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MOLLUSCAN ASSEMBLAGES OF RECENT CALCAREOUS TUFAS IN THE PODHALE BASIN AND PIENINY MTS (S. POLAND)

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ABSTRACT: Recently precipitated travertines and calcareous tufas occur commonly in the Podhale Basin and Pieniny Mts. They contain more or less rich subfossil mollusc assemblages which were analysed in 73 samples collected from 43 localities. Seven types and two subtypes of assemblages were distinguished, according to their structure and species composition, depending closely on the local ecological conditions. The whole material comprised 74 species. Only one of them – *Bithynella austriaca* (Frauenfeld) – was found in many profiles and in substantial numbers, while the remaining species were rare. Malacological investigations of Late Holocene and recent calcareous tufas enable a reconstruction of conditions in which such deposits are formed, and determining the diversity of mollusc assemblages associated with the differentiation of the sedimentary environment. They are also useful for actuopalaeontological analysis which is important for palaeogeographic and palaeoecological interpretations of Holocene and Late Glacial calcareous deposits of southern Poland.

KEY WORDS: calcareous tufa, travertine, Late Holocene, molluscan assemblages, Podhale Basin, Pieniny Mts

INTRODUCTION

Calcareous tufa belongs to the most characteristic types of interglacial sediments. In Poland it was deposited mainly during the Late Glacial and Holocene. In several geographical regions, especially in the Carpathians and Middle Polish Uplands, accumulation of fresh-water calcareous sediments can be observed also recently. These deposits result from precipitation of calcium carbonate from water, stimulated by physico-chemical or biological processes, but most often as a combination of both. Most localities with Early/Middle Holocene calcareous tufa and with Late Glacial tufa have been studied in detail using lithological, palaeontological and isotopic methods. Results of these investigations have been published by numerous authors (for references see S. W. ALEXANDROWICZ 1983, W. P. ALEXANDROWICZ 2004). On the other hand, the youngest sediments, deposited during the historical period (mainly the last 500 years) and/or recently formed, have not been investigated in detail till now. Most localities of these sediments were found mainly during the geological mapping and investigations of tectonic structures (MASTELLA 1975, GRUSZCZYŃSKI & MASTELLA 1986).

Calcareous tufas show a high diversity controlled by different depositional processes. Two main lithological types can be distinguished. There are hard, strongly porous fresh-water limestones (travertines) and granular calcareous tufa composed of blocks of travertines, calcareous sand, mud and clay. In several localities calcareous sediments are accompanied by alluvial sands and muds, slope deposits and peat. Five types of occurrence of such sediments can be distinguished. One includes calcareous encrustations on pebbles and on base-rock, calcareous clusters, calcareous encrustations on plants and calcareous covers. The second comprises sediments deposited in small, sometimes temporary water bodies with rich vegetation. Calcareous tufa accumulated on terraces or flat slopes represents the third type. The fourth includes calcareous fans deposited on steep slopes near springs or at the base of rock faces. Travertine and grained calcareous deposits accumulated near water-

falls constitute the last type (GRUSZCZYŃSKI & MASTELLA 1986).

In the Pieniny Mts. and the Podhale Basin hard, strongly porous travertines are most common but in numerous localities granular tufas are also found. The latter contain more or less rich and diverse mollusc assemblages.

MATERIAL AND METHODS

Most calcareous tufas of the Podhale Basin and Pieniny Mts are developed as hard travertines and thin (1–5 cm) encrustations or calcareous covers. However, during the field work, granular mollusc-bearing sediments were found in 43 localities (Fig. 1, Table 1). The whole analysed material included 74 samples; they were washed to select all identifiable mollusc shells and their fragments. Species identification was based on monographs, keys and comparative collections. The frequency was expressed as the number of complete shells and shell fragments, recalculated according to the scheme proposed by LOŽEK (1964) and S. W. ALEXANDROWICZ (1987, 1999). More than 8,200 specimens of 74 snail and bivalve species were identified (68 land snails, 4 water snails, 2 bivalves).

Standard methods of malacological analysis (LOŽEK 1964, S. W. ALEXANDROWICZ 1987, 1999) were applied. Each taxon was assigned to one of five ecological groups: F – shade-loving, forest and shrubland species, O – open-country species of habitats with varied humidity (meadow, bare rocks, xerothermic), M – mesophile, species of high ecological tolerance (mesophile, catholic), H – hygrophile snails and W – aquatic species (of ephemeral and permanent freshwaters). The results of ecological analysis were presented as triangular diagrams which made it possible to distinguish seven types and two subtypes of molluscan assemblages. The taxonomic diversity index (TDI; S. W. ALEXANDROWICZ 1987) was calculated for each sample. Indices of constancy and dominance (C-D) as well as normalised index of constancy (C_i) and dominance (D_i) were also calculated (S. W. ALEXANDROWICZ 1987, 1999). Zoogeographical classification of the fauna followed LOŽEK (1964), KÖRNIG (1966) and S. W. ALEXANDROWICZ (1987, 1999).

LOG DESCRIPTION

During field work fourteen localities of recently precipitating mollusc-bearing calcareous tufa were found in the Podhale Basin (MP-1–MP-14) and twenty nine localities – in the Pieniny Mts (MP-15–MP-43) (Fig. 1, Table 1). Some localities described below had been tentatively mentioned by HALICKI & LILPOP (1932), URBAŃSKI (1932), MASTELLA (1975), S. W. ALEXANDROWICZ (1984a, b), W. P. ALEXANDROWICZ (1997, 2001, 2003, 2004) and others.

Dzianisz (MP-1) – calcareous cover formed of hard, white travertines, found in the terrace bank of the Kijów Stream, the left bank tributary of the Dzianisz Stream in Dzianisz village (Fig. 1). Calcareous tufa with numerous travertine blocks was found in a small niche. A single sample (Mp-1) contained a poor mollusc assemblage (8 species and 78 specimens). The fauna was dominated by water taxa: *Bithynella austriaca* (Frauenfeld) and *Pisidium personatum* Malm (Table 1).

Ostrysz (MP-2) – recently accumulated calcareous tufa forming a small fan near a spring in the middle part of northern slopes of the Ostrysz Hill (Fig. 1). This fan was twenty centimetres thick and built of coarse- and fine-grained calcareous sediment with small fragments of strongly porous, white travertines. Two samples (Mp-2 and Mp-3) contained a relatively rich fauna, composed of 22 species and 893 specimens (Table 1). *Bithynella austriaca* (Frauenfeld) clearly prevailed, constituting more than 90% of specimens. The large exposure of Late Glacial, Early and Middle Holocene calcareous tufa, situated in the upper part of this slope, has been described in detail by W. P. ALEXANDROWICZ (1997, 2001).

Gliczarów (MP-3) – young calcareous sediments accumulated near a small waterfall about 50 m below the road from Czarny Dunajec to Lower Gliczarów (Fig. 1). They were developed as yellowish-gray granular tufa, about 30 cm thick, consisting of numerous travertine blocks and underlain by a single layer of white, hard travertine. Four samples (Mp-3–Mp-7) were collected in this locality (Table 1). Each contained a poor fauna with many shells of *Bithynella austriaca* (Frauenfeld). This dominant species was accompanied by snails of moist, more or less shady habitats (*Carychium minimum* O. F. Müller, *Zonitoides nitidus* (O. F. Müller), *Perforatella vicina* (Rossmässler)), as well as by catholic species (*Cochlicopa lubrica* (O. F. Müller) and *Euconulus fulvus* (O. F. Müller)). In all, 19 taxa and 371 shells were found in the locality (Table 1). The main exposure of Late Glacial, Early and Middle Holocene calcareous tufa in Gliczarów has been described by several authors (HALICKI & LILPOP

1932, URBAŃSKI 1932, PAZDUR 1987, W. P. ALEXANDROWICZ 1997, 2003 and others) is situated about 100 m higher, on the slope of the Gliczarowski Wierch.

Czarna Góra (MP-4) – coarse-grained calcareous tufa with blocks of hard travertines, forming an irregular lens within alluvial gravel and sand. The described locality is situated on the flat part of the landslide developed on the western slope of Czarna Góra near Białka Tatrzańska (Fig. 1). A single sample (Mp-8) contained more than 200 shells representing 18 species (Table 1). The fauna was dominated by two groups of molluscs: shade-loving taxa preferring more or less moist habitats: *Vestia gulo* (E. A. Bielz), *Perforatella vicina* (Rossmässler), *Vitrea diaphana* (Studer), *Vitrea crystallina* (O. F. Müller), and numerous specimens of *Bithynella austriaca* (Frauenfeld), accompanied by single shells of *Galba truncatula* (O. F. Müller).

Trybsz (MP-5) – calcareous encrustations precipitated on the moss near a spring situated on the lower terrace of the Trybska River in Trybsz village (Fig. 1). A poor mollusc assemblage (3 species and 111 specimens), composed exclusively of water species, mainly *Bithynella austriaca* (Frauenfeld) and *Pisidium personatum* Malm, was found there (sample Mp-9) (Table 1).

Łapsze Wyżne (MP-6) – calcareous cover with several niches filled by granular calcareous tufa, located near a small spring on the eastern slope of the Bliźna Hill. Its mollusc assemblage was relatively rich and contained 16 species represented by 125 specimens (sample Mp-10). *Bithynella austriaca* (Frauenfeld) was the most important component of this fauna. Hygrophile and mesophile taxa completed the assemblage, while shade-loving ones were few (Table 1). The locality was first mentioned by W. P. ALEXANDROWICZ (1997).

Łapszanka (MP-7) – granular calcareous tufa and two layers of hard, porous travertines located within sediments forming the lower terrace of the Łapszanka Stream (Fig. 1). The fauna included 15 species and nearly 200 specimens (sample Mp-11). Water molluscs (*Bithynella austriaca* (Frauenfeld) and *Pisidium personatum* Malm), snails inhabiting forests (*Perforatella vicina* (Rossmässler), *Aegopinella pura* (Alder)) and catholic taxa (*Cochlicopa lubrica* (O. F. Müller)) were the main components of this assemblage (Table 1).

Stawiska (MP-8) – fine- and coarse-grained calcareous tufa abounding in blocks of hard travertines, developed as a fan on the flat surface of the lower terrace of the Kacwiński Stream valley, near the southern border of the Stawiska hamlet (Fig. 1). The thickness of this fan is up to 50 cm, and the calcareous sediments are underlain by alluvial gravel. In two samples (Mp-12 and Mp-13) a very rich and diverse mollusc assemblage (total of 38 species and nearly 1,000 specimens) was found (Table 1). Water molluscs: *Bithynella austriaca* (Frauenfeld), *Pisidium personatum* Malm, *Galba truncatula* (O. F. Müller) and mesophile snails: *Cochlicopa lubrica* (O. F. Müller), *Euconulus fulvus* (O. F. Müller), *Punctum pygmaeum* (Draparnaud), and some other taxa were the most important ecological groups of this fauna. Forest and shade-loving snails: *Acicula polita* (Hartmann), *Eucobresia nivalis* (Dumont et Mortillet) and hygrophile species – *Carychium minimum* (O. F. Müller) supplemented this assemblage. Single shells of open-country meadow species: *Pupilla muscorum* (Linnaeus) and *Vallonia pulchella* (O. F. Müller), were also noted. This locality was first described by W. P. ALEXANDROWICZ (1997).

Łapsze Niżne (MP-9) – calcareous encrustations on moss, precipitating near a spring situated on a low terrace of a small stream close to the outlet to the Łapszanka river on the eastern border of the village Łapsze Niżne (Fig. 1). Quite a poor fauna (4 species, 43 shells), clearly dominated by *Bithynella austriaca* (Frauenfeld), was found in the single sample (Mp-14) collected in this locality (Table 1).

Kacwin I (MP-10) – calcareous cover with niches filled by granular calcareous tufa was found near the lower waterfall in the Kacwinka Stream valley (Fig. 1). In the single sample (Mp-15) only four species and 68 specimens were found, forming an assemblage with more then 90% of *Bithynella austriaca* (Frauenfeld) (Table 1).

Kacwin II (MP-11) – calcareous encrustations on plants near the upper waterfall in the Kacwinka Stream valley (Fig. 1). A poor molluscan assemblage (4 species and 28 specimens) found in this place was quite similar to the one described above (sample Mp-16) (Table 1).

Niedzica (MP-12) – coarse-grained calcareous tufa with large fragments of hard travertines, deposited in a small stream valley in the eastern part of the Niedzica village (Fig. 1). Two samples (Mp-17 and Mp-18) contained a relatively rich fauna (23 taxa and 141 specimens) (Table 1). Shade-loving species: *Vitrea subrimata* (Reinhardt), *Perforatella incarnata* (O. F. Müller), *Isognomostoma isognomostoma* (Schröter) and few others were the most important components of this assemblage. Mesophile and hygrophile species as well as water molluscs completed the fauna. A profile of Middle Holocene calcareous tufa containing a very rich fauna with forest snails, located about 100 m west of this site, was described by W. P. ALEXANDROWICZ (1997).

Niedzica Majerz (MP-13) – fine-grained calcareous tufa, accumulated in the middle part of southern slopes of the Majerz Hill, close to the spring in a small and much vegetated kettle (Fig. 1). A poor fauna (6 taxa and 22 specimens) dominated by hygrophile species: *Zonitoides nitidus* (O. F. Müller) and *Succinea putris* (Linnaeus) was found in a single sample (Mp-19) (Table 1).

Falsztyn (MP-14) – granular calcareous tufa with few fragments of hard travertines and numerous blocks of limestones, forming a fan at the foot of rock face of the Patria Rocky Hill in Falsztyn (Fig. 1). Two collected samples (Mp-20 and Mp-21) contained a very rich and diverse mollusc fauna (35 taxa and more than 350 specimens) (Table 1). Shade-loving species: *Vitrea crystallina* (O. F. Müller), *V. diaphana* (Studer), *Aegopinella pura* (Alder), *Arianta arbustorum* (Linnaeus), *Perforatella incarnata* (O. F. Müller) and many others were the main components of this assemblage. Catholic species: *Nesovitrea hammonis* (Ström), *Cochlicopa lubrica* (O. F. Müller) and *Carychium tridentatum* (Risso), constituted the second most important group, while hygrophile and water species occurred rarely.

Czorsztyn (MP-15) – granular calcareous tufa 10 cm thick cropping out close to the spring near the Czorsztyn castle (Fig. 1). A poor molluscan fauna (11 taxa and 65 specimens) with numerous shells of *Bithynella austriaca* (Frauenfeld) accompanied by catholic snails was found in sample Mp-22 (Table 1).

Harcygrunt (MP-16) – calcareous tufa found by S. W. ALEXANDROWICZ (1984a) in the Harcygrunt Stream valley near a spring at the foot of the large landslide (Fig. 1). In one sample (Mp-23) shells representing all ecological groups of molluscs (13 species but only 25 specimens) were found (Table 1).

Limbargowy Stream (MP-17) – coarse-grained calcareous tufa forming a layer about 20 cm thick, distinguished in top part of the lower terrace in the Limbargowy Stream valley. Its mollusc assemblage (13 species, 123 specimens) found in two samples (Mp-24, Mp-25) was dominated by forest snails: *Trichia unidentata* (Draparnaud), *Perforatella vicina* (Rossmässler), *Arianta arbustorum* (Linnaeus) as well as by catholic species (*Cochlicopa lubrica* (O. F. Müller), *Euconulus fulvus* (O. F. Müller) and *Nesovitrea hammonis* (Ström)) (Table 1).

Kąty (MP-18) – fine-grained calcareous tufa in a small marsh, strongly overgrown by plants. This marsh is situated near a spring, on the flat surface of the lower terrace (Fig. 1). In two samples (Mp-26, Mp-27) collected here, a rich and diverse molluscan

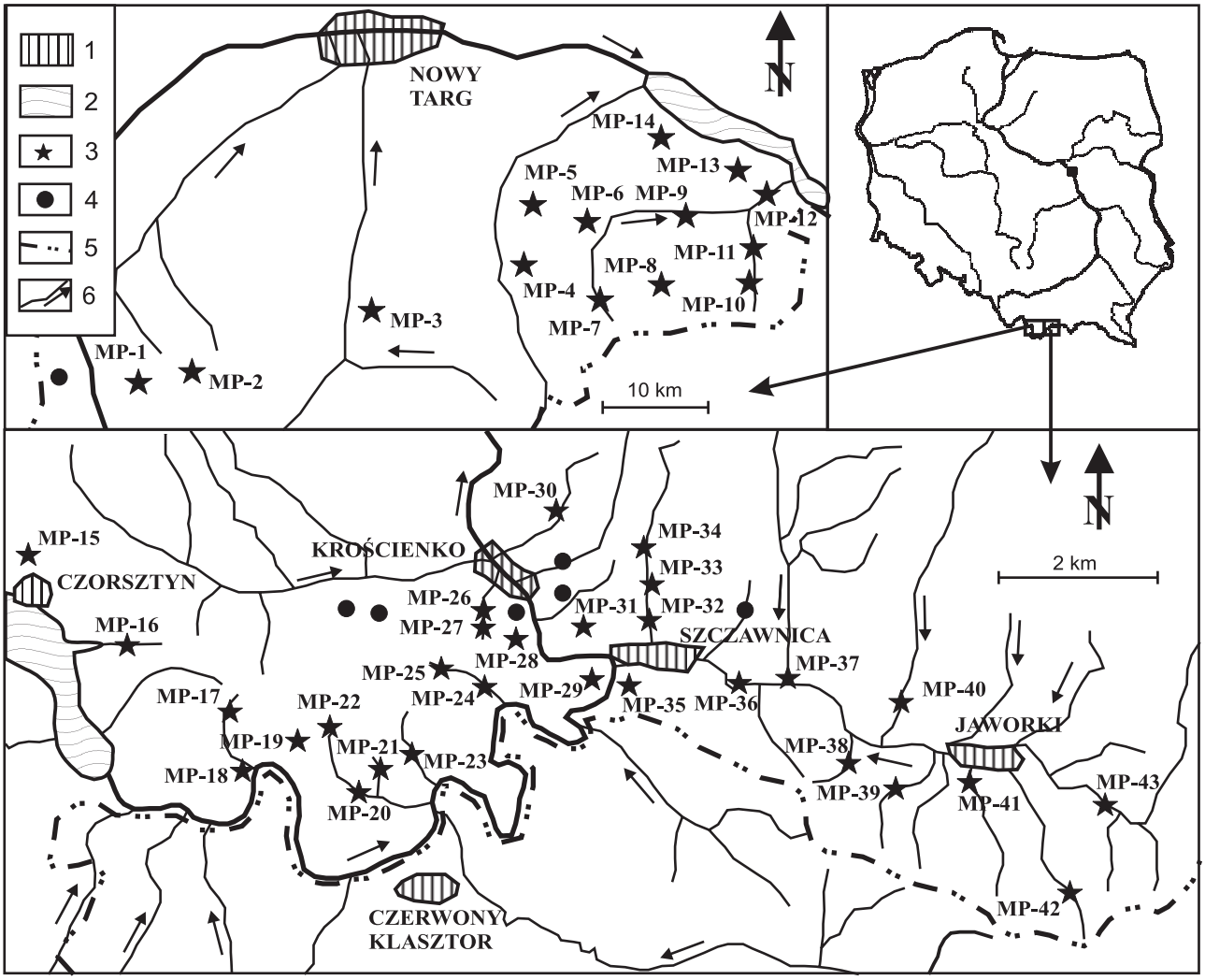

Fig. 1. Localisation of profiles of Upper Holocene calcareous tufa in Podhale Basin and Pieniny Mts. 1 – towns and villages, 2 – Czorsztyn dam lake, 3 – main sites, 4 – supplementary sites, 5 – state border, 6 – rivers and streams

Table 1. Profiles of Upper Holocene calcareous tufa in Podhale Basin and Pieniny Mts. N_{tax} – number of taxa, N_{spec} – number of specimens

	Locality	Samples	N_{tax}	N_{spec}
MP-1	Dzianisz	Mp-1	8	78
MP-2	Ostrysz	Mp-2, Mp-3	22	893
MP-3	Gliczarów	Mp-4 – Mp-7	19	371
MP-4	Czarna Góra Hill	Mp-8	18	206
MP-5	Trybsz	Mp-9	3	111
MP-6	Łapsze Wyżne	Mp-10	16	125
MP-7	Łapszanka	Mp-11	15	196
MP-8	Stawiska	Mp-12, Mp-13	38	997
MP-9	Łapsze Niżne	Mp-14	4	43
MP-10	Kacwin I	Mp-15	4	68
MP-11	Kacwin II	Mp-16	4	28
MP-12	Niedzica	Mp-17, Mp-18	23	141
MP-13	Majerz	Mp-19	6	22
MP-14	Falsztyn	Mp-20, Mp-21	35	352
MP-15	Czorsztyn	Mp-22	11	64
MP-16	Harcygrunt	Mp-23	13	25
MP-17	Limbargowy Stream	Mp-24, Mp-25	13	123
MP-18	Kąty	Mp-26, Mp-27	34	424
MP-19	Straszny Stream	Mp-28 – Mp-30	12	42
MP-20	Macelowy Stream	Mp-31	20	103
MP-21	Kotłowy Gorge	Mp-32, Mp-33	13	151
MP-22	Gorczyński Gorge	Mp-34	18	159
MP-23	Sobczański Gorge	Mp-35	9	71
MP-24	Pieniński Stream I	Mp-36, Mp-37	23	241
MP-25	Pieniński Stream II	Mp-38, Mp-39	8	167
MP-26	Krościenko Toporzyska I	Mp-40, Mp-41	17	70
MP-27	Krościenko Toporzyska II	Mp-42, Mp-43	17	65
MP-28	Ociemny Stream	Mp-44	22	273
MP-29	Długi Gronik	Mp-45 – Mp-48	22	288
MP-30	Szczawny Stream	Mp-49, Mp-50	11	227
MP-31	Zakijowski Stream	Mp-51, Mp-52	23	226
MP-32	Skotnicki Stream I	Mp-53, Mp-54	19	86
MP-33	Skotnicki Stream II	Mp-55, Mp-56	19	43
MP-34	Skotnicki Stream III	Mp-57 – Mp-59	25	316
MP-35	Głęboki Stream	Mp-60	10	83
MP-36	Grajcarek Stream I	Mp-61 – Mp-63	29	181
MP-37	Grajcarek Stream II	Mp-64, Mp-65	14	95
MP-38	Pałkowski Stream	Mp-66	4	83
MP-39	Krupianka	Mp-67, Mp-68	27	133
MP-40	Szlachtowa	Mp-69, Mp-70	10	130
MP-41	Homole Gorge	Mp-71, Mp-72	29	308
MP-42	Zaskale	Mp-73	5	174
MP-43	Biała Woda Gorge	Mp-74	14	364

assemblage with 34 species and 424 specimens was found. Hygrophile taxa, mainly *Succinea putris* (Linnaeus), were the most important components of the fauna. Water molluscs, represented by *Bithynella austriaca* (Frauenfeld) and *Galba truncatula* (O. F. Müller), catholic taxa like *Nesovitrea hammonis* (Ström), *Cochlicopa lubrica* (O. F. Müller) and forest snails: *Vitrea subrimata* (Reinhardt), *Isognomostoma isognomostoma* (Schröter) and *Chilostoma faustinum* (Rossmässler), were also numerous. Single shells of meadow species were present (Table 1).

Straszny Stream (MP-19) – travertine cover with small niches filled by granular calcareous tufa containing fragments of travertines, cropping out near the spring in the middle part of the Straszny Stream valley (Fig. 1). A poor mollusc fauna (12 species and 42 specimens) was found in three samples (Mp-28, Mp-29 and Mp-30). Mesophile snails represented mainly by *Succinea oblonga* Draparnaud were the most important components of the assemblage; they were accompanied by water molluscs and shade-loving species (Table 1).

Macelowy Stream (MP-20) – thin lens of granular calcareous tufa cropping out close to the small spring in the lower course of the Macelowy Stream valley (Fig. 1). Relatively rich fauna (20 taxa and more than 100 specimens) was found in a single sample (Mp-31). Water species: *Bithynella austriaca* (Frauenfeld.) and *Galba truncatula* (O. F. Müller) as well as snails living in moist habitats: *Carychium minimum* O. F. Müller, *Vertigo antivertigo* (Draparnaud) were the main components of the assemblage, while specimens of the remaining ecological groups were few (Table 1). Several metres downstream from this locality, a Late Holocene calcareous mollusc-bearing tufa, radicarbon-dated at 1,430±60 (Gd-5112) and 900±50 (Gd-5259) years BP was described by S. W. ALEXANDROWICZ (1990).

Kotłowy Gorge (MP-21) – a small outcrop of coarse-grained calcareous tufa with numerous blocks of hard travertines and angular fragments of limestones was found near a spring in the upper part of the Kotłowy Gorge (Fig. 1). In two samples (Mp-32 and Mp-33) a poor fauna of molluscs (13 taxa, 151 specimens) was found (Table 1). The high proportion of water snails: *Bithynella austriaca* (Frauenfeld) and *Galba truncatula* (O. F. Müller), was the most characteristic feature of this assemblage, while species of the remaining ecological groups were represented occasionally.

Gorczyński Gorge (MP-22) – calcareous cover with numerous blocks of limestones cropping out in the uppermost part of the Gorczyński Gorge (Fig. 1). Sample Mp-34 contained a rich fauna (18 species and 159 specimens) dominated by water molluscs, mainly *Bithynella austriaca* (Frauenfeld) and *Pisidium personatum* Malm. Snails typical of shaded habitats, like *Vitrea diaphana* (Studer) and *Perforatella vicina* (Rossmässler) were additional components of the fauna, while the remaining ecological groups were subordinate (Table 1). This locality was first noted by S. W. ALEXANDROWICZ (1984b).

Sobczański Gorge (MP-23) – small fan of recently accumulated sediments situated at the foot of the rock face in the Sobczański Gorge close to its gate. The fan was composed of fine-grained calcareous tufa abounding in limestone fragments (Fig. 1). A poor fauna (9 species and 71 specimens) with numerous shells of *Bithynella austriaca* (Fauenrfeld) was found in sample Mp-35 (Table 1). Other localities of young calcareous tufa in the Sobczański Gorge were described by S. W. ALEXANDROWICZ (1984b, 1988), S. W. ALEXANDROWICZ et al. (1985) and W. P. ALEXANDROWICZ (2004).

Two localities of granular calcareous tufa are known in the Pieniński Stream valley. One of them – Pieniński Stream I (MP-24), a layer of granular calcareous tufa with irregular fragments of travertines and limestones 15 cm thick, was found near a spring in the middle part of the Pieniński Stream valley (Fig. 1). Two samples taken one below another (Mp-36, Mp-37) yielded a relatively rich fauna – 23 species and almost 250 specimens (Table 1). In the lower sample (Mp-35) a high proportion of shade-loving species: *Isognomostoma isognomostoma* (Schröter), *Perforatella vicina* (Rossmässler), *Arianta arbustorum* (Linnaeus), *Aegopinella pura* (Alder) and others was noted. The assemblage was supplemented by the following catholic snails: *Carychium tridentatum* (Risso), *Cochlicopa lubrica* (O. F. Müller) and *Euconulus fulvus* (O. F. Müller). Species of the remaining ecological groups occurred rarely. The mollusc assemblage in the second sample was poorer and dominated by water and mesophile snails: *Bithynella austriaca* (Frauenfeld), *Cochlicopa lubrica* (O. F. Müller) and *Nesovitrea hammonis* (Ström).

Pieniński Stream II (MP-25) – the locality was situated 100–150 m upstream of the preceding one. Granular calcareous tufa occurred there in two niches developed within a travertine cover (Fig. 1). Two samples (Mp-38, Mp-39) contained a poor fauna (8 species, 167 specimens) dominated by water molluscs: *Bithynella austriaca* (Frauenfeld) and *Pisidium personatum* Malm (Table 1).

Two sites of hard travertines with niches filling by granular calcareous tufa were found in a small stream valley south-west of the centre of Krościenko (Krościenko–Toporzyska). In the first one – Krościenko-Toporzyska I (MP-26) – two layers of white, hard and strongly porous travertines separated by granular calcareous tufa occurred (Fig. 1). Two samples (Mp-40, Mp-41) contained a relatively poor fauna (17 species 70 specimens), including mainly snails of shaded habitats and mesophile snails: *Oxychilus depressus* (Sterki), *Laciniaria plicata* (Draparnaud) and *Euconulus fulvus* (O. F. Müller).

Krościenko-Toporzyska II (MP-27) – very similar to the preceding one, situated about 70 m upstream

(Fig. 1). Calcareous sediment in two samples (Mp-42, Mp-43) contained a fauna of 17 taxa represented by 65 shells, with a high proportion of water molluscs (Table 1).

Ociemny Stream (MP-28) – calcareous tufa in the form of a small fan near a spring in the middle part of the Ociemny Stream valley (Fig. 1). A rich fauna was found in sample Mp-44, with 22 species and almost 300 specimens. The community comprised two main groups of molluscs: one with *Bithynella austriaca* (Frauenfeld) and *Galba truncatula* (O. F. Müller), another represented by snails of more or less shaded moist habitats: *Succinea putris* (Linnaeus), *Vestia gulo* (E. A. Bielz.) and *Perforatella vicina* (Rossmässler). Catholic and forest species supplemented this assemblage. Several metres downstream a locality of Lower and Middle Holocene mollusc-bearing deposits was found and described in detail by W. P. ALEXANDROWICZ (2004).

Długi Gronik (MP-29) – calcareous sediments about 50 cm thick, developed near a spring as hard porous travertines, forming two layers separated by coarse-grained tufa (Fig. 1). Four samples (Mp-45 – Mp-48) were collected in this site. They contained a relatively poor mollusc assemblage (22 taxa and nearly 300 specimens). The fauna was dominated by catholic snails: *Nesovitrea hammonis* (Ström), *Cochlicopa lubrica* (O. F. Müller), *Succinea oblonga* Draparnaud and others. Molluscs of the remaining ecological groups were few (Table 1).

Szczawny Stream (MP-30) – travertine fan with small niches filled with granular calcareous tufa, located in the middle part of the Szczawny Stream valley north-east of Krościenko (Fig. 1). Two samples (Mp-49 and Mp-50) contained 227 specimens of 11 species. Two groups of molluscs were the most important components of this fauna. Water species, mainly *Bithynella austriaca* (Frauenfeld) and *Pisidium personatum* Malm, constituted the first one, while snails typical of moist, more or less shaded habitats: *Perforatella vicina* (Rossmässler) and *Zonitoides nitidus* (O. F. Müller), belonged to the second group (Table 1).

Zakijowski Stream (MP-31) – outcrop of coarse-grained calcareous tufa, located in the middle part of the Zakijowski Stream valley, on the lower terrace about 10 m below a small spring (Fig. 1). The whole collected material (samples Mp-51 and Mp-52) included 23 species and 226 specimens. Hygrophile snails: *Carychium minimum* O. F. Müller and *Succinea putris* (Linnaeus), as well as species inhabiting moist forests: *Macrogastra ventricosa* (Draparnaud), *Vestia gulo* (E. A. Bielz.) and *Perforetella vicina* (Rossmässler), were the most important components of this fauna. In the upper sample (Mp-52) numerous shells of water molluscs: *Galba truncatula* (O. F. Müller) and *Pisidium personatum* Malm were also noted. Snails typical of shaded habitats and catholic species supplemented the community (Table 1).

Three localities of recently deposited calcareous tufa were found in the Skotnicki Stream valley (northern part of Szczawnica). In the outcrop Skotnicki Stream I (MP-32), situated about 300 m upstream of the stream outlet (Fig. 1), calcareous tufa was developed as a thin layer between alluvial deposits. Samples Mp-53 and Mp-54 contained a relatively poor fauna (19 taxa, 86 specimens) with a high proportion of *Bithynella austriaca* (Frauenfeld), accompanied by forest and catholic species (Table 1).

Skotnicki Stream II (MP-33) – the second locality is about 100 m upstream of the preceding one. Calcareous sediments contained a poor fauna (19 species, 43 specimens) found in samples Mp-55 and Mp-56. The assemblage was dominated by forest snails: *Arianta arbustorum* (Linnaeus) and *Aegopinella pura* (Alder), with a limited proportion of species representing the remaining ecological groups (Table 1).

Skotnicki Stream III (MP-34) – granular calcareous tufa up to 20 cm thick cropping out on the terrace in the upper part of the Skotnicki Stream valley (Fig. 1). Three samples: Mp-56, Mp-57 and Mp-58, containing a fauna with 25 taxa and 315 specimens, were collected in this locality. In the lower part of the layer the fauna was dominated by forest snails: *Vitrea transsylvanica* (Clessin), *Arianta arbustorum* (Linnaeus), *Discus perspectivus* (Mühlfeld). The assemblage found in the uppermost sample (Mp-58) included numerous shells of *Bithynella austriaca* (Frauenfeld), which constituted about 90% of the assemblage (Table 1).

Głęboki Stream (MP-35) – calcareous encrustations on plants, found near a small spring at the mouth part of the Głęboki Stream valley in the southern part of Szczawnica (Fig. 1). Only one sample (Mp-60), comprising a very poor mollusc assemblage, derives from this locality. The most important component was *Bithynella austriaca* (Frauenfeld), accompanied by forest snails: *Vitrea diaphana* (Studer), *Oxychilus glaber* (Rossmässler) and *Vestia gulo* (E. A. Bielz) (Table 1).

Two localities of recently deposited, coarse-grained calcareous tufa were located in the Grajcarek Stream valley between Szczawnica and Szlachtowa. In the site Grajcarek Stream I (MP-36) a layer of granular calcareous tufa 15 cm thick cropped out in the upper part of a low terrace of the Grajcarek Stream (Fig. 1). Three samples (Mp-61, Mp-62 and Mp-63) contained quite a rich mollusc assemblage with 29 species and 181 specimens. Forest snails: *Aegopinella pura* (Alder), *Eucobresia nivalis* (Dumont et Mortillet) and *Oxychilus depressus* (Sterki) were frequent, while catholic species and water molluscs: *Vitrea contracta* (Westerlund) and *Bithynella austriaca* (Frauenfeld) supplemented the fauna (Table 1).

Grajcarek Stream II (MP-37) – a locality very similar to the preceding one, situated near the outlet of the Sopotnicki Stream (Fig. 1). Samples Mp-64, Mp-65 contained a poor fauna (14 species and less than 100 specimens) with *Bithynella austriaca* (Frauen-

feld), forest snails – *Aegopinella pura* (Alder) and *Arianta arbustorum* (Linnaeus) as well as hygrophile species – *Succinea putris* (Linnaeus). A few other outcrops of alluvial sediments with mollusc-bearing layers of granular calcareous tufa, located in the Grajcarek Stream valley between Szlachtowa and Jaworki, were described by W. P. ALEXANDROWICZ (2004).

Pałkowski Stream (MP-38) – travertine cover with a small niche filled with coarse-grained calcareous tufa, deposited near a spring in the middle part of the Pałkowski Stream valley (Fig. 1). A very poor mollusc fauna (4 species and 83 specimens) was found in sample Mp-66. It was dominated by *Bithynella austriaca* (Frauenfeld) which constituted nearly 90% of the whole assemblage (Table 1).

Krupianka (MP-39) – thin layer (20 cm) of coarse-grained calcareous tufa with numerous fragments of hard travertines, found on the surface of the lower terrace of the Krupianka Stream (Fig. 1). It contained a rich fauna (27 species, 133 specimens) extracted from two samples (Mp-67, Mp-68). A high proportion of forest snails: *Aegopinella pura* (Alder) and *Eucobresia nivalis* (Dumont et Mortillet), accompanied by catholic species: *Euconulus fulvus* (O. F. Müller) and *Cochlicopa lubrica* (O. F. Müller), was the most characteristic feature of the assemblage (Table 1).

Szlachtowa (MP-40) – travertine cover with niches filled by coarse-grained calcareous tufa containing fragments of travertines, cropping out close to a spring near the outlet of the Sielski Stream valley in the Szlachtowa village (Fig. 1). A relatively poor fauna (10 species, 130 specimens) with numerous shells of *Bithynella austriaca* (Frauenfeld) was found in samples Mp-69 and Mp-70 (Table 1).

Homole Gorge (MP-41) – granular calcareous tufa with numerous blocks of hard travertines and fragments of limestones, forming a cone near the entrance to the Homole Gorge (Fig. 1). A rich and diverse malacofauna (29 taxa and more than 300 specimens) was found in samples Mp-71 and Mp-72. Shade-loving species were the most important components of this assemblage. There were both typical forest snails: *Vitrea diaphana* (Studer), *Aegopinella pura* (Alder), *Macrogastra plicatula* (Draparnaud), and snails associated mainly with moist forests, such as: *Macrogastra ventricosa* (Draparnaud), *Vestia gulo* (E. A. Bielz), *V. turgida* (Rossmässler), *Perforatella vicina* (Rossmässler). Shells of catholic species: *Euconulus fulvus* (O. F. Müller), *Cochlicopa lubrica* (O. F. Müller) and *Punctum pygmaeum* (Draparnaud), were also numerous. Species of other ecological groups occurred occasionally (Table 1).

Zaskale (MP-42) – calcareous encrustations on plants near a small spring in the upper course of the Skalski Stream valley (Fig. 1). Sample Mp-73 contained a very a poor fauna: 5 species and 174 specimens. Two water taxa: *Bithynella austriaca* (Frauenfeld) and *Pisidium personatum* Malm constituted about 85% of this assemblage (Table 1). Numerous localities of Holocene calcareous tufa in the Skalski Stream valley were recorded by S. W. ALEXANDROWICZ (1984b, 1985) and described in detail by W. P. ALEXANDROWICZ (2004).

Biała Woda Gorge (MP-43) – small fan situated at the foot of the rock face in the middle part of the Biała Woda Gorge. The fan is built of fine-grained calcareous tufa with very numerous of fragments of limestones (Fig. 1). The fauna in sample Mp-74 was composed of 14 species and 364 specimens. *Bithynella austriaca* (Frauenfeld) was the most typical component of this assemblage. It was accompanied by open country snails of dry, sunny habitats: *Pupilla muscorum* (Linnaeus), *Vallonia pulchella* (O. F. Müller) and *V. costata* (O. F. Müller). Species associated with shaded habitats occurred rarely, while catholic and hygrophile snails were practically absent (Table 1).

Supplementary sites included numerous other localities of Late Holocene and recently accumulated mollusc-bearing calcareous tufa from the Pieniny Mts., described by S. W. ALEXANDROWICZ (1985, 1993, 1996) (Witów, Ścigocki Stream, Kozłecki Stream) and W. P. ALEXANDROWICZ (2004) (Tylka, Płaśnie, Zawiasy, Klimontowski Stream, Kozłecki Stream) (Fig. 1). In some of them the deposits were radiocarbon-dated: Ścigocki Stream – 250±40 BP (Gd-3095) and 640±50 BP (Gd-1807), Kozłecki Stream – 140±50 BP (Gd-5754) (S. W. ALEXANDROWICZ 1985, 1993, 1996), Tylka – 535±30 BP (Gd-3197), Płaśnie – 680±80 BP (Gd-6268) (W. P. ALEXANDROWICZ 2004).

RESULTS

The outcrops and profiles of Late Holocene and recently accumulated calcareous tufa, described above, comprise very diverse molluscan assemblages. Their taxonomic composition and structure are closely associated with the depositional environments. The number of taxa in particular samples varies from 4 to 35. Poor assemblages include less than 15 species per sample while rich ones – between 15 and 35. A great proportion (ca. 72%) of the whole analysed material represents the first group while rich and diverse communities were found in 20 samples (28%) (Fig. 2). The number of specimens varies from 4 to 708 per sample and in most assemblages it is generally 40–200 specimens (60% of samples). Both poorer (4–40 specimens) and richer (more than 200 specimens) assemblages were found in about 20% of the samples (Fig. 2).

All the ecological groups of molluscs defined by LOŽEK (1964) and S. W. ALEXANDROWICZ (1987, 1999)

are represented in the analysed material. The quantitative relationships between these groups in particular samples are used to characterise the diversity of assemblages. Seven types and two subtypes of assemblages can be distinguished on this basis (Figs 3–5).

AW – assemblage with water molluscs. A typical feature of this usually poor assemblage is the very common occurrence of *Bithynella austriaca* (Frauenfeld). It is a stenoecious snail, inhabiting mainly spring areas of stable temperature. Several species of the genus have been distinguished as a result of the revision by FALNIOWSKI (1987). Their identification based on shell alone is practically impossible. Thus, in this study, the taxon is understood in its broad sense and includes the few taxa distinguished as a result of the revision. On the other hand, all species of the genus *Bithynella*, recorded from Poland, occur in similar habitats and often together. From the point of view of palaeoecological interpretation their identification is not a major issue. *B. austriaca* often constitutes from 50 to 80% of the total number of specimens in a sample and is the dominant component of the assemblage. It is often accompanied by *Pisidium personatum* Malm and *Galba truncatula* (O. F. Müller). The first mentioned taxon inhabits the vicinity of springs and fast flowing mountain streams. The second species is typical of small and much vegetated ponds and temporary water bodies. Other water molluscs, such as *Ancylus fluviatilis* O. F. Müller, *Radix peregra* (O. F. Müller) and *Pisidium casertanum* (Poli) occur occasionally. The limited admixture of land snails preferring moist habitats: *Succinea putris* (Linnaeus), *Perforatella vicina* (Rossmässler), *Vestia gulo* (E. A. Bielz) is usually noted. The remaining ecological groups occur rarely. The assemblage with a high proportion of *Bithynella austriaca* (Frauenfeld) is most typical of calcareous tufa deposited close to springs (S. W. ALEXANDROWICZ 1984b, W. P. ALEXANDROWICZ 2004). The described type of fauna was found in 26 samples (36% of the total number) (Figs 3, 5).

AW-FM – assemblage with water molluscs, catholic and shade-loving snails. It comprises three groups of species. Water molluscs, constituting about half of the assemblage, are represented mainly by *Bithynella austriaca* (Frauenfeld) and *Galba truncatula* (O. F. Müller). Species of moist forests: *Perforatella vicina* (Rossmässler), *Vestia gulo* (E. A. Bielz) and additionally typical woodland snails represent the second group, while catholic species, such as *Cochlicopa lubrica* (O. F. Müller), *Euconulus fulvus* (O. F. Müller), *Carychium tridentatum* (Risso) and few others supplement this assemblage. A limited admixture of hygrophile taxa (*Succinea putris* (Linnaeus)) was also noted. The described assemblage, found in six samples (about 8%) is typical of forests of moist valley bottoms with numerous springs (Figs. 3, 5).

AFM – assemblage with woodland and mesophile snails. It is a very rich and diverse assemblage, found in calcareous tufa accumulated within forests, and recorded in 27 samples (37% of the total number) (Figs 3, 5). Two sub-types of this assemblage can be distinguished.

The sub-assemblage with forest species (**AF**) represents a rich fauna including typical woodland snails, represented by numerous species, such as *Vitrea diaphana* (Studer), *Aegopinella pura* (Alder), *Macrogastra plicatula* (Draparnaud), *Vitrea crystallina*

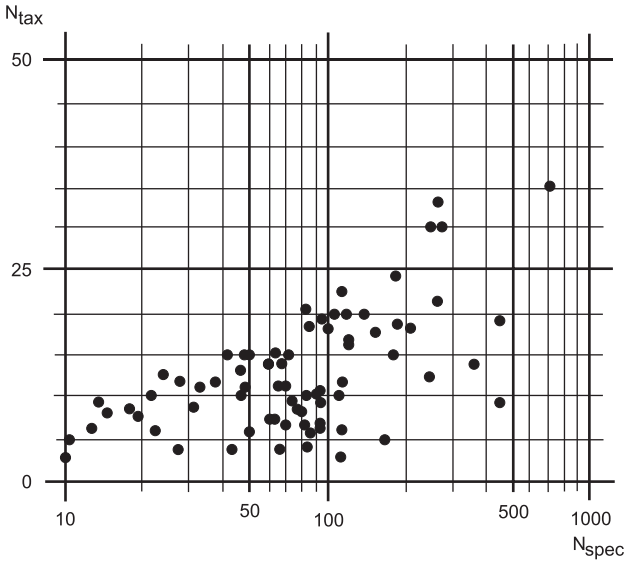

Fig. 2. Relation between number of taxa (N_{tax}) and number of specimens (N_{spec}) in Upper Holocene calcareous tufa in Podhale Basin and Pieniny Mts

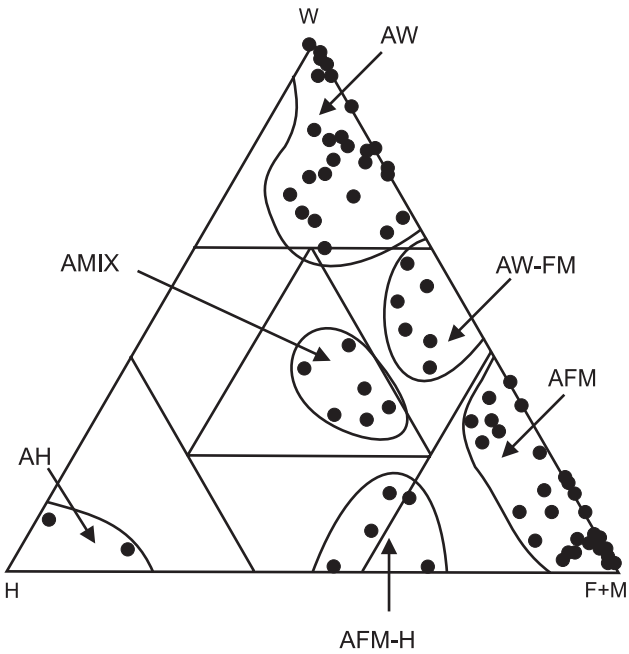

Fig. 3. Mollusc assemblages of Upper Holocene calcareous tufa in Podhale Basin and Pieniny Mts. Ecological groups of molluscs (according to LOŽEK 1964, S. W. ALEXANDROWICZ 1987, 1999): W – water species, H – hygrophile species, M – mesophile species, F – forest species. For symbols of assemblages see text

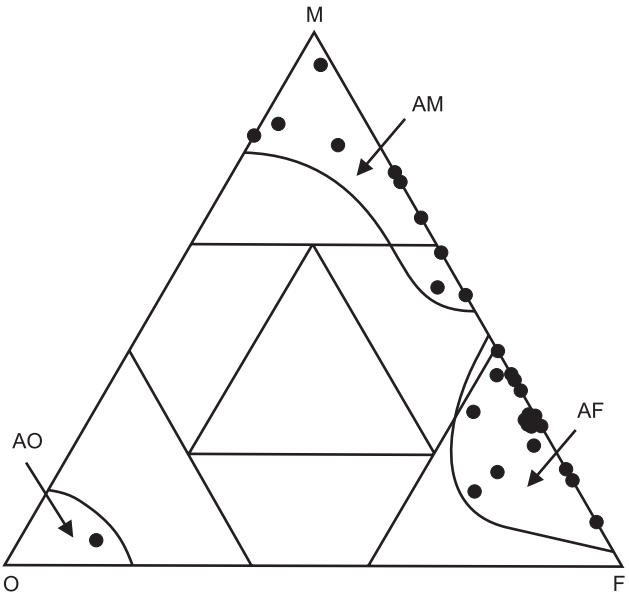

Fig. 4. Shade-lowing and open-country mollusc assemblages of Upper Holocene calcareous tufa in Podhale Basin and Pieniny Mts. Ecological groups of molluscs (according to LOŽEK 1964, S. W. ALEXANDROWICZ 1987, 1999): M – mesophile species, O – open-country species, F – forest species. For symbols of assemblages see text

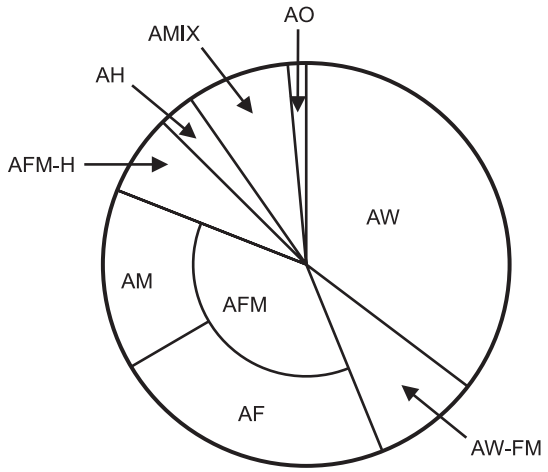

Fig. 5. Frequency of occurrence of mollusc assemblages. For symbols of assemblages see text

(O. F. Müller), *Arianta arbustorum* (Linnaeus), *Perforatella incarnata* (O. F. Müller) and others. They are accompanied by taxa of shaded and moist habitats: *Perforatella vicina* (Rossmässler), *Vestia gulo* (E. A. Bielz) as well as by mesophile snails: *Euconulus fulvus* (O. F. Müller), *Cochlicopa lubrica* (O. F. Müller) and *Punctum pygmaeum* (Draparnaud). In many samples numerous shells of *Bithynella austriaca* (Frauenfeld) are also present. Hygrophile species: *Succinea putris* (Linnaeus) and *Zonitoides nitidus* (O. F. Müller) are subordinate components of this fauna, while open-country taxa are practically absent. This fauna characterises profiles of calcareous tufa situated on the surface of lower terraces developed in relatively narrow and much wooded stream valleys. The sub-assemblage in question was found in 17 samples (23%) (Figs 4, 5).

The sub-assemblage with mesophile species (**FM**) comprises catholic species with a substantial admixture of shade-loving ones. The former are usually represented by numerous shells of *Euconulus fulvus* (O. F. Müller), *Cochlicopa lubrica* (O. F. Müller), *Punctum pygmaeum* (Draparnaud), *Nesovitrea hammonis* (Ström) and other species of wide ecological tolerance. Snails inhabiting mainly sparse forests and shrubland, such as *Arianta arbustorum* (Linnaeus), *Vitrea crystallina* (O. F. Müller), as well as those living in moist forests: *Perforatella vicina* (Rossmässler) and *Vestia gulo* (E. A. Bielz) also occur commonly. The fauna is supplemented by water and hygrophile molluscs. The described fauna is characteristic of calcareous tufa deposited on bush-covered terraces. This sub-assemblage was found in 10 samples (14%) (Figs 4, 5).

AFM-H – Assemblage with shade-loving and hygrophile snails. It is a relatively rich assemblage with a high proportion of two ecological groups. One comprises woodland species typical for moist, shaded habitats: *Perforatella vicina* (Rossmässler), *Vestia gulo* (E. A. Bielz), *Perforatella umbrosa* (C. Pfeiffer), *Macrogastra ventricosa* (Draparnaud) as well as catholic species: *Euconulus fulvus* (O. F. Müller), *Cochlicopa lubrica* (O. F. Müller) and others. Hygrophile snails: *Succinea putris* (Linnaeus), *Zonitoides nitidus* (O. F. Müller), *Carychium minimum* O. F. Müller, belong to the other group. Water species, represented mainly by *Galba truncatula* (O. F. Müller) and also *Bithynella austriaca* (Frauenfeld), occur commonly. This fauna occurs in calcareous tufa accumulated in marshes, on flat surfaces of lower bush-covered terraces. The fauna was found in five samples (7%) (Figs 3, 5).

AFH – assemblage of hygrophile species. It is a poor assemblage dominated by species of moist, more or less open habitats: *Succinea putris* (Linnaeus), *Zonitoides nitidus* (O. F. Müller), *Carychium minimum* O. F. Müller and *Vertigo antivertigo* (Draparnaud). Water molluscs typical of temporary water bodies: *Galba truncatula* (O. F. Müller) and snails inhabiting moist forests – *Perforatella vicina* (Rossmässler) – supplement this community. Species of the remaining ecological groups occur rarely. This fauna is typical of calcareous tufa developed in marshes or even in small, temporary water bodies, much vegetated. It was found only in two samples (2%) (Figs 3, 5).

AMIX – mixed assemblage. This fauna is composed of relatively equal proportions of the main ecological groups. It was found in six samples (9%) (Figs 3, 5).

AO – assemblage with open-country species. It is a fauna comprising two main components: snails of relatively dry, open habitats: *Pupilla muscorum* (Linnaeus), *Vallonia pulchella* (O. F. Müller) and *V. costata* (O. F. Müller) and water molluscs represented mainly by shells of *Bithynella austriaca* (Frauenfeld.). The remaining ecological groups are represented by single

specimens or absent. This assemblage was found in one sample of calcareous tufa precipitated close to a spring within a completely deforested area (Figs 4, 5).

The diversity index TDI indicates mollusc diversity in particular samples. Its values vary between 0.07 (poor communities dominated by one taxon) and 0.99 (communities with nearly equal number of specimens of different species) (S. W. ALEXANDROWICZ 1987, 1999). The relations between TDI and the number of species allow to distinguish four types of assemblages (Figs 6, 7). Poor assemblages (less than 10 species per sample) with low TDI values (<0.5) belong to the first type (A). Oligomictic, less diversified assemblages recognised in nine samples (12% of the total number) can be assigned to this type (Figs 6, 7). Oligomictic, multispecies assemblages (B) characterised by low TDI values (<0.5), but composed of more than 10 taxa per sample, were found only in two samples (3%) (Figs 6, 7). The third type comprises a limited number of taxa (less than 10) but is characterised by relatively high TDI values, exceeding 0.5 (C). Such fauna was found in 27% of the analysed samples (20 samples) (Figs 6, 7). Rich and diverse assemblages occur in the majority of samples (42–58%) as the most common type of assemblages – D (Figs 6, 7).

The composition and structure of the assemblages in the whole set of samples are described using indices of constancy (C) and dominance (D). Only one species – *Bithynella austriaca* (Frauenfeld), can be placed in the highest classes of C and D (C=5, D=5). This snail occurs most commonly (65 samples – 89% of the total) and is often represented by numerous shells (3,279 specimens – 40% of the total). Six other taxa: *Aegopinella pura* (Alder), *Perforatella vicina* (Rossmässler), *Euconulus fulvus* (O. F. Müller), *Cochlicopa lubrica* (O. F. Müller), *Carychium minimum* O. F. Müller and *Galba truncatula* (O. F. Müller) are included in classes C=3 and D=1, while the remaining species (67) are represented only by a low number of specimens, with C=2 or C=1, D=1 (Fig. 8).

The presented molluscan assemblages include species of various geographical range. The zoogeographical structure of the fauna found in Late Holocene and recently accumulated calcareous tufa comprises three

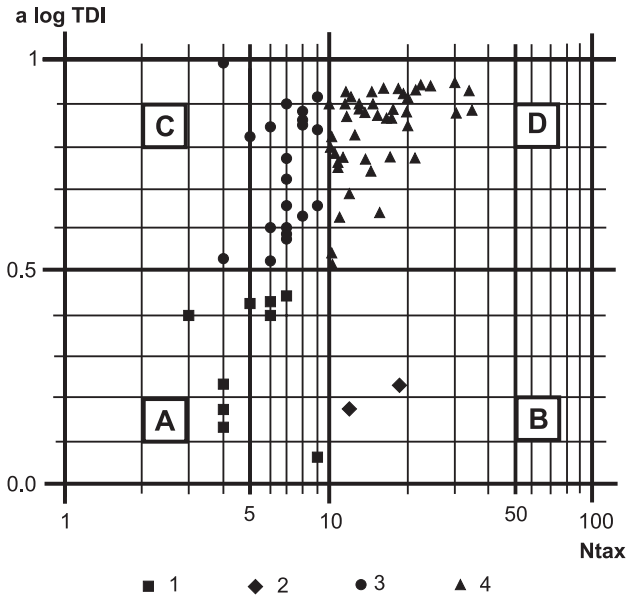

Fig. 6. Diversity of mollusc assemblages of Upper Holocene calcareous tufa in Podhale Basin and Pieniny Mts. Types of assemblages: 1 – oligomictic, low-diversity assemblages (A), 2 – oligomictic multiple assemblages (B), 3 – polimictic, low-diversity assemblages (C), 4 – polimictic multiple assemblages (D); a log TDI – antilogarithm TDI; N_{tax} – number of taxa

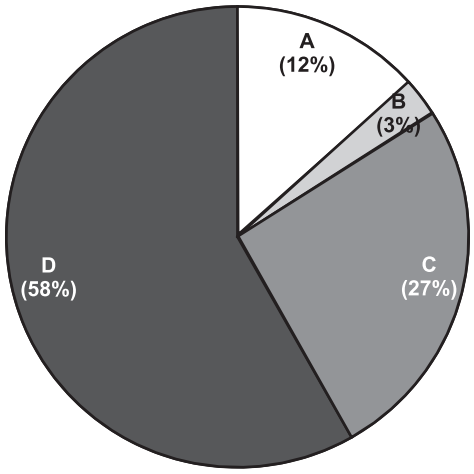

Fig. 7. Proportion of types of mollusc assemblages in Podhale Basin and Pieniny Mts. A – oligomictic, low-diversity assemblages, B – oligomictic multiple assemblages, C – polymictic, low-diversity assemblages, D – polymictic multiple assemblages

	D-1	D-2	D-3	D-4	D-5
C-5					1
C-4					
C-3	6				
C-2	19				
C-1	48				

D=5; C=5 *Bythinella austriaca*

D=1; C=3

Aegopinella pura
Perforatella vicina
Cochlicopa lubrica
Euconulus fulvus
Carychium minimum
Galba truncatula

D_i=1 C_i=7.75

Fig. 8. Constancy and dominance of assemblages of Upper Holocene calcareous tufa in Podhale Basin and Pieniny Mts. C – constancy, D – dominance, C_i – normalised index of constancy (according to S. W. ALEXANDROWICZ 1999), D_i — normalised index of dominance (according to S. W. ALEXANDROWICZ 1999)

main groups of taxa: widespeared species (HP), Central-European species (ME) and species of limited geographical range (EO) (Fig. 9). The first category includes Holarctic (Hl), Palaearctic (Pl), European (Ep) and Eurosiberian (Es) taxa and constitutes 42% of the whole collected material (Fig. 9). Holarctic snails are represented mainly by *Cochlicopa lubrica* (O. F. Müller), *Euconulus fulvus* (O. F. Müller) and *Galba truncatula* (O. F. Müller) (14% of the fauna). European taxa: *Aegopinella pura* (Alder) and *Vitrea crystallina* (O. F. Müller) constitute 12%, Eurosiberian species – *Pisidium personatum* Malm., *Succinea oblonga* Draparnaud and *Carychium minimum* O. F. Müller – 11% of the fauna, while Palaearctic taxa: *Punctum pygmaeum* (Draparnaud) and *Nesovitrea hammonis* (Ström) are less numerous (5%).

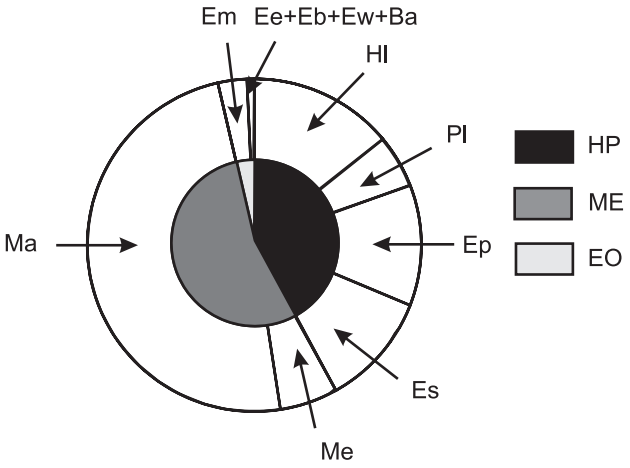

Fig. 9. Zoogeographical structure of molluscan fauna from Upper Holocene calcareous tufa in Podhale Basin and Pieniny Mts. HP – widespread species, ME – Middle-European species, EO – European species of limited ran

Species inhabiting mainly Central Europe (ME) are the most important components of the assemblages (54% of the analysed material). Among them, montane molluscs associated with the Carpathians and the Alps (Ma): *Bithynella austriaca* (Frauenfeld), *Vestia gulo* (E. A. Bielz.) and *Perforatella vicina* (Rossmässler) occur very frequently, forming about 49% of the fauna. The proportion of Central European taxa (Me), such as *Perforatella incarnata* (O. F. Müller) and *Arianta arbustorum* (Linnaeus) is only about 5%. Species of limited geographical range can be regarded as subordinate components. They include mainly South European (Em) species: *Vitrea diaphana* (Studer) and *V. subrimata* (Reinhardt) and form about 3% of the material. The remaining zoogeographical groups: East European (Ee), Balkan and Pontic (Eb), West European (Ew) and Boreal (Ba) are represented only by single shells and in total constitute 1% of the described fauna (Fig. 9).

CONCLUSIONS

Late Holocene and recently precipitated calcareous tufa occur commonly in the Podhale Basin and in the Pieniny Mts. In most outcrops and profiles presented in this paper hard, porous travertines and granular calcareous tufas are accessible. These latter deposits form layers and lenses, or fill niches inside the travertine covers. In several localities, fans built of coarse-grained calcareous tufa with numerous blocks of travertines and angular fragments of base rock are found. Granular calcareous tufa usually contains more or less rich and diverse molluscan assemblages. The described sediments are precipitated most often close to springs, especially mineralised ones. According to their lithological variability, three main types can be distinguished. The first type includes typical spring travertines in the form of covers or encrustations on plants. The second type comprises granular calcareous tufa with numerous shells of *Bithynella austriaca* (Frauenfeld), found only in small niches or fissures, as well as layers, lenses and fans built of coarse-grained calcareous tufa, usually containing blocks of travertines, pebbles and angular fragments of base rock, deposited on terraces. They often contain rich and diverse mollusc assemblages with a high proportion of shade-loving species, catholic species and numerous shells of *B. austriaca*. The last type is represented by fine-grained calcareous tufa, deposited in temporary, small and much vegetated water bodies developed close to springs. Water species, mainly *B. austriaca* and *Galba truncatula* (O. F. Müller), accompanied by a hygrophile snail – *Succinea putris* (Linnaeus) and taxa inhabiting moist forests, like *Perforatella vicina* (Rossmässler), are the most important components of the fauna.

Recently precipitated calcareous tufas and travertines, mainly travertine covers, are often partly or even completely destroyed during floods. However, they regenerate in the same places during several years (MASTELLA 1975, GRUSZCZYŃSKI & MASTELLA 1986) and represent only a very short time span. Calcareous tufas deposited on terraces in small water bodies are more stable and correspond with much longer periods (several dozen or even several hundred years).

Malacological analyses made it possible to distinguished seven types and two sub-types of mollusc assemblages. Communities with a high proportion of shade-loving species occur commonly. However, the fauna with *Bithynella austriaca* (Frauenfeld) seems to be the most characteristic of recently precipitated calcareous tufas. Particular assemblages are strongly associated with local environmental conditions. Polymictic communities are the most common in the

analysed material. Similar, strongly differentiated faunas have been described from numerous localities of Late Glacial and Holocene calcareous tufa in the Polish Carpathians (S. W. ALEXANDROWICZ 1984b, 1994, S. W. ALEXANDROWICZ & Z. ALEXANDROWICZ 1998, 1999, S. W. ALEXANDROWICZ & GERLACH 1983, S. W. ALEXANDROWICZ & CHMIELOWIEC 1991, W. P. ALEXANDROWICZ 1997, 2001, 2003, 2004) and in Middle Polish Uplands (S. W. ALEXANDROWICZ 1983, W. P. ALEXANDROWICZ 2004).

The poor assemblages in several samples are dominated by *Bithynella austriaca* (Frauenfeld). Such faunas have been recorded only from the Carpathians (S. W. ALEXANDROWICZ 1984b, W. P. ALEXANDROWICZ 1997, 2004). *B. austriaca* is the most important species for recently precipitated calcareous tufa and was identified in the majority of samples, often in large numbers. In calcareous tufas of Late Glacial and Holocene age the species is very rare or absent (S. W. ALEXANDROWICZ 1983, W. P. ALEXANDROWICZ 2004). This problem is difficult to explain directly. Shells of *B. austriaca* are thin and very delicate, and prone to physical and chemical destruction. On the other hand, they occur in large numbers only in profiles of typical spring travertines, where granular calcareous tufa occurs in small niches or fissures and can be easily removed by erosion.

Malacological investigations of recently precipitated calcareous tufas are very important for the interpretation of subfossil assemblages found in deposits developed of the Late Glacial and Holocene. Calcareous sediments accumulated on the surface of low terraces, forming fans on relatively flat slopes or filling small water bodies can be preserved for long periods (hundreds or even thousands of years). Deposits accumulated close to springs are usually not older than several years. From this point of view, the mass occurrence of *Bithynella austriaca* (Frauenfeld), typical of the last-mentioned sediments, can be regarded as an indicator of their age.

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