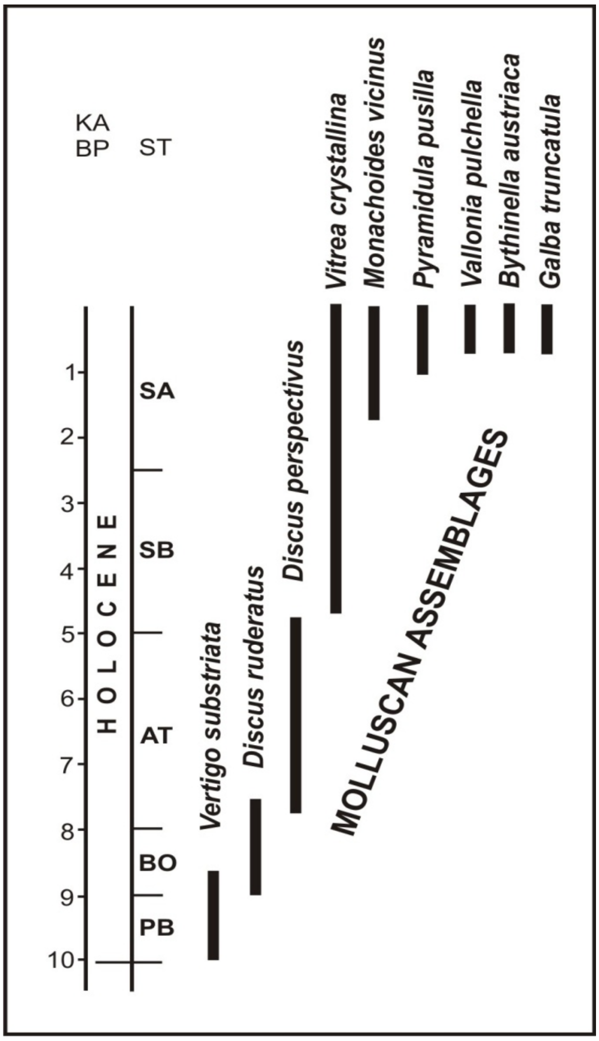

Figure 6. Startigraphical range of molluscan assemblages from profiles of calcareous tufa in the Pieniny Mountains ST. stratigraphical subdivision (after: Mangerud et al., 1974); for explanation see figure 2.

Assemblage with Vallonia pulchella – is poor malacocenosis, in which open-country taxa: *Vallonia pulchella*, *Vallonia costata*, *Pupilla muscorum*, complemented by mesophilous snails, have the biggest importance. Shade-loving and hygrophilous species are usually rare. The presence of *Ceciloides acicula* – a species living in soil and particularly willingly inhabiting zones of cultivated fields (Alexandrowicz et al., 1997; Alexandrowicz, 1997b, 2004; Alexandrowicz & Gołas-Siarzewska, 2013; Alexandrowicz, 2013c) is noted. The discussed assemblage is characteristic of open habitats strongly affected by human agricultural activity (Figs. 4, 5). Fauna with Vallonia pulchella is typical of the Subatlantic Phase and was found in: Skalski Stream, Jaworki, Homole Gorge (480±40 years BP (1298 – 1527 cal AD; Gd 5268), Kąty, Długi Gronik 480±50 years BP (1388 – 1499 cal AD; Gd 4253) and Grajcarek (450±35 years BP (1410 – 1491 cal AD; Gd 5287) (Alexandrowicz, 1996b, 2004, 2010) (Figs 1, 6, Tables 2, 3). Assemblages with similar composition were noted from many profiles of deposits accumulated in terrains subjected to agricultural human activity (Alexandrowicz et al., 1997; Alexandrowicz, 1997b, 2004, 2013c; Alexandrowicz & Rybska, 2013).

Assemblage with Pyramidula pusilla – the most important component of this fauna are petrophylous taxa inhabiting limestone rocks (*Pyramidula pusilla*, *Chondrina clienta*). Snails of open environments (*Vallinoa pulchella*, *Pupilla muscorum*) or species typical of more shaded habitats (*Argna bielzi*, *Cochlodina orthostoma*, *Pseudalinda stabilis*) can constitute the addition. *Bythinella austriaca* inhabiting spring zones also appears often (Figs. 4, 5) The discussed assemblage is characteristic of tufa of type I (Fig. 2) and, in terms of age, it is related to the Subatlantic Phase (Fig. 6) (radiocarbon dates: 620±80 years BP (1253 – 1431 cal AD; MKL 1352) and 60±30 years BP (1697 – 1916 cal AD; MKL 1350) (Alexandrowicz, 2014); (Tabs 2, 3). Assemblage with Pyramidula pusilla was recognised in: Sobczański Gorge and Limbargowy Gorge. Faunas with similar character were noted from occurrences of calcareous tufa and slope deposits accumulated at the rock walls in the area of the Tatras (Alexandrowicz, 2001a, 2004), Podhale (Alexandrowicz & Rudzka, 2006) and the Kraków-Częstochowa Upland (Alexandrowicz, 2000a, b).

Assemblage with Bythinella austriaca − is fauna characteristic of Subatlantic calcareous tufa noted from very numerous sites of these deposits in the Carpathians (Alexandrowicz, 1997b, 2001b, 2003, 2004, 2009a, 2010, 2013a, c). It's typical feature is numerous occurrence of stenotopic snail *Bythinella austriaca*, a share of which in the assemblage ranges from 60 – 90%, but can sometimes exceed 95%. The complement of the discussed malacocenosis is usually land species represented most frequently by hygrophilous forms of more open habitats: *Succinea putris* or more shaded habitats: *Perforatella bidentata*. Sometimes water molluscs, of which the most numerous is usually *Pisidium personatum*, constitute the important addition. The presented above association is typical of cool water with constant temperature (Figs. 4, 5). The presented fauna is the most typical malacocenosis of calcareous tufa related to the historical period (Fig. 6, Tables 2, 3). It was recognised in: Zawiasy (320±40 lat BP (1496 – 1646 cal AD; MKL 1353), Limbargowy Stream, Tylka, Płaśnie, Skalski Stream, Kozłecki Stream (140±50 years BP (1670 – 1950 cal AD; Gd 5754), Ścigocki Stream (250±40 years BP (1515 – 1805 cal AD; Gd 3095), Kotłowy Gorge, Pieniński Stream, Krościenko, Szczawny Stream, Zakijowski Stream, Krupianka Stream, Jaworki-Homole and Biała Woda Gorge (Fig. 1, Tab. 3). The discussed assemblage was repeatedly described from Subatlantic deposits in the southern Poland (Alexandrowicz et al., 1997, 2014; Alexandrowicz, 1997b, 2001b, 2003, 2004, 2009a, 2010, 2013a, c).

Assemblage with Galba truncatula – is fauna with high share of water species, especially forms typical of small, highly overgrown with reeds and temporary bodies of water: *Galba truncatula*, *Anisus calculiformis*. Molluscs characteristic of flowing waters *Bithynella austriaca*, *Pisidium personatum* are the frequent addition. Land snails are less numerous and represented mainly by hygrophilous and mesophilous forms. The discussed fauna is typical of deposits accumulated in small, shallow lakes formed as a result of damming valleys by coluvial barriers (Figs. 4, 5). Such deposits filling the small landslide lakes in the Pieniny Mountains are related to the Subatlantic Phase and were recognised in: Tylka (535±30 years BP (1330 – 1430 cal AD; Gd 3197); Płaśnie (680±80 years BP (1206 – 1423 cal AD; Gd 6268); and Ścigocki Stream: (640±50 years BP (1275 – 1404 cal AD; Gd 1807)) (Alexandrowicz, 1993a, 1996a, 1997a, 2009b, 2013a) (Figs. 1, 6, Tables 2, 3).

4.2. Environmental changes

The malacological analysis conducted in the sites of calcareous tufa occurring in the Pieniny Mountains enables to characterise environmental changes generated by natural factors (mainly climate) and in the historical period also by human activity. The majority of the presented sites are tufa formed during the Late Holocene, and only three (Homole Gorge, Ociemny Stream and Skalski

Stream) represent the Early and Middle Holocene (Fig. 3).

The occurrence of assemblage with Vertigo substriata is connected with the beginning of the Holocene (the Preboreal Phase). During this period, forests appeared in the area of the Pieniny Mountains. However, in many places, wet and poorly shaded environments remained (Table 3). Numerous occurrence of cold-loving forms: *Vertigo genesii*, *Vertigo geyeri*, *Columenlla columella* indicates cool climate, and the presence of *Vertigo substriata* and Discus ruderatus proves significant continental influences (Table 3). Fauna with Vertigo substriata was noted from sites of the Early Holocene deposits in the area of Podhale (Alexandrowicz, 1997b, 2004; Alexandrowicz et al., 2014) and also in numerous profiles in central and western Europe (e.g. Alexandrowicz, 1983, 1997c, 2004; Limondin-Lozouet & Rousseau 1991; Rousseau et al., 1994; Gedda, 2001, 2006; Meyrick, 2001, 2002; Meyrick & Precce, 2001; Limondin-Lozouet, 2011). It corresponds to the separated in the palynological profiles *Pinus phase* (Obidowicz, 1990). In the Boreal Phase, fauna with Vertigo substriata was gradually replaced by assemblage with Discus ruderatus characterised by a high share of snails typical of coniferous forests developing in cool, continental climate (Table 3). During this period, dense coniferous forests of the taiga type appeared in the area of the Pieniny Mountains. Such a dominating type of habitats is indicated by both features of the molluscan assemblage and very high frequency of tree pollen in palynological profiles (phases: *Corylus*, *Ulmus* and *Betula*) (Obidowicz, 1990). The discussed assemblage corresponds to the characteristic of the Early Holocene *Ruderatus*-fauna (Dehm, 1967) and was described from many sites in both southern Poland (Alexandrowicz, 1983, 1997c, 2004, 2015; Alexandrowicz & Alexandrowicz 1995a, b; Alexandrowicz et al., 2014) and other areas of Europe (e.g. Ložek, 1964, 2000; Preece & Day, 1994; Preece, 1998; Preece & Bridgland, 1999; Gedda, 2001, 2006; Žak et.al., 2002; Meyrick, 2002; Limondin-Lozouet & Preece, 2004; Limondin-Lozouet, 2011). The climatic optimum of the Holocene (the Atlantic Phase) is the period of the maximum development of forest communities in the Pieniny Mountains (palynological phases: *Ulmus*-*Tilia*-*Quercus*-*Fraxinus* and *Corylus* in the peatbogs of Podhale; Obidowicz, 1990). Rich forest communities with a large share of deciduous trees with high ecological environments developed in conditions of warm and wet climate with significant oceanic influences. The occurrence of malacofauna with the dominance of forest shade-loving species (assemblage with Discus perspectivus) is characteristic of this period (Table 3). Similar malacocenoses corresponding to *Perspectivus*-fauna (Dehm, 1987) were described from many other sites of calcareous tufa (e.g. Ložek, 1964, 1972, 1982; Alexandrowicz, 1983, 1997c, 2004; Dehm, 1987; Füköh, 1995; Alexandrowicz & Alexandrowicz, 1995a, b; Meyrick, 2002; Alexandrowicz et al., 2014). Deterioration of climatic conditions in the Subboreal Phase was the main cause of limiting tempo or stopping of calcareous tufa sedimentation. (e.g. Ložek, 1964; Jäger and Ložek, 1968; Alexandrowicz, 1983, 1997b, c, 2004; Pazdur, 1987; Pazdur et al., 1988a, b; Dobrowolski et al., 2005, 2012; Alexandrowicz & Rybska 2013). Climatic phenomena caused also reduction of species spreading and diversity of forest communities (phases: *Fagus*-*Abies*, *Carpinus*-*Abies* and *Picea*; Obidowicz, 1990) Calcareous tufa corresponding to the discussed phase contains poor and not very diverse assemblage with Vitrea crystallina (Table 3). During the Subatlantic Phase climatic changes coincided with human activity. This led to important environmental changes and consequently to a strong differentiation of molluscan assemblages (Table 3). In older part of the Subatlantic Phase in the terrain of Podhale forest communities still prevailed (phases: *Carpinus*-*Abies*-*Fagus* and *Fagus*-*Abies*; Obidowicz, 1990). Their species diversification and spread gradually decreased during the discussed phase. This phenomenon can be indirectly connected with the progressing human impact. It has manifested itself to a lesser degree in areas of flat slopes and broad river valleys. In zones less favourable for human economy, shaded environments inhabited by diverse molluscan assemblages dominated. The presence of fauna with Monachoides vicinus is characteristic in habitats with higher humidity, assemblage with Vitrea crystallina occurred in more dry sites, malacocenosis with Bythinella austriaca - in narrow valleys and in source zones, and fauna with Pyramidula pusilla developed in exposed rocky walls. Evident human influence manifests itself in the terrain of the Pieniny Mountains since XII-XIIIth century (Jaguś et al., 2006). The introduction of pastoral and agricultural economy was a important cause of significant environmental changes generated mainly by deforestation. In palynological profiles of the Podhale peatbogs, the manifestation of these processes is the rapid increase in the share of pollen of herbaceous plants, including also cultivated ones and the accompanying significant decrease in the frequency of tree pollen (the NAP phase; Obidowicz, 1990). In the areas subjected to strong anthropogenic impact, tufa appears very rarely and usually contains poor assemblage with species of open environments (fauna with Vallonia pulchella) (Table 3). Related malacocenoses are commonly found in profiles of subatlantic fluvial deposits described from the Podhale Basin (Alexandrowicz, 1997b, 2013c) and the Pieniny Mountains (Alexandrowicz 1990, 1993b). Small, shallow, periodical lakes related to landslide zones are the specific and occurring locally type of habitats. They are inhabited by assemblage with Galba truncatula (Table 3). The research on the development of mass movements conducted in the terrain of the Pieniny Mountains indicates the existence of several phases of their intensity possible to correlate with the periods of climatic fluctuations in the period of the last several hundred years (Alexandrowicz 1993a, 1996a, 1997a, 2013a).

5. CONCLUSIONS

In profiles of calcareous tufa recognised in the Pieniny Mountains, rich and diverse molluscan assemblages occurred. The malacological analysis based on rich material enables to conduct reconstruction of environmental changes of this area in the period from the Holocene until contemporary times. The characterised succession of faunistic assemblages manifests many common features with similar reconstructions conducted in neighbouring areas, mainly of the Podhale Basin. This indicates the existence of regional climatic trends which are the main and most important factor deciding on environmental conditions. This regional trends coincide with local factors, and additionally, also with human activity manifesting itself during the last several hundred years.

The succession of molluscan assemblages recognised in calcareous tufa occurring in the Pieniny Mountains indicates the progressing forestation of the area during the Early Holocene and relatively cool, continental climate. As the climate conditions improved and the importance of oceanic air masses increased, these forest communities were enriched by deciduous tree species with higher ecological requirements. In the Middle Holocene, the Pieniny Mountains was covered by mixed and deciduous trees. From the Subboreal Phase, impoverishment of forest environments marks itself. In the Subatlantic Phase, as a result of increasing human impact and deforestation related to it, there was strong diversification of environments. Flat areas were taken for cultivation or pastures, while narrow valleys and more steep slopes largely retained their natural forest character. A similar trend of environmental changes generated by climatic fluctuations and human activity is noted also in the Podhale Basin (Alexandrowicz, 1997b, 2013c; Alexandrowicz et al., 2014) and in the upland areas (Alexandrowicz, 1983, 1997c, 2004; Alexandrowicz & Gołas-Siarzewska, 2013).

On the basis of the conducted research it can be stated that the Holocene malacological succession described in the Pieniny Mountains demonstrates many similarities to the succession of the described from the neighbouring geographical regions (Podhale Basin and the Flysch Carpathians). This proves the existence of common for these areas trends of climatic changes and history of their inhabitation by human. There are, however, several differences resulting from the local conditions. The first of them is observed in the Pieniny Mountains smaller amount of calcareous tufa sites representing the Early and Middle Holocene. Explanation of this observation is difficult, given the particularly favourable conditions of calcareous tufa deposition in the Pieniny Mountains (ground very rich in calcium carbonate, relatively mild microclimate, a large number of surface water courses, numerous sources including also natural outflows of mineral waters of acidic type). Probably the most important factor responsible for this situation are the terrain conditions, mainly the presence of narrow and steep valleys and intensive erosion activity of streams. Calcareous tufa, and particularly their loose varieties, which are the main subject of the malacological research, are easily subjected to destruction, which to a large extent hinders their preservation over longer periods of time. This conclusion seems to confirm very numerous occurrence of tufa related to the period of the last several hundred years or precipitated contemporarily with almost total absence of older deposits. Another important difference is the observed in malacocenoses related to the Early Holocene fast disappearance of shade-loving species (*Semilimax kotulae, Vertigo genesii*, *Vertigo geyeri*, *Columella columella*), which practically already do not occur in deposits of the Boreal Phase. The above mentioned forms in the Podhale Basin and the Flysch Carpathians are common in formations of the Early Holocene, they also appear in deposits of the Atlantic Phase, and sometimes even in deposits deposited contemporarily (*Semilimax kotulae*). This phenomenon is most probably related to relatively milder and slightly warmer microclimate of the Pieniny Mountains in comparison to the neighbouring areas.

Human impact in the Pieniny Mountains manifests itself, like in Podhale Basin and in the Flysch Carpathians only within the last several hundred years (from the XII-XIIIth century) (Jaguś et al., 2006), significantly later than in the upland areas

(Alexandrowicz et al., 1997). It was unevenly distributed and led to large diversification of environments. The varied terrain conditions were the decisive factor. The important human impact manifested itself in mild slopes and in broad valleys. In narrow valleys and on steep slopes the effect of human activity on environmental conditions is still relatively small.

Acknowledgements

This study has been sponsored by AGH University of Science and Technology through the University grant no 11.11.140.173.

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Received at: 10. 06. 2015
Revised at: 19. 09. 2015
Accepted for publication at: 25. 09. 2015
Published online at: 01. 10. 2015