Carpathian Journal of Earth and Environmental Sciences, November 2013, Vol. 8, No. 4, p. 13 - 26

ENVIRONMENTAL CHANGES OF INTRAMONTANE BASINS DERIVED FROM MALACOLOGICAL ANALYSIS OF PROFILE OF CALCAREOUS TUFA IN NIEDZICA (PODHALE BASIN, SOUTHERN POLAND)

Witold Paweł ALEXANDROWICZ[1] & Eliza RYBSKA[2]

[1]*AGH University of Science and Technology, Faculty of Geology, Geophysics and Environment Protection, Chair of General Geology and Geotourism, Al Mickiewicza 30, 30-059 Cracow, e.mail: wpalex@geol.agh.edu.pl*

[2]*Adam Mickiewicz University, Faculty of Biology, Laboratory for Teaching Biology and Natural Sciences, Umultowska 89, 61-614 Poznań, e.mail: elizary@amu.edu.pl*

Abstract: The site of calcareous tufa in Niedzica is located in the eastern part of the Podhale Basin within the Polish section of the Carpathians. The calcareous tufas exposed there are underlain and covered by slope deposits. The entire profile is 2.5 m thick. The deposits contain numerous and well preserved shells of molluscs. The malacological analysis performed allowed the distinction of four faunistic assemblages differing in composition and structure. In the two oldest assemblages, representing the Preboreal and Boreal Phases, cold-loving species which are glacial relicts occur in large numbers along with shade-loving taxa. The younger assemblage, which corresponds to the Atlantic Phase, is marked by the predominance of shade-loving species with high ecological demands. The fourth and youngest assemblage represents historical times and its characteristic feature is the predominance of snails of open spaces. It provides a record of anthropogenic deforestation. Deposits from the Subboreal Phase and the lower part of the Subatlantic Phase are not represented in the profile. The age of each assemblage was determined using radiocarbon dating.

Key Worlds: calcareous tufa, malacofauna, environmental changes, Holocene, Podhale Basin, South Poland

1. INTRODUCTON

Calcareous tufas are deposits which facilitate the preservation of molluscan shells in a subfossil state. This is due to the peaceful character of the sedimentation process and high calcium carbonate content in the deposit. The former factor minimizes the risk of damaging the shells during the deposition, while the latter hinders the chemical resolution and physical crashing of the shells already present in the deposit. Moreover, the limited redeposition of shell material facilitates the interpretation of ambient habitat changes in the immediate vicinity of the deposition site. The molluscan assemblages occurring in calcareous tufas reflect both regional conditions and local environmental characteristics. The former of the mentioned aspects is the basis for determining the trends in palaeogeographic and climatic changes, whereas the latter creates a unique possibility to reconstruct local conditions, both in terrestrial and aquatic habitats, which is usually unattainable by other methods. Systematic studies of malacological assemblages occurring in calcareous tufas have been undertaken only within the last 30-40 years. Their scope has covered a range of sites where such deposits were located in mountain and upland belts as well as in the Polish Lowlands, as illustrated in numerous publications, (e.g. Alexandrowicz at al., 1987; Alexandrowicz, 1983, 1997a,b, 2001a, 2003, 2004, 2012, 2013a,b; Alexandrowicz & Kobojek, 1997; Dobrowolski et al., 2005, 2012).

In other European countries, as in Poland, large-scale studies on the Late Glacial and Holocene malacocoenoses of calcareous tufas were first undertaken towards the end of the 20th century, in: the Czech Republic and Slovakia (Ložek, 1964, 1972, 2000; Žak et al., 2002), Germany (Mania, 1973, 1995; Meyrick, 2001, 2002), Hungary (Krolopp, 1983; Füköh, 1993; Füköh et al., 1995), France (Limondin-Lozouet & Rousseau, 1991; Rousseau et al., 1993, 1994; Limondin-Lozouet, 1995, 2011; Limondin-Lozouet & Preece, 2004), Great Britain (Preece, 1980; Kerney et al., 1980; Preece & Day 1994), Sweden (Gedda, 2001, 2006).

Studies on the malacofauna of calcareous tufas occurring in the Podhale region were initiated in the interwar period, however these deposit sites were only described in detail in terms of malacology much more recently (Alexandrowicz, 1997a, 2001a, 2003, 2010, 2013a,b). These studies have revealed the changes in malacofauna and their relation to environmental changes mainly driven by climatic factors, but also by human activities over the last several centuries.

The calcareous tufa profile in Niedzica and the malacofauna contained within were described by Alexandrowicz (1997a). Due to road redevelopment works that have been underway in recent years, the site in question has been exposed, which has enabled new material to be obtained.

The major objective of the study is to present the malacofauna of the calcareous tufa and the relevant slope deposits in Niedzica. The features and sequence of molluscan assemblages found in the site served as a basis for the reconstruction of the palaeoenvironment, the determination of climatic changes, as well as human activity and its impact.

The Podhale Basin is an intramontane basin depressed by ca. 500–1000 m in relation to the surrounding mountain ranges (the Tatra Mts. to the south and the Beskidy Mts. to the north) (Fig. 1). The geological substrate of the Podhale Basin is formed by slightly folded Paleogene flysh (Podhale Flysh). They are sandstone and shale complexes with a relatively high calcium carbonate level. Limestone outcrops belonging to the Pieniny Klippen Belt occur in the eastern part of the Podhale Basin. The considerable calcium carbonate content in the underlying Quaternary rocks is the decisive factor entailing the abundant occurrence of calcareous tufas within the Podhale Basin. It also facilitates the formation of calcareous slope covers containing molluscan shells.

The discussed calcareous tufa profile is located in the village of Niedzica (GPS: 49°24’52”N; 20°18’19”E) in the immediate vicinity of the road between Niedzica and Łapsze, at a distance of ca. 750 m from Niedzica Castle (Fig. 1). A holiday resort was built on a plateau carved out on a slope above the outcrop. The site is currently exposed and clearly visible, due to the ongoing roadworks.

2. MATERIAL AND METHOD

Sixteen samples containing molluscan shells were collected from the site of calcareous tufas in Niedzica. The samples weighed ca. 3kg each and represented 15 cm thick intervals. The samples were subjected to flushing on a 0.5 mm mesh, and after drying all molluscan shells that were preserved whole, both adult and juvenile forms, and shell fragments that could be clearly identified, were selected. The latter were recalculated into whole specimens in accordance with the formula developed by Alexandrowicz (1987) and Alexandrowicz & Alexandrowicz (2011).

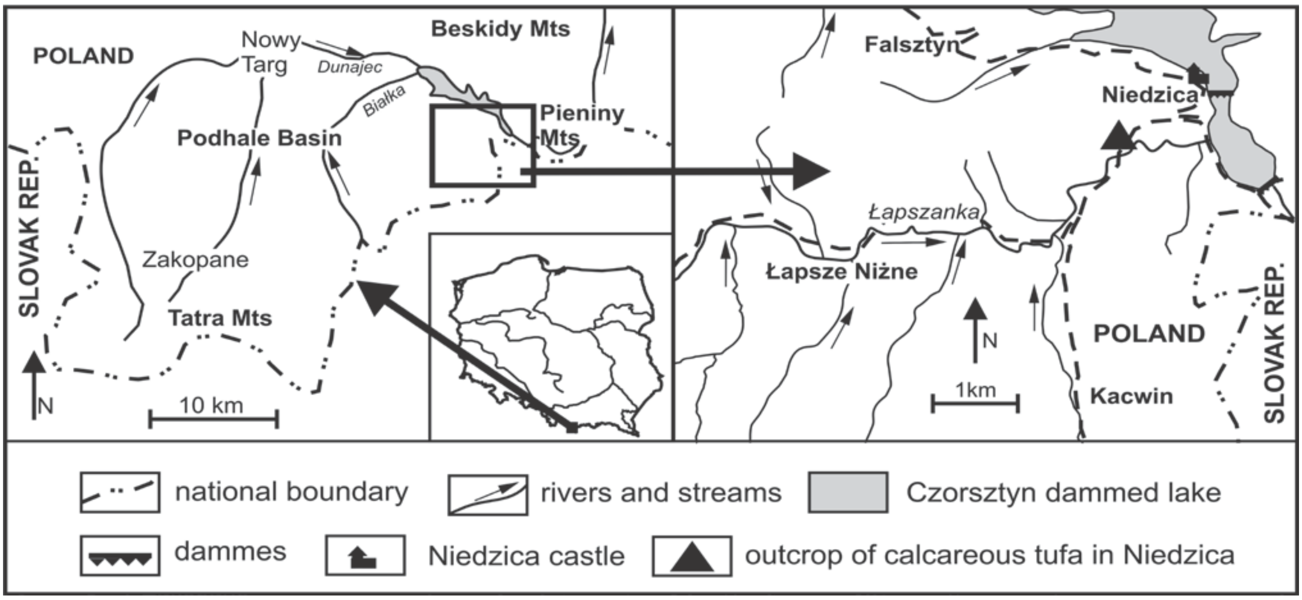

Figure 1. Location of the profile of slope deposits and calcareous tufas in Niedzica.

In order to describe the lithology of the deposits, a granulometric analysis was performed using Casagrande's areometric method. The proportions of each fraction (gravel, sand, silt, and clay) in the deposit were derived from the results. The percentage share of calcium carbonate was also determined.

The malacological analysis was conducted using the methods described by Ložek (1964), Alexandrowicz (1987) and Alexandrowicz & Alexandrowicz (2011). Particular species were classified into ecological groups (F – shade-loving species, O – open-country species, M – mesophilous species, H – hygrophilous species, and W – aquatic species). The percentage shares of particular ecological groups served as a basis for the construction of a malacological diagram. Two-component diagrams and a ternary diagram were used in order to describe the variability of the fauna features throughout the vertical profile. The taxonomic analysis carried out based on Morisita's method (Morisita, 1959) enabled faunistic assemblages representing successive phases of environmental changes to be distinguished. Taxonomic calculations were completed using the PAST statistical software package (Hammer et al., 2001). The direct determination of the deposit age was possible owing to radiocarbon dating using the scintillation technique on four samples in the Radiocarbon Laboratory in Skała near Cracow by Prof Marek Krąpiec (laboratory reference number: MKL). The results were calibrated with OxCal software (Bronk Ramsey, 2001). Additionally, conclusions derived from palynological (Obidowicz, 1990) and malacological studies (Alexandrowicz, 1997a, 2001a, 2003, 2010, 2012, 2013a,b) conducted in the Podhale region were used.

3. RESULTS

3.1. Lithology

The profile of calcareous tufas exposed in Niedzica is ca. 2.5m thick (Fig. 2). Starting from the bottom, the following sections can be distinguished:

0.00 – 0.40 m – yellowish loam with very numerous, sharp-edged sandstone and limestone blocks. The maximum size of clasts amounts to 8 cm, and the average is 3–5 cm. The gravel fraction content reaches its maximum at 24% (Fig. 2). The matrix is highly sandy (sand fraction content usually exceeds 50%). The proportion of finer fractions (silt and clay) fluctuates between 20% and 30% and increases gradually towards the top (Fig. 2). The discussed deposits are marked by a fairly considerable calcium carbonate content, up to 50%. It is a typical slope deposits. Traces of a highly vague lamination and an indistinct sorting of larger clasts can be seen at some places.

0.40 – 0.70 m – yellowish, unconsolidated, coarse grained and nodule calcareous tufa. They are mostly formed of calcareous material from the sand fraction. Larger tufa clasts occur mainly in the bottom section of the layer and disappear towards its top (Fig. 2). The increase in the silt fraction becomes apparent along the same direction. The deposits in question can be classified as medium-grained tufas (*sensu* Alexandrowicz, 2004). Calcium carbonate content is high and reaches 70% in the topmost part of the layer.

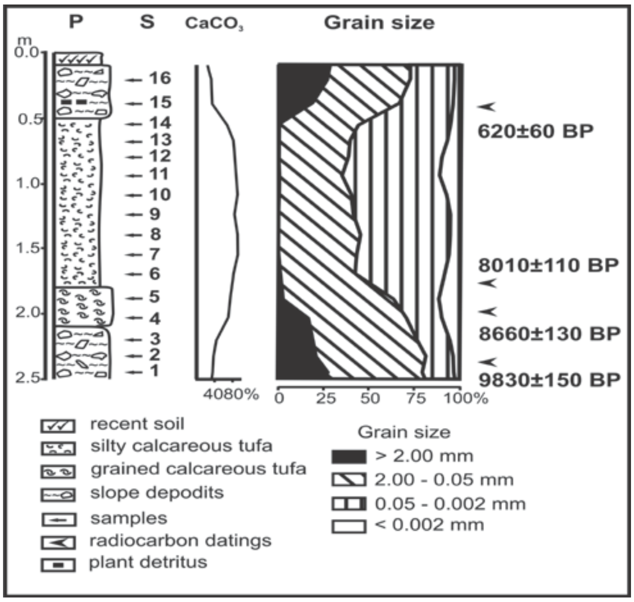

Figure 2. Lithology of profile in Niedzica
P. profile, S. samples, $CaCO_3$. calcium carbonate content

0.70 – 2.00 m – white, silty calcareous tufa formed nearly exclusively of carbonate material from sand and silt fractions. Larger tufa clasts or sharp-edged limestone blocks occur sporadically. In terms of granular composition, they are fine-grained tufas (*sensu* Alexandrowicz, 2004) with a predominance of sand (48–60%) and silt (25–32%) fractions (Fig. 2). Calcium carbonate content is very high and does not drop below 80% (Fig. 2). The top part of this layer is eroded. The discussed tufas form the main part of the profiles.

2.00 – 2.40 m – yellow, at some places brown, slope deposits with numerous sharp-edged rock blocks (sandstone and limestone) and fragments of tree branches. Small nodule of calcareous tufa can be found at some places, and calcium carbonate encrustations are discernible on limestone blocks. The proportion of gravel fraction reaches a maximum of 25% in the highest part of the interval described. The matrix is calcareous ($CaCO_3$ content 30–40%) in major part composed of sands and silts (Fig. 2). Tree branches occur in fairly large numbers in the lower part of the layer.

2.40 – 2.50 m – recent soil.

3.2. Malacofauna

Malacological analysis was conducted based on the material obtained from 16 samples, in which 55 species of molluscs were identified (including 53 taxa of terrestrial snails and 2 species of aquatic snails) represented by 4,324 specimens. The number of taxa in individual samples varied from 9 to 35, whereas the number of specimens varied from 81 to 551 respectively (Fig. 3 N).

The largest group were species inhabiting shaded habitats (shade-loving species – ecological group F). Both forms typical of dense canopy forests and species characteristic of thin forests and shrublands could be accounted to this group. It includes as many as 39 species and over 2,800 specimens (Table 1, Fig. 3). The particularly distinct dominance of shade-loving snails is evident in the middle part of the profile. It is clearly apparent in the two-component diagram curve, as well as in the cluster of points representing individual samples in the ternary projection (Fig. 4 D-1, Tr).

The proportion of shade-loving species is slightly smaller in the bottom part of the profile. In the top section, these forms gradually disappear. Snails of open spaces (open-country species – ecological group O) are represented by 3 taxa (Table 1, Fig. 3). The mentioned ecological group is a subordinate component and its occurrence is of secondary importance. The two highest samples are an exception, where the taxa of open spaces, particularly *Vallonia pulchella* and *Vallonia costata*, are dominant elements (Figs. 3, 4).

Mesophilous snails (ecological group M) are represented by 8 forms (Table 1). The presence of a cold-loving taxon *Columella columella* in the bottom interval of the profile is particularly noteworthy. It usually occurs together with *Vertigo substriata*, a species typical of boreal forests (Fig. 3). Three forms have been classified in ecological group H (hygrophilous forms). The occurrence of cold-loving form *Vertigo geyeri* in the bottom part of the profile should be considered most important in this context (Fig. 3).

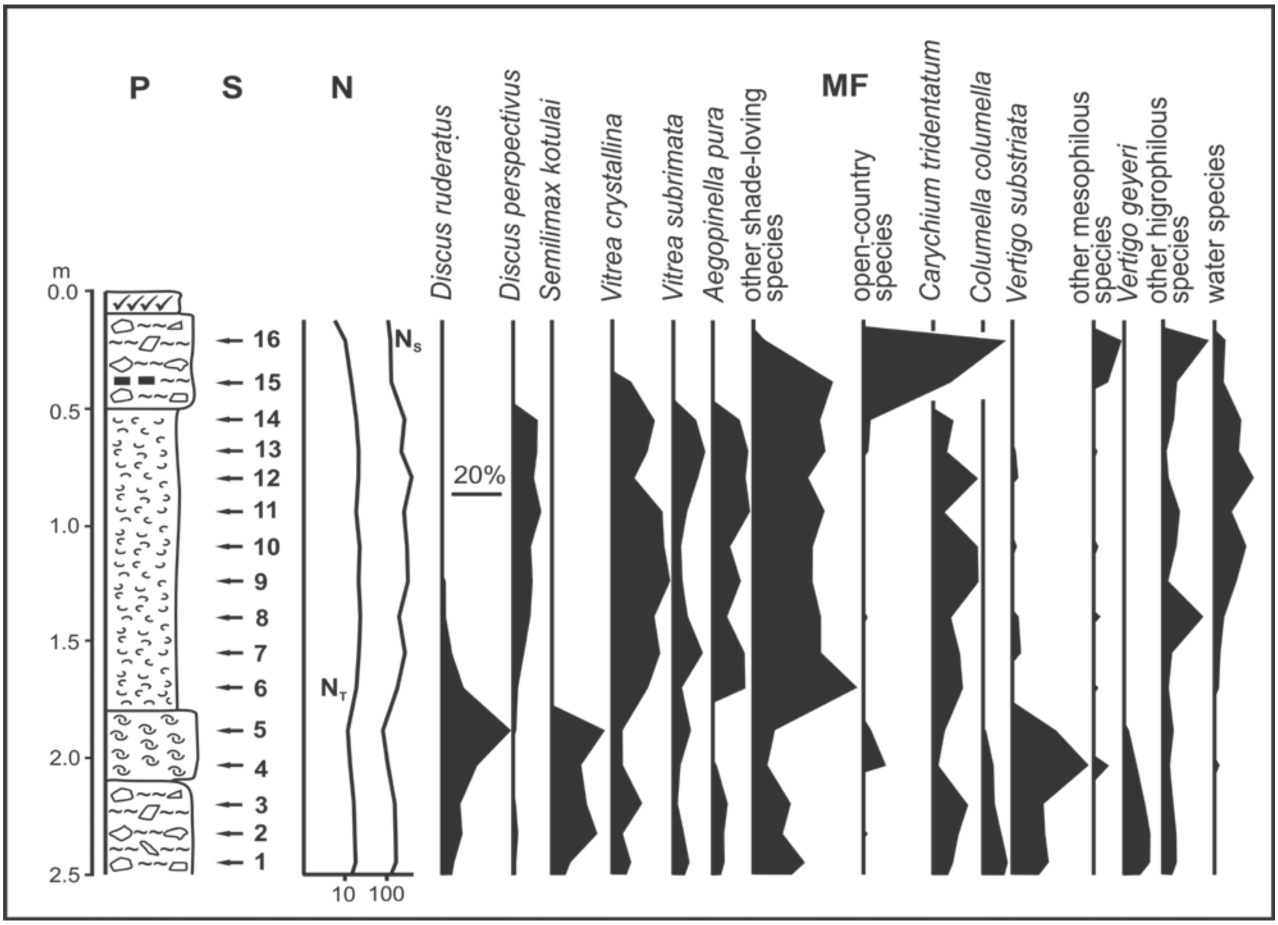

Figure 3. Malacological percentage diagram. P. profile, S. samples, N. number of species (N_T) and specimens (N_S), MF. malacofauna. For other explanations see Figure 2.

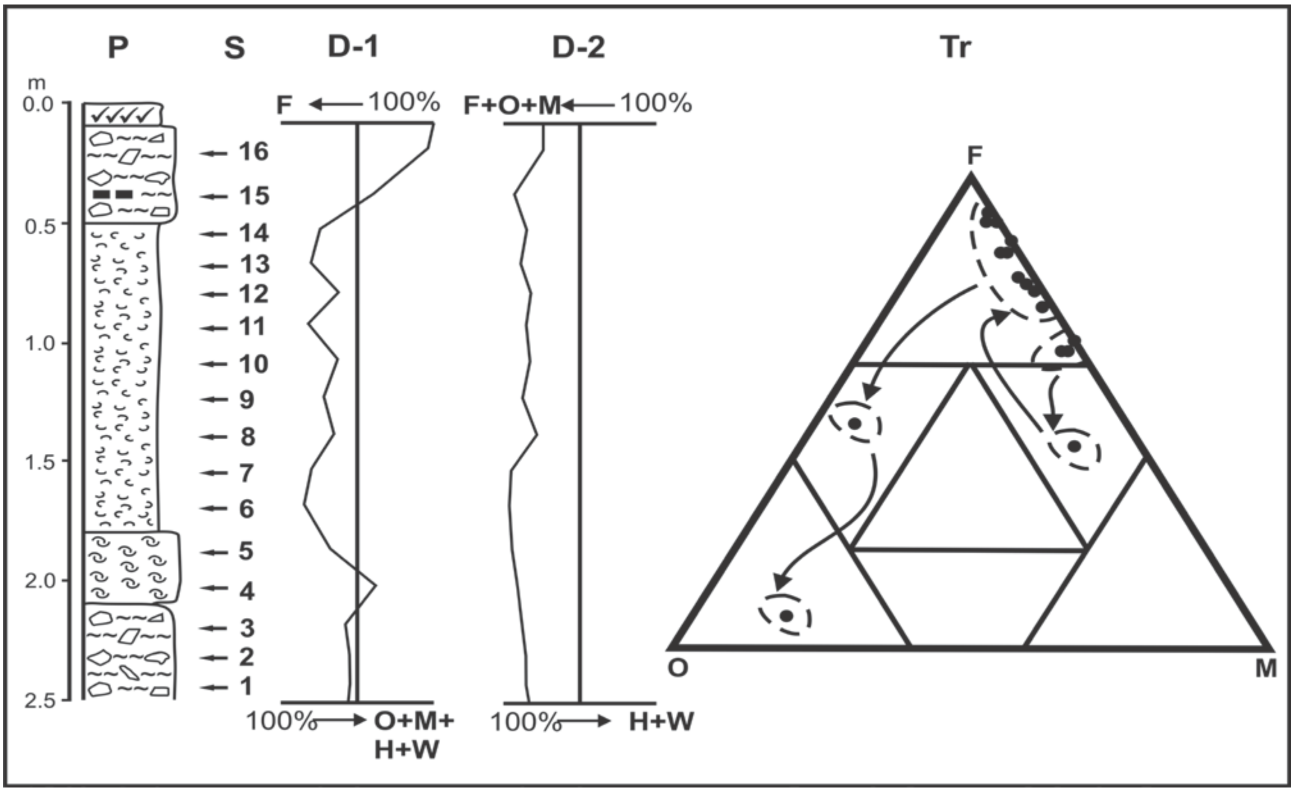

Figure 4. Changes of molluscan fauna in profile of calcareous tufa in Niedzica
P. profile, S. samples, D-1, D-2. Two-component diagrams, ecological group of molluscs (after: Ložek, 1964; Alexandrowicz, 1987; Alexandrowicz & Alexandrowicz, 2011): F. shade-loving species, O. open-country species, M. mesophilous species, H. hygrophilous species, W. water species, Tr. ternary diagram of malacofauna

The proportions of hygrophilous and mesophilous remains constant in individual samples (Fig. 4). Aquatic species are represented by two taxa, out of which only *Bythiniella austriaca* occurs in larger numbers (Fig. 3). This species is characteristic of spring zones and commonly found in tufa sediments throughout the entire Polish Carpathians (Alexandrowicz, 1997a, 2004, 2009, 2010, 2013a). The proportion of taxa typical of high-moisture habitats (aquatic and hygrophilous species) does not exceed 25% within the whole profile (Fig. 4 D-2).

3.3 Molluscan assemblages

The malacofauna identified in the calcareous tufa site in Niedzica demonstrates a fairly distinct diversity in the vertical profile. Taxonomic analysis indicates the presence of four molluscan assemblages that differ in species composition and in structure (Fig. 5). They are associated with the changes of environmental conditions that occurred during the sedimentation of the calcareous tufa exposed in the mentioned site.

Assemblage with *Columella columella* (FCL; Fig. 5). It is found in the lowest part of the profile, within the deposits underlying calcareous tufa (samples: Gl-1 – Gl-3) (Fig. 2). The characteristic feature of this fauna is the abundant occurrence of cold-loving taxa: *Columella columella*, *Vertigo geyeri*, *Semilimax kotulai*. The presence of the two former ones is particularly interesting. These forms are typical of cold, polar climate, and are widely found in Late Glacial deposits of various origins (e.g. Ložek, 1964; Preece, 1998; Alexandrowicz, 1983, 1997a,b, 1999, 2001a, 2003, 2004, 2013b; Limondin-Lozouet & Rousseau, 1991; Limondin-Lozouet, 1992; Krolopp & Sümegi, 1993; Preece & Day, 1994; Alexandrowicz & Alexandrowicz, 1995a, 1995b; Mania, 1995; Meyrick & Preece, 2001; Gedda, 2001, 2006). They are considerably rarer in Holocene formations, where usually only single specimens occur, if any. The species described are found in large numbers in the bottom interval in the Niedzica site. They are accompanied by shadow-loving species of broad ecological tolerance – *Semilimax kotulai*, *Discus ruderatus*, *Arianta arbustorum* – as well as forms that prefer warmer climates – *Vitrea crystallina*, *Aegipinella pura* (Fig. 3). The age of the interval discussed was established using radiocarbon dating, which was performed based on an *Arianta arbustorum* shell, as 9830±150 years BP (9872–8797 cal BC (94,4%)); (MKL–1364) (Fig. 2).

Table 1. List of species recognized in profile of calcareous tufas in Niedzica.

	Taxon	SAMPLES															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
F	*Acicula parcelineata* (Cless.)	S	S	S			S	S	S	S	S	S	R	S	S	S	
F	*Acicula polita* (Hartm.)	S		R	S	S	R	R	R	N	N	N	N	R	N	R	
F	*Argna bielzi* (Rossm.)	S	S				R	R	S	S		R	R	S	S		
F	*Acanthinula aculeata* (Müll.)			S			S	R	S	S	S	S	S	S	S		
F	*Ena montana* (Drap.)	S		S				S	S	S	S	S		S	S		
F	*Discus ruderatus* (Fér.)	R	R	R	R	R	R	R	S	R	S	S	S	S	S		
F	*Discus rotundatus* (Müll.)						R	R	R	R	R	R	R	R	R		
F	*Discus perspectivus* (Mühlf.)	S	R	S		S	R	R	R	R	R	N	N	R	R		
F	*Eucobresia nivalis* (Dum.et Mort)	S	R	S	S		R	R	S	R	S	R	R	S	S		
F	*Semilimax kotulai* West.	R	N	R	R	R			S								
F	*Semilimax semilimax* (Fér.)	S	S								S	S	S				
F	*Vitrea crystallina* (Müll.)	N	R	N	R	S	C	C	C	A	C	C	C	C	C	R	
F	*Vitrea diaphana* (Stud.)	N	S	R			N	N	N	N	N	N	N	N	N	R	
F	*Vitrea transsylvanica* (Cless.)				S	S	S	S	N	S	R	R	R	R	R	N	
F	*Vitrea subrimata* (Reinh.)	N	R	R	S	R	R	C	N	N	N	N	C	C	N		
F	*Aegopinella minor* (Stab.)	R	S			S	R	N	R	N	R	N	R	R	S		
F	*Aegopinella nitens* (Mich.)						N	R		S	S		N	S	R		R
F	*Aegopinella pura* (Ald.)	N	R	N	R		C	C	N	C	N	C	C	C	C		
F	*Oxychilus glaber* (Rossm.)			S					N		S						
F	*Oxychilus depressus* (Sterki)	S	S	R		S	S	S	S	S	R		R				
F	*Cochlodina orthostoma* (Menke)						S	S				S		S	R		
F	*Ruthenica filograna* (Rossm.)	S		S	S		R	R	R	R	N	N	R	R	R	S	
F	*Macrogastra latestriata* (A.Sch.)	S	S						S	S							
F	*Macrogastra plicatula* (Drap.)			S			S	R		S	S	S					
F	*Macrogastra tumida* (Rossm.)	S							S			S		S	S		
F	*Clausilia pumila* Pfr.													S	S		
F	*Alinda biplicata* (Mont.)			S			S				S				S		
F	*Vestia gulo* (Bielz)										S	S	R	S			
F	*Vestia turgida* (Rossm.)						S	R			S						
F	*Bradzbaena fruticum* (Müll.)							S	S		S			S			
F	*Perforatella incarnata* (Müll.)						S			S							
F	*Perforatella vicina* (Rossm.)	S	S	S		S		S	S	S		S		S	S	N	S
F	*Trichia unidentata* (Drap.)						R	R		S	S		S	S			
F	*Chilostoma faustinum* (Rossm.)			S				S		S			S				
F	*Isiognomostoma isonom.* (Schr.)	R	S			S	R	R	S	S	R	S	S	S	R		
F	*Arianta arbustorum* (L.)		R										S				
O	*Pupilla muscorum* (L.)				R											R	R
O	*Vallonia costata* (Müll.)								S	S	S		S	S	S	N	N
O	*Vallonia pulchella* (Müll.)	S	S		R	S		S	S	S			S			N	C
M	*Carychium tridentatum* (Risso)	N	N	N	S	R	N	C	N	C	C	N	C	N	N		
M	*Cochlicopa lubrica* (Müll.)				S		S		R								
M	*Columella columella* (G.Mart.)	N	N	R	R	S											
M	*Vertigo substriata* (Jeff.)	N	N	N	N	N		N	S		S	S	R	S			
M	*Vitrina pellucida* (Müll.)																R
M	*Vitrea contracta* (West.)			S	S									S		R	
M	*Euconulus fulvus* (Müll.)	S			S			S			S		S				
M	*Clausilia dubia* Drap.								S		S					S	
H	*Carychium minimum* Müll.	R	N	R		S	R	N	C	R	N	N	N	S	N	R	
H	*Succinea putris* (L.)								S								N
H	*Vertigo geyeri* Lindh.	N	N	N	R	S											
W	*Bythinella austriaca* (Frfld.)						S	N	R	C	C	N	C	N	C	R	R
W	*Galba truncatula* (Müll.)										S	S					R

E. ecological groups of molluscs (after Ložek, 1964; Alexandrowicz, 1987; Alexandrowicz & Alexandrowicz, 2011): F. shade-loving snails, O. open-country snails, M. mesophilous snails, H. hygrophilous snails, W. water snails; Frequency of species: S. single (1–3), R. rare (4–10), N. few (11–32), C. common (33–100), A. abundant (<100).

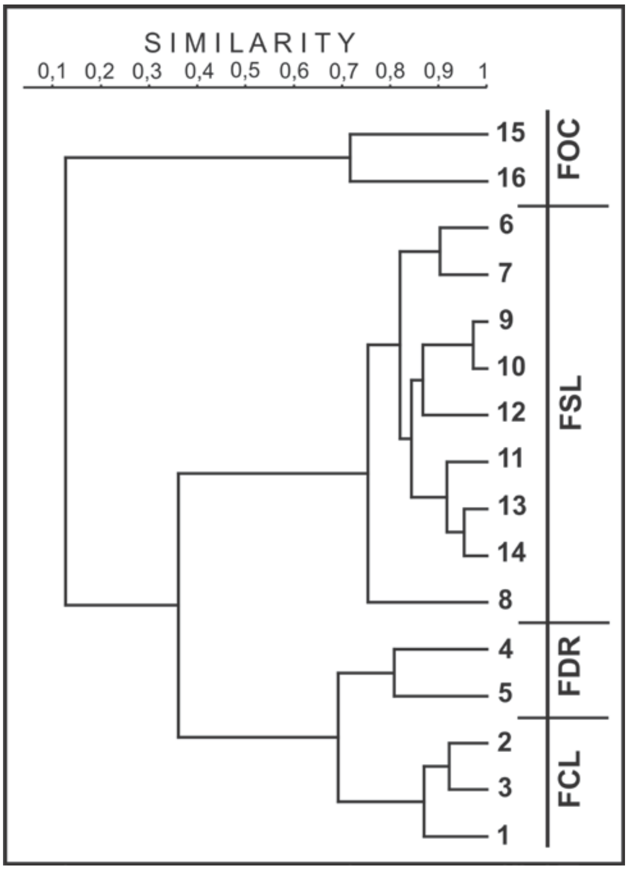

Figure 5. Types of molluscan fauna from profile of calcareous tufa in Niedzica.
FCL, FDR, FSL, FOC molluscan assemblages described in text, 1–16. Samples.

Both the radiocarbon dating result and the features of fauna indicate that the lowest part of the profile in Niedzica is associated with the Preboreal Phase. Faunas of similar composition and showing similar age were described in several other sites of calcareous tufas in the Podhale region (Alexandrowicz, 1997a, 2001a, 2003, 2013b), as well as several sites described from northern and western Europe (e.g. Limondin-Lozouet & Rousseau, 1991; Limondin-Lozouet, 1992; Preece & Day, 1994; Gedda, 2001, 2006).

Assemblage with *Discus ruderatus* (FDR; Fig. 5). It was identified in two samples obtained from the layer of coarse grained and nodule calcareous tufa resting directly on the slope sediments (samples: Gl-4 and Gl-5) (Fig. 2). The following species occur in the mentioned section of the profile in very large numbers: *Discus ruderatus* and *Vertigo substriata*, both of which are dominant taxa. Shade-loving species with higher ecological requirements can also be found, though in small numbers (*Aegopinella pura*). Single shells of cold-loving species, typical of the previously described assemblage, are present as well (Fig. 3). The assemblage with *Discus ruderatus* is an abundant and diversified malacocoenosis with a considerable proportion of shade-loving species. It is typical of forested areas with diverse moisture levels of the substrate, and the dominant community was that of taiga-type coniferous forests. A significant admixture of *Carychium tridentatum* (Risso), which often occurs, is considered one of the most characteristic features of the association in question (Gedda 2001, Meyrick 2002). This fauna is typical of the Early Holocene and related mainly to the Boreal and the beginning of the Atlantic period (8660±130 years BP – 8206−8039 and 8018−7517 cal BC (94.4%); MLK−1344) (Fig. 2). Similar molluscan assemblages showing similar composition and age were described in several other sites of calcareous tufas in the Podhale region (Alexandrowicz & Alexandrowicz, 1995a,b; Alexandrowicz, 1997a, 2001a, 2003, 2013b), as well as several sites described from Europe (e.g. Ložek, 1964, 2000; Dehm, 1967; Limondin-Lozouet & Rousseau, 1991; Limondin-Lozouet, 1992; Meyrick, 2001, 2002; Gedda, 2001, 2006, Žak et.al., 2002; Limondin-Lozouet & Preece, 2004).

Assemblage with shade-loving species (FSL; Fig. 5). This abundant and highly diverse malacofauna is found in the layer of silty tufas forming the main part of the profile (samples: Gl-6 – Gl-14) (Fig. 2). The dominant role is played by shade-loving taxa, of which many forms prefer a warm climate with a fairly high moisture level and dense canopy forests with major proportions of deciduous trees (*Discus perspectivus*, *Aegopinella minor*, *Ruthenica filograna*). Snails typical of cold climates disappear and the frequency of boreal species is clearly lower. The proportion of shade-loving taxa in this association usually exceeds 70%, reaching 90% in some samples (Figs. 3, 4). Open-country, mesophilous and hygrophilous forms (except *Carychium tridentatum* and *Carychium minimum*) occur very rarely. In the higher section of the said interval, aquatic species gain importance, represented mostly by *Bythiniella austriaca*, which is a form typical of spring zones (Alexandrowicz, 2009, 2010, 2013a) (Fig. 3). The timeframe within which the described association had occurred has been derived from radiocarbon dates of the bottom part of the silty tufa layer: 8010±110 years BP; 7297–7224 and 7193–6641 cal BC (94.4%) (MKL–1347) (Fig. 2) indicates that the deposition of silty tufas started in the early part of the Atlantic Phase. Similar fauna was described in other localities of calcareous tufas in the Podhale region (Alexandrowicz & Alexandrowicz, 1995a,b; Alexandrowicz, 1997a, 2001a, 2003).

Assemblage with species of open spaces (FOC; Fig. 5). It is a relatively sparse fauna identified in slope deposits covering the calcareous tufas (samples Gl-15 and Gl-16) (Fig. 2). Snails typical of relatively dry and open habitats are the dominant component of this fauna (*Vallonia pulchella*, *Vallonia costata*) (Figs. 3, 4). Mesophilous and hygrophilous snails are supplementary elements. At the same time, the rapid decline of shadow-loving forms is noted. This malacofauna corresponds to the Subatlantic Phase (620±60 years BP; 1275–1415 cal AD (94.4%); (MKL–1345)) (Fig. 2). Similar molluscan assemblages were found in localities of calcareous tufas and river deposits in the Podhale region (Alexandrowicz & Alexandrowicz, 1995a, b; Alexandrowicz, 1997a, 2001a, 2003, 2013a).

4. DISCUSSIONS

The changes in the composition and structure of malacocoenoses observed in the vertical profile, which form a basis for drawing the distinction between the assemblages described above, are closely related to environmental changes during the sedimentation of deposits. The performed radiocarbon dating enabled the timeframe of these changes to be determined. The basis of the conducted radiocarbon analyses were molluscan shells and, in the case of the youngest sample, plant remains (fragments of tree branches). Well-preserved shells of large snails (*Arianta arbustorum*, *Discus ruderatus*, *Discus perspectivus*, *Aegopinella pura*) were most often subjected to the dating. The samples weighed 40–50g. The age derived from the analysis of snail shells, particularly those of land snails, is often subject to error. The reservoir effect is suspected to be responsible for the old age of the radiocarbon results. This is frequently seen in numerous sites with genetically different deposits, including calcareous tufas related to the late Glacial and early Holocene (Pazdur, 1987; Pazdur et al., 1988a,b). Therefore, it is highly probable that the radiocarbon dates obtained in the Niedzica site show an age slightly older than the actual date. On the other hand, in the immediate vicinity of the profile analysed, there are several more outcrops of deposits containing similar molluscan assemblages, which gave highly similar dating results (Pazdur, 1987; Pazdur et al., 1988a, b; Alexandrowicz, 1997a, 2012, 2013a,b). Moreover, palynological studies and numerous radiocarbon datings performed in peat sites located in the Podhale region allowed the characterisation of the main stages of environmental changes in this area (Obidowicz, 1990). The results of these analyses shows a good correlation with the conclusions drawn from malacological studies (Alexandrowicz, 1997a, 2001a, 2003, 2004, 2013a,b). These facts demonstrate that, although the dating results in the Niedzica site are likely to be inflated, the dating errors are not very large and do not have a major impact on the course of interpretation and the ensuing conclusions.

The oldest elements of the sequence exposed in Niedzica are the slope deposits with fauna containing cold-loving snail species (assemblage with *Columella columella*; Fig. 6). Slope deposits with cold-loving fauna often form the substrate of calcareous tufas. Within the Podhale region, such profiles were described in Gliczarów, Ostrysz and Groń (Alexandrowicz & Alexandrowicz, 1995a,b; Alexandrowicz, 1997a, 2001, 2003, 2013a). The malacocoenoses found in these deposits usually contain an assemblage with *Vertigo genesii*, which is typical of the Late Glacial. The fauna is considered to be typical of the Younger Dryas and has been reported from this stratigraphic position in numerous sites throughout Europe (e.g. Ložek, 1964; Preece, 1998; Alexandrowicz, 1983, 1997a, b, 2001a, 2003, 2004, 2013a; Limondin-Lozouet & Rousseau, 1991; Limondin-Lozouet, 1992; Krolopp & Sümegi, 1993; Preece & Day, 1994; Alexandrowicz & Alexandrowicz, 1995a,b; Mania, 1995; Meyrick, 2001, 2002; Meyrick & Preece, 2001; Gedda, 2001, 2006). Alongside cold-loving forms typical of the Late Glacial (*Vertigo genesii*, *Columella columella*), which constitutes the oldest element of malacological succession in the profile in Niedzica, is marked by the occurrence of fairly numerous shade-loving taxa (*Semilimax kotulai*, *Discus ruderatus*), and even forms with relatively high temperature demands (*Aegopinella pura*). The composition of the fauna indicates its age as the Early Holocene.

The discussed assemblage inhabited poorly shaded environments, although no longer of the nature of arctic tundra, typical of which is the assemblage with *Vertigo genesii*. The occurrence of shade-loving taxa, including the forms with higher ecological requirements, combined with the radiocarbon dating results (9830±150 years BP; 9872−8797 cal BC; MKL−1364) indicates the correspondence of the bottom section of the profile in Niedzica with the Preboreal Phase of the Holocene (Fig. 6). The gradual development of forests and decline of tundra zones in the Podhale region in the lowest part of the Holocene can be inferred from the results of palynological studies (*Betula* phase) (Obidowicz, 1990) and the malacological analyses conducted in the neighbouring sites (Alexandrowicz, 1997a, 2001, 2003, 2013a).

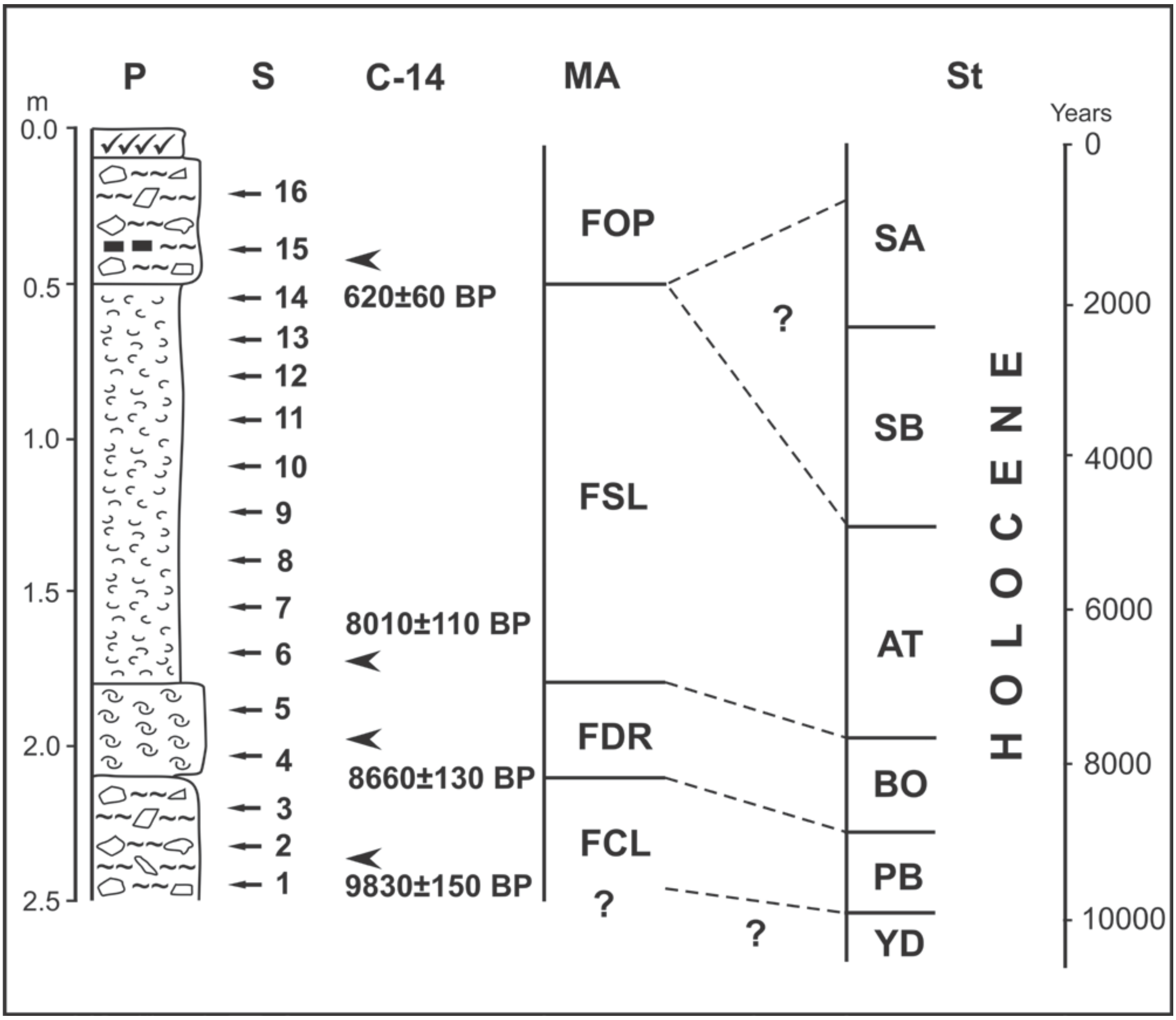

Figure 6. Stratigraphy of profile of calcareous tufas in Niedzica.
P. profile, S. samples, C-14. Radiocarbon dating, MA. molluscan assemblages (described in text) St. startigraphy (after Mangerud et al., 1974): YD. Younger Dryas, PB. Preboreal Phase, BO. Boreal Phase, AT. Atlantic Phase, SB. Subboreal Phase, SA. Subatlantic Phase

The Boreal Phase involved the rapid expansion of forests in the Podhale region. It manifests itself in palynological profiles as a sudden increase in the proportion of tree pollen, especially of conifers (*Pinus* phase) (Obidowicz, 1990). Malacocoenoses associated with this period are marked by the domination of mollusc species connected with taiga-type coniferous forests, which develop in continental climate conditions, and the typical assemblage is fauna with *Discus ruderatus*. In the Niedzica site it occurs in the lowest part of calcareous tufas, and its age was determined as 8660±130 years BP; 8206–8039 and 8018–7517 cal BC; MLK–1344 (Fig. 6). The discussed fauna is known from very numerous Early Holocene sites found across western and central Europe (e.g. Ložek, 1964, Dehm, 1967; Alexandrowicz, 1983, 1997a, b, 2001a, 2004, 2012, 2013a; Preece & Day, 1994; Alexandrowicz & Alexandrowicz, 1995a, b; Gedda 2001, 2006; Žak et al., 2002; Meyrick, 2002; Limondin-Lozouet & Preece, 2004). Assemblages having similar composition and structure are often referred to as „Ruderatus-Fauna" (Dehm, 1967; Alexandrowicz, 2004, 2009, 2013a). The appearance of assemblage with *Discus ruderatus* indicates the rapid forestation of the Podhale area and gradual warming of the climate. A characteristic feature is the presence of forms typical of the late Glacial (*Vertigo genesii*, *Columella columella, Semilimax kotulai*).

Highly essential changes in the malacofauna composition, chiefly the disappearance of cold-loving forms and the increase in the proportion of shade-loving species with high ecological requirements (e.g. *Discus perspectivus*, *Aegopinella minor*, *Ruthenica filograna*), become evident in the higher part of the profile. This assemblage displays the traits of fauna with *Discus perspectivus* („Perspectivus-Fauna" Dehm 1987), which is deemed an indicator for the Middle Holocene and is known from calcareous tufa outcrops in the Podhale region (Alexandrowicz, 1997a, 2001a, 2003), as well as very numerous sites in central and western Europe (e.g. Ložek, 1964; Alexandrowicz, 1983, 1997a, b, 2004; Alexandrowicz & Alexandrowicz, 1995a, b; Füköh, 1995; Meyrick, 2002). In the Niedzica site this fauna occurs in a series of silty tufas, whose bottom part has been dated to be 8010±110 years BP; 7297–7224 and 7193–6641 cal BC (94,4%) (MKL–1347) (Fig. 6).

The tufas are covered by slope deposits containing fragments of tree branches and fauna with an entirely different structure and composition. Thus, there is undoubtedly a stratigraphic gap between the tufas and the slope deposits, which probably extends over the Subboreal Phase and the early part of the Subatlantic Phase (Fig. 6). The cessation of calcareous tufa sedimentation at the end of the Atlantic Phase is a phenomenon noted not only in all calcareous tufa sites in the Podhale region (Alexandrowicz 1997a, 2001a, 2003, 2004, 2013a), but also in many profiles of these deposits in central Europe (e.g. Ložek, 1964; Jäger & Ložek, 1968; Pazdur, 1987; Pazdur et al., 1988a, b; Dobrowolski et al., 2005, 2012). This phenomenon most likely results from climatic conditions or can be related to the growing anthropogenic impact, especially in upland areas (Alexandrowicz 1983, 2004; Alexandrowicz et al., 1997).

Slope deposits, which constitute the youngest parts of the Niedzica profile, contain a scarce assemblage dominated by open-country species. Radiocarbon dating: 620±60 years BP; 1275–1415 cal AD; MKL–1345 shows that they formed in the Middle Ages (Fig. 6). The intensified settlement in the Podhale region, particularly the northern part, dates back to the 13th century (Obidowicz, 1990). This period involved granting municipal charters to several settlements and the construction of two fortified castles. One of them (Niedzica Castle) is located 1 km from the studied site. Vital environmental changes occurred alongside the growth of human population. Such environmental changes principally concern rapid deforestation (phase NAP; Obidowicz, 1990). The consequence of this phenomenon was the intensification of fluvial processes, as well as increased slope processes (Starkel et al., 2006, Alexandrowicz, 1997c, 2013a; Margielewski, 1998). The composition and structure of malacocoenoses were also subject to essential changes. The formerly prevalent assemblages with forest species were replaced by poor faunas with a major proportion of forms of open spaces and an admixture of mesophilous snails. These alterations correspond to the phase of significant climate warming known as the Medieval Warm Period (Grove & Switsur, 1994; Bradley, 2000; Briffa, 2000; Jones & Mann, 2004). The distinct changes in the characteristics of molluscan assemblages associated with anthropogenic deforestation are commonly noted both in mountainous and upland regions (e.g. Starkel et al., 2006; Alexandrowicz et al., 1997). These changes occur at different times, depending on the periods and intensity of settlement development. However, upland areas were typically settled earlier than mountainous regions.

5. CONCLUSIONS

The calcareous tufa site in Niedzica represents the Early and Middle Holocene, as well as historical times (since the 13th century). Abundant molluscan assemblages found in calcareous tufa and the accompanying slope deposits allow changes in the natural environment to be traced. The fauna occurring in the bottom part of the sequence indicates a cold climate with marked continental features and represents the Preboreal Phase. The Podhale region had already been overgrown by thin coniferous and birch forests in that period (Obidowicz, 1990; Alexandrowicz, 1997a). During the Boreal Phase, the development of taiga-type coniferous forests took place (*Pinus* phase; Obidowicz, 1990). Due to the progressive warming of the climate the malacocoenoses were enriched with forest species with relatively high environmental requirements. On the other hand, the forms characteristic of a cold climate gradually withdrew from the Podhale region. Substantial climate-warming and the transition from continental to oceanic circulation at the end of the Boreal Phase was the determinant factor that caused essential transformation of plant formations during Atlantic Phase. Taiga-type forests were replaced by mixed forests composed of more diverse species and high proportions of deciduous trees. This phenomenon has been well documented in the palynological profiles of peatbogs in Podhale (*Ulmus-Corylus* phase; Obidowicz, 1990). Deposits representing the Subboreal and the lower part of the Subatlantic phase have not been preserved. The topmost part of the profile shows clear traces of human impact. It entails the deforestation of slopes, and the malacocoenoses relevant to this period are dominated by species of open spaces.

The sequence of molluscan assemblages identified in the calcareous tufa profile in Niedzica displays considerable similarities to malacological sequences found in other Quaternary deposit sites in the Podhale region (Alexandrowicz, 1997a, 2001a, 2003, 2013a). These similarities are particularly clear in the profile sections representing the Early and Middle Holocene. The characteristic feature shared by all these sites is a long-sustaining presence of cold-loving species typical of the Late Glacial (e.g. *Columella columella*, *Vertigo arctica*, *Semilimax kotulai*, *Vertigo genesii*, *Vertigo geyeri*) in malacocoenoses. They are a substantial component of assemblages representing the Preboreal and Boreal phases, and in some sites they occur even in the deposits representing Atlantic Phase (Alexandrowicz 1997a, 2001a, 2003, 2013a). The mentioned forms are found in very large numbers in Late Glacial deposits, though are very rarely found in Holocene deposits. This fact has been widely reported in numerous sites throughout central and western Europe (e.g. Ložek, 1964; Preece, 1998; Alexandrowicz, 1983, 1997b, 2004, 2012; Limondin-Lozouet & Rousseau, 1991; Limondin-Lozouet, 1992; Krolopp & Sümegi, 1993; Preece & Day, 1994; Alexandrowicz & Alexandrowicz, 1995a, b; Mania, 1995; Meyrick, 2001, 2002; Meyrick & Preece, 2001; Limondin-Lozouet & Preece, 2004; Limondin-Lozouet, 2011). Nevertheless, they are commonly found in Middle Holocene deposits in northern Europe (Gedda, 2001, 2006). The relatively abundant occurrence of these cold-loving forms in Holocene deposits in the Podhale region is doubtlessly related to the local climatic conditions. In intramontane basins, such as the Podhale Basin, cold stagnant air lingering in the depressions is a frequent occurrence, and the climate of these areas is much colder than the surrounding areas, thereby enhancing the chances for the survival of the cold-loving species. These forms are therefore glacial relics. Most of them withdrew from the Podhale region during the Atlantic Phase. Some of them (*Columella columella*, *Vertigo arctica*, *Semilimax kotulai*) can currently be found in the Tatra Mts (Dyduch-Falniowska, 1991; Alexandrowicz, 2001b). The latter can be found in the Podhale region to date (Alexandrowicz, 1997a, 2001a, 2013a).

Malacocoenoses corresponding to historical times show a considerably wider diversity. It ensues from many factors, from landforms to the distance from major human settlements (Alexandrowicz, 1997a). The Niedzica region had been subject to strong anthropogenic pressure already since the 13th century, and the record of intense deforestation leading to the intensified fluvial and slope processes can be found in malacological sequences described in several sites in the immediate environs of this village.

The profile of Holocene calcareous tufas in Niedzica represents a characteristic pattern of malacocoenoses sequence, which is modified by local factors only to a certain extent. In view of the presented malacological sequence, radiocarbon dating, and the comparability with other malacological and palynological profiles in close vicinity, the studied site can be considered a model example of the application of mollusc analysis to provide a reconstruction of the environment.

ACKNOWLEDGEMENT

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

REFERENCES

Alexandrowicz, S.W., 1983. *Malakofauna of the Holocene calcareous sediments of the Cracow Upland.* Acta Geologica Polonica, 33, 117-158.

Alexandrowicz, S.W., 1987. *Malacological analysis in Quaternary research.* Kwartalnik AGH, Geologia, 12, 3-240. (in Polish with English summary).

Alexandrowicz, S.W., 1997b. *Malakofauna of Holocene sediments of the Prądnik and Rudawa River Valleys (Southern Poland).* Folia Quaternaria, 68, 133-188.

Alexandrowicz, S.W., 1997c. *Holocene dated landslides in the Polish Carpathians.* In: Frenzel, B. (Ed.), Rapid Mass Movement as a Source of Climatic Evidence for the Holocene. Palaeoclimate Research, 19, 75-83.

Alexandrowicz, S.W. & Alexandrowicz, W.P., 1995a. *Quaternary molluscan assemblages of the Polish Carpathians.* Studia Geomorphologica Carpatho-Balcanica 29, 41-54.

Alexandrowicz, S.W. & Alexandrowicz, W.P., 1995b. *Molluscan fauna of the Upper Vistulian and Early Holocene sediments of South Poland.* Biuletyn Peryglacjalny 34, 5-19.

Alexandrowicz, S.W. & Alexandrowicz, W.P., 2011. *Malacological analysis, methods of research and interpretations.* Rozprawy Wydziału Przyrodniczego PAU 3, 5-302. (in Polish).

Alexandrowicz, S.W., Alexandrowicz, W.P., Krąpiec, M. & Szychowska-Krąpiec, E., 1997. *Environmental changes of Southern Poland during historical period.* Geologia, Kwartalnik AGH, 23, 339-387. (in Polish with English summary).

Alexandrowicz, S.W., Awsiuk, R., Pazdur, A., Pazdur, M.F. & Śnieszko, Z., 1987. *Holocene calcareous* *tufa in Sieradowice – geology, minaralogy radiochronology and stable isotopes.* Geochronometria, 4, 43-60.

Alexandrowicz, W.P., 1997a. *Malacofauna of Quaternary deposits and environmental changes of the Podhale Basin during the Late Glacial and Holocene.* Folia Quaternaria, 68, 7-132. (in Polish with English summary).

Alexandrowicz, W.P., 1999. *Evolution of the malacological assemblages in North Poland during the Late Glacial and Early Holocene*. Folia Quaternaria, 70, 39-69.

Alexandrowicz, W.P., 2001a. *Late Vistulian and Holocene molluscan assemblages from calcareous tufa at Ostrysz Hill (Podhale Basin).* Folia Malacologica, 9, 159-169.

Alexandrowicz, W.P., 2001b. *Molluscan assemblages from deposits filling small karst forms in the Tatra Mountains (Southern Poland).* Acta Carstologica, 30, 125-142.

Alexandrowicz, W.P., 2003. *The exposure of calcareous tufa in Gliczarów in the Podhale Basin.* Chrońmy Przyrodę Ojczystą, 53, 17-31. (in Polish with English summary).

Alexandrowicz, W.P., 2004. *Molluscan assemblages of Late Glacial and Holocene calcareous tufas in Southern Poland.* Folia Ouaternaria, 75, 1-309.

Alexandrowicz, W.P., 2009. *Malacostratigraphy of Vistulian and Holocene in Poland*. Studia Quaternaria, 26: 55-63.

Alexandrowicz, W.P., 2010. *Molluscan assemblages of recent calcareous tufas in the Podhale Basin and Pieniny Mts (S. Poland).* Folia Malcologica, 18, 99-112.

Alexandrowicz, W.P., 2012. *Assemblages of molluscs from Sulisławice (Małopolska Upland, southern Poalnd) and their significance for interpretation of depositional conditions of calcareous tufas in small water bodies.* Annales Societatis Geologorum Poloniae, 82, 161-176.

Alexandrowicz, W.P., 2013a. *Molluscan assemblages in the deposits of landslide dammed lakes as indicators of late Holocene mass movements in the polish Carpathians*. Geomorphology, 180-181, 10-23.

Alexandrowicz, W.P., 2013b. *Malacological sequence from profile of calcareous tufa in Groń (Podhale Basin, southern Poland) as an indicator of the Late Glacial/Holocene boundary*. Quaternary International, 293, 196–206.

Alexandrowicz, W.P. & Kobojek, S., 1997. *The malacofauna of Upper Vistulian and Holocene sediments at Bełszno near Częstochowa (Southern Poland).* Folia Quaternaria, 68, 189-201.

Bradley, K.R., 2000. *Past global changes and their significance for the future.* Quaternary Science Reviews, 19, 391-402.

Briffa, K.R., 2000. *Annual climate variability in the Holocene: interpreting the message of ancient trees.* Quaternary Science Reviews, 19, 87-105.

Bronk Ramsey, C., 2001. OxCal Program 3.9. University of Oxford. Radiocarbon Accelerator Unit.

Dehm, R., 1967. *Die landschnecke Discus ruderatus im Postglazial Süddeutschlands.* Mitteilungen der Bayerische Staatssammlung für Paläontologie und Historische Geologie, 7, 135-155.

Dehm, R., 1987. *Die landschnecke Discus perspectivus im Postglazial Südbayerns*. Mitteilungen der Bayerische Staatssammlung für Paläontologie und Historische Geologie, 27, 21-30.

Dobrowolski, R., Hajdas, I., Melke, J. & Alexandrowicz, W.P., 2005. *Chronostratigraphy of calcareous mire sediments at Zawadówka (Eastern Poand) and their use in palaeogeographical reconstruction*. Geochronometria, 24, 69-79.

Dobrowolski, R., Pidek, I.A., Alexandrowicz, W.P., Hałas, S., Pazdur, A., Piotrowska, N., Buczek, A., Urban, D. & Melke, J., 2012. *Interdisciplinary studies of spring mire deposits from Radzików (South Podlasie Lowland, East Poland) and their significance for palaeoenvironmental reconstructions.* Geochronometria, 39, 10-29.

Dyduch-Falniowska, A., 1991. *The Gastropods of the Polish Tatra Mountains.* Studia Naturae, 38, 5-111.

Füköh, L., 1993. *Holocene malacofaunal assemblages in Hungary.* Scripta Geologica, Special Issue, 2, 121-125.

Füköh, L., 1995. *History of the Hungarian Holocene mollusc fauna*. Geojournal, 36, 255-259.

Füköh, L, Krolopp, E. & Sümegi, P., 1995. *Quaternary malacostratigraphy in Hungary*. Malacological Newsletter, Supplement, 1, 5-219.

Gedda, B., 2001. *Environmental and climatic aspects of the Early and Mid Holocene calcareous tufa and land mollusc fauna in southern Sweden.* Lundqua Thesis, 45, 1-50.

Gedda, B., 2006. *Terrestrial mollusc succession and stratigraphy of a Holocene calcareous tufa deposit from the Fyledalen valley, southern Sweden.* The Holocene 16, 137-147.

Grove, J.M., & Switsur, R., 1994. *Glacial geological evidence for the Medieval Warm Period.* Climatic Change, 26, 143-169.

Hammer, Ø., Harper, D.A.T. & Ryan, P.D., 2001. *Past: paleontological statistics software package for education and data analysis*. Palaeontologica Electronica, 4, 1-9.

Jäger, K. D. & Ložek, V., 1968. *Beobachtungen zur Geschichte der Karbonatdynamik in der Holozän Warmzeit.* Československý Kras, 19, 7-20.

Jones, P.D., Mann, M.E., 2004. *Climate over past millennia*. Reviews of Geophysics, 42, 1-42.

Kerney, M.P., Precce, R.C. & Turner, C., 1980. *Molluscan and plant biostartigraphy of some Late Devensian and Flandrian deposits in Kent.* Philosophical Transactions of the Royal Society of London, B 291, 1-43.

Krolopp, E., 1983. *Biostratigraphic division of Hungarian Pleistocene formations according to their mollusc fauna.* Acta Geologica Hungarica, 26, 69–82.

Krolopp, E. & Sümegi P., 1993. *Vertigo modesta (Say 1924), Vertigo geyeri Lindholm 1925 and Vertigo genesii (Gredler 1856) species in Pleistocene formations of Hungary*. Malakological Newsletter, 12, 9-14.

Limondin-Lozouet, N., 1992. *Biogeographie Holocene de Vertiginidae (Mollusca - Gastropoda) Europeens: relations la derniere deglaciation*. Compest Rendus de l'Académie des Sciences Paris, 315, 1281-1287.

Limondin-Lozouet, N., 1995. *Late-Glacial and Holocene malacofaunas from archaeological sites in the Somme Valley (North France).* Journal of Archaeological Science, 22, 683-698.

Limondin-Lozouet, N., 2011. *Successions malacologiques à la charnière Glaciaire/ Interglaciaire: du modèle Tardiglaciaire-Holocène aux transitions du Pleistocène*. Quaternaire, 22, 211-220

Limondin-Lozouet, N. & Preece, R.C., 2004. *Molluscan successions from the Holocene tufa of St Germain-le-Vasson, Normandy (France) and their biogeographical significance*. Journal of Quaternary Science, 19, 55-71.

Limondin-Lozouet, N., & Rousseau, D.D., 1991. *Holocene climate as reflected by a malacological sequence at Verriers, France.* Boreas, 20, 207-229.

Ložek, V., 1964. *Quartärmollusken der Tschechoslowakei.* Rozpravy Ustředniho Ustavu Geologického, 31, 1-374.

Ložek, V., 1972. *Holocene Interglacial in Central Europe and its land snails.* Quaternary Research, 2, 327-334.

Ložek, V., 2000. *Palaeoecology of Quaternary Mollusca.* Antropozoikum, 24, 35-59.

Mangerud, J., Andersen, S.T., Berglund, B.E. & Donner, J., 1974. *Quaternary stratigraphy of Norden, a proposal for terminology and classification.* Boreas 3, 109-126.

Mania, D., 1973. *Paläoökologie, Faunenentwicklung und Stratigraphie des Eiszeitalters im mittleren Elbe-Saalegebiet auf Grund von Molluskengeselschaften.* Geologie, Beiheft, 78-79, 1-175.

Mania, D., 1995. *The influence of Quaternary Climatic development on the Central European mollusc fauna.* Acta Zoologica Cracoviensis, 38, 17-34.

Margielewski, W., 1998. *Landslide phases in the Polish Outer Carpathians and their relation to the climatic changes in the Late Glacial and Holocene*. Quaternary Studies in Poland, 15, 37-53.

Meyrick, R.A., 2001. *The development of terrestial mollusc faunas in the 'Rheinland region' (western Germany and Luxembourg) during the Lateglacial and Holocene.* Quaternary Science Reviews, 20, 16-17, 1667-1675.

Meyrick, R.A., 2002. *Holocene molluscan faunal history and environmental change at Kloster Mühle, Rheinland-Pfalz, western Germany.* Journal of Quaternary Science, 18, 121-132.

Meyrick, R.A & Preece, R.C., 2001. *Molluscan succesions from two Holocene tufas near Northampton, English Midlands.* Journal of Biogeography, 28, 77-93.

Morisita, M., 1959. *Measuring of interspecific association and similarity between communities.* Memoris of the Faculty of Sciences, Kyushu University, 3, 65-80.

Obidowicz, A., 1990. *Eine pollenanalytische und moorkundlische Studie zur Vegetationgeschichte des Podhale-Gebietes (West-Karpaten).* Acta Palaeobotanica, 30, 147-219.

Pazdur, A., 1987. *Isotopic composition of carbon and oxygen in Holocene calcareous tufa sediments.* Geochronometria, 3, 14-75. (in Polish with English summary).

Pazdur, A., Pazdur, M. F. & Szulc, J., 1988a. *Radiocarbon dating of Holocene calcareous tufa from south Poland.* Radiocarbon, 30, 133-146.

Pazdur , A., Pazdur, M. F., Starkel, L. & Szulc, J., 1988b. *Stable isotopes of the Holocene calcareous tufa in southern Poland as palaeoclimatic indicators.* Quaternary Research, 30, 177-189.

Preece, R.C., 1980. *The biostratigraphy and dating of the tufa deposit at the Mesolitic site at Blashenwell, Dorset, England*. Journal of Archaeological Science, 7, 345-362.

Preece, R.C., 1998. *Mollusca*. In: Preece, R.C., Bridgland, D.R. (Eds.), *Late Quaternary environmental change in North-West Europe: excavations at Holywell Coombe, South-West England.* Chapman & Hall, London, pp. 158-212.

Preece, R.C. & Day, S.P., 1994. *Comparison of Post-glacial mollusccan and vegetational successions from a radiocarbon-dated tufa sequence in Oxfordshire*. Journal of Biogeography, 21, 463-468.

Rousseau, D.D., Limondin-Lozouet, N., Magnin, F. & Puissegur, J.J., 1994. *Temperature oscillations over the last 10,000 years in western Europe estimated from terrestrial mollusc assemblages.* Boreas, 23, 66-73.

Rousseau, D.D., Limondin-Lozouet, N. & Puissegur, J.J., 1993. *Holocene environmental signals from mollusc assemblages in Burgundy (France).* Quaternary Research, 40, 237-253.

Starkel, L., Soja, R. & Michczyńska, D.J., 2006. *Past hydrological events reflected in Holocene history of Polish Rivers.* Catena, 66, 24-33.

Žak, K., Ložek, V., Kadlec, J., Hladikova, J., & Cilek, V., 2002. *Climate-inducted changes in Holocene calcareous tufa formations, Bohemian Karst, Czech Republic.* Quaternary International, 91, 137-152.

Received at: 30. 05. 2013
Revised at: 07. 08. 2013
Accepted for publication at: 26. 08. 2013
Published online at: 07. 09. 2013