acta
geologica
polonica

Vol. 33, No. 1-4 Warszawa 1983

STEFAN WITOLD ALEXANDROWICZ

Malacofauna of Holocene calcareous sediments of the Cracow Upland

ABSTRACT: The calcareous tufas and travertines of the Cracow Upland were formed in the Boreal, Atlantic and Sub-Boreal periods of the Holocene. The contained rich malacofauna testifies the variation and evolution of habitats in response to changing climatic conditions and the human activities. At the initial stage of calcareous deposition, the assemblages were not very distinctive. During the climatic optimum the content of forest snails increased markedly, then gradually decreased, and there appeared abundant species pointing to the progressing deforestation of the Upland. In the investigated profiles two types of facies sequences are distinguished, characterized by mollusc assemblages of different composition. One shows the predominance of species preferring moist, meadow and poorly wooded environments, the other contains the species inhabiting a variety of environments, including snails thriving in shaded habitats. Tufas and travertines were deposited on flat valley floors, in the midst of moist and watery meadows, brushwood and forests, as well as in water basins. In the Sub-Atlantic period erosional processes intensified, due to which the deposition of calcareous sediments was completed, and valley floors dissected and deepened to the present-day level.

INTRODUCTION

Tufas, travertines, foamy sinters, loamy sinters and calcareous silts have been reported from many localities in the Cracow Upland. They contain rich fossil assemblages consisting mainly of molluscs, ostracodes and plant remains. These sediments occur in valleys that cut through Paleozoic and Mesozoic carbonate formations, particularly through Middle and Upper Devonian dolomites and limestones, Lower Carboniferous limestones, Lower Permian calcareous conglomerates, Lower and Middle Triassic limestones and dolomites, and Upper Jurassic limestones. The outcrops of travertines, tufas and sinters are situated in the floor and slopes of valleys, in terrace scarps, small waterfalls, and around the springs. They are unstable, susceptible to erosion and subsequently covered with colluvia and hillwash. Pronounced changes in the state of outcrops are produced by floods, the shifting of stream channels, the regulation of streams and the development of their banks.

The sediments in question have been known since the 18*th* and the first half of 19*th* century (Rzączyński, Staszic, Pusch, Zeuschner). In the years preceding the First World War many authors (Alth, Roemer, Tietze, Raciborski, Kuźniar, Wiśniowski) gave brief descriptions of major outcrops and mentioned the occurrence of malacofauna and leaf prints in tufas and travertines.

Relatively ample informations was given by Zaręczny (1894), who described tufas and travertines of Szklarka, Racławka and Czernka valleys near Krzeszowice, and of the area of Rybna and Chrzanów in the southern part of the Cracow Upland. This author was of the opinion that most Quaternary sinters formed in zones of Paleozoic carbonate rock outcrops, appearing only sporadically in areas of Jurassic limestone outcrops. Zaręczny distinguished two stages in formation of the Holocene calcareous sediments. At the early stage, tufas and travertines filled up some depressions and parts of valleys up to a height of a few or even dozen or so metres, and the bulk of them was removed by erosion. Travertines of younger generation are being formed at present in the immediate vicinity of springs flowing out from Paleozoic or Triassic limestones and dolomites. Rich snail assemblages found by Zaręczny in the tufas and travertines do not differ essentially from those inhabiting today the Cracow Upland, which fact was regarded as being indicative of Holocene age of these sediments.

Detailed studies of the sinters occurring near Ojców were carried out by Lewiński (1913), who found that sinters were wide-spread in valleys cutting through Upper Jurassic limestones. They covered the flat floor of these valleys and containend abundant snails which there were no representatives of the family Clausillidae, so common in the present-day faunal assemblages. According to Lewiński, tufas and travertines deposited under the conditions of dry steppe climate, partly in the period preceding the formation of loess.

The Holocene calcareous sediments of the Cracow Upland attracted again the scientific attention in the middle of this century. Walczak (1965) described tufas and travertines exposed in the Będkowska valley; compact travertines form here two waterfalls, and loose tufas containing fairly abundant snails are exposed nearly. The formation of these sediments was determined as the Late Glacial — Early Holocene. Brief descriptions of other outcrops were given by Gołąb (1949), Siedlecki (1952), Bukowy (1956), Wilk (1958), Gradziński (1972), Alexandrowicz & Wilk (1962), and Alexandrowicz & Alexandrowicz (1970).

Over the past few years the present author carried out studies of malacofauna occurring in the younger Quaternary tufas, sinters and travertines of southern Poland. Investigations were made in the Cracow Upland, *i.a.* within the Racławka valley (Alexandrowicz & Stworzewicz 1983) and the Będkowska valley (Alexandrowicz 1982).

The systematic investigation of all available sites comprised profiles located mainly in the northern part of the Upland, between Cracow, Przeginia and Trzebinia (Text-fig. 1). Samples for malacologic studies were collected from outcrops in two or three stages. First they were taken from each bed at intervals of 10—40 cm, and after the tentative determination of the distribution and frequency of snails and bivalve shells, further samples were collected, mostly from beds abounding in malacofauna and from sediments in which malacofaunal assemblages showed wide variation. The total number of samples was 237, their weight being 2—4 kg. They were disintegrated by soaking in water and drying, and in some cases also by boiling, and then washed on a 0.5 mm mesh sieve. All identifiable shells or fragments of shells were carefully picked from the residuum, and the number of specimens of each taxon in a sample was determined using the method proposed by Ložek (1964) and Puissegur (1976). The analysis of differentiation of malacofauna concerned the whole palaeontological material, whilst 72 samples, representing all the profiles and outcrops, were selected to illustrate the characteristics of the assemblages and their variation. The frequency of taxons was determined by semi-quantitative method (*cf.* Alexandrowicz 1980, 1981). The composition of malacofauna (*see* Pls 1—3) is represented by malacospectra of species (*MSS*) and individuals (*MSI*) which show quantitative proportions of molluscs assignated to the ecological groups defined by Ložek (1964, 1969) and Puissegur (1976).

The present studies are a contribution to the Project *MR I/25*, sponsored by the Polish Academy of Sciences. The author's thanks are due to Dr. E. Stworzewicz for her kind delivery of comparative collections of molluscs, and to Dr. J. Rutkowski for supplying data on the tufa outcrop at Mirów.

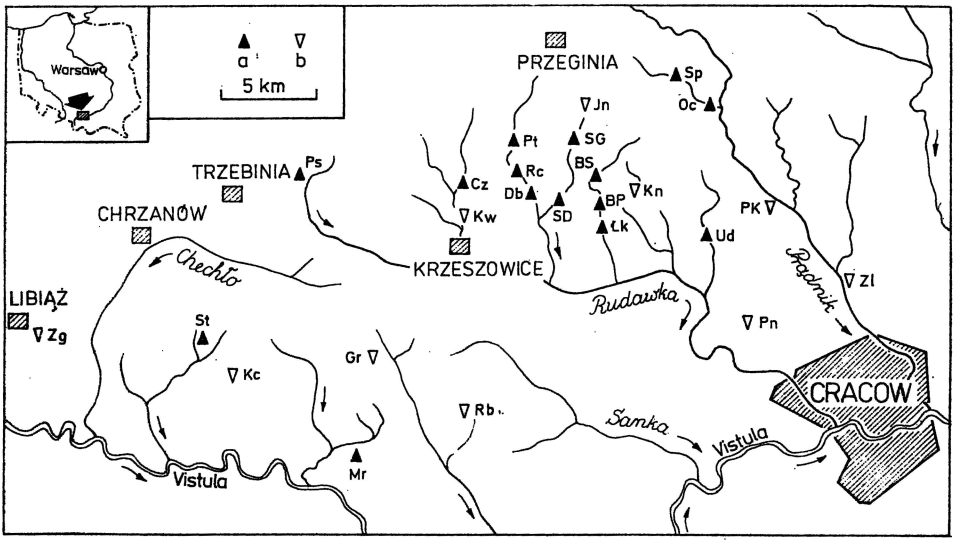


Fig. 1. Location of Holocene tufa and travertine outcrops in the Cracow Upland: **a** — outcrops described in this paper, **b** — inaccessible outcrops, described by former authors

PROFILES AND OUTCROPS

The investigated tufas and travertines of the Cracow Upland are mostly located in the northern part of the Upland, in the Prądnik and Sąspówka valleys and in the stream valleys belonging to the drainage area of the Rudawa river north of Krzeszowice (*cf.* Text-fig. 1). A few outcrops of tufas are located in the southern part of the Upland, in the valleys of streams running directly to the Vistula.

Some outcrops of Quaternary travertines which were known in the past have failed to be found by the present author. In the Prądnik valley, the exposure accessible twenty-five years ago at Zielonki, was situated on the left side of the valley (*Zl* in Text-fig. 1), where a bed of tufas and loose travertines 1.5 m thick with abundant shells of snails rested on gravels (Bukowy 1956). The exposure at Prądnik Korzkiewski, mentioned by Lewiński (1913), showed a thin layer of loose tufa in the stream bed of the Prądnik (*PK* in Text-fig. 1).

Fragments of compact travertines can be found in the Karniowice valley (*Kn* in Text-fig. 1), yet no profile from which they derive is exposed. Similar travertines were reported by Zaręczny (1894) from the Filipowice valley (*Fl* in Text-fig. 1).

In the upper part of the Szklarka valley, at Jerzmanowice (*Jn* in Text-fig. 1), there occur white tufas with abundant snails, covered with a layer of compact travertine. They rest on clays and clayey silts, attaining a thickness of 1.5 m (Lewiński 1913). This outcrop is now covered up and so is a sinter outcrop at Czatkowice, at the tectonic contact of Carboniferous and Jurassic limestones (*Kw* in Text-fig. 1), where these sinters formerly well exposed and contained abundant molluscs (Zaręczny 1894).

In the southern part of the Upland, outcrops of travertines and tufas, now covered and inaccessible, were reported from Rybna, Grojec and from the area of Kwaczała (*Rb, Gr, Kc* in Text-fig. 1). Rich mollusc assemblages were found by Zaręczny (1894) in travertines at Rybna. Sandy tufas devoid of fauna are also known (Wilk 1958) from Zagórcze Małe near Libiąż (*Zg* in Text-fig. 1).

OJCÓW

An outcrop of tufas and travertines is located in the Sąspówka stream valley at Ojców (*Oc* in Text-fig. 1), near its debouchment into the Prądnik river (Lewiński 1913, Alexandrowicz & Wilk 1962, Alexandrowicz & Alexandrowicz 1976). In the past sixty years the condition of this outcrop changed considerably, mainly due to the recesion of the waterfall edge in which there is a compact travertine layer.

Tufas and travertines are now exposed on the right bank of the Sąspówka stream by the waterfall, in a scarp that is more than 5 m high (Text-fig. 2). In the lower part of the profile, the travertines are compact, cavernous and porous, with leaf prints and scarse snail shells. There is also a layer of friable loose travertines containing a poor malacofaunal assemblage (sample *Oc-1*). It is overlain by grey-whitish and yelow nodular tufas with inserts and lenses of travertines, containing fairly abundant snail shells (*Oc-2, Oc-3, Oc-4*). They pass upward into silty tufas and grey or light-grey loamy sinters intercalated by calcareous silts, in which rich malacofauna has been found (*Oc-5, Oc-6, Oc-7*).

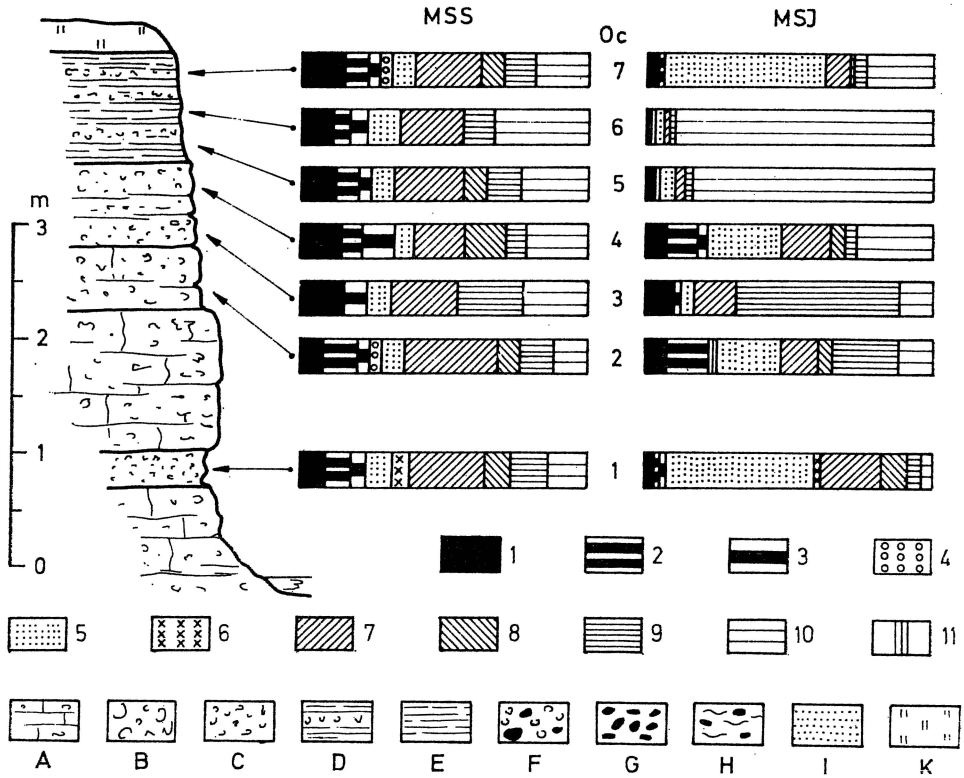


Fig. 2. Profile of tufas and travertines at Ojców (*Oc*) in the Sąpsówka valley
MSS — malacospectra of species, **MSI** — malacospectra of individuals; both for successive samples (*1*—*7*)

LITHOLOGIC SYMBOLS (for Text-figs 2—16): **A** — compact porous travertines, **B** — nodular travertines, **C** — loose tufas with calcareous nodules, **D** — silty and fine-grained tufas, **E** — calcareous silts with parallel bedding, **F** — slope breccia cemented with tufa or travertine, **G** — talus, debris and block-fields, **H** — loams with limestone fragments, **I** — sands and silts, **K** — loess hillwash

ECOLOGICAL GROUPS (*according to* Ložek, 1964): *1* typical forest species, *2* species inhabiting mainly forests, *3* species of moist forests, *4* steppe and xerothermic species, *5* meadow species of woodless or poorly wooded areas, *6* mesophile species of moderately dry environments, *7* mesophile species of moderately moist environments, *8* mesophile species of moist environments, *9* species of very moist, watery environments and swamps, *10* aquatic species, *11* accessory ecological groups

The composition of mollusc assemblages in the profile is diversified (Table 1). This variation is well reflected by malacospectra of individuals (*MSI*), i.e. it consists in a different number of specimens representing each ecological group. Malacospectra of species (*MSS*) show little variation (Text-fig. 2), the content of taxons having a preference of specific environments being; forest species 23—30%, meadow species 9—12%, eurytopic species 22—40%, hygrophilic and aquatic species 27—40%.

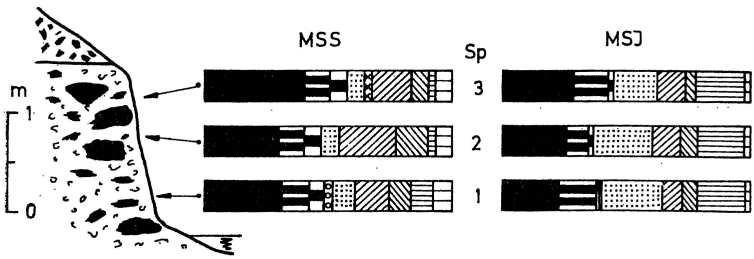
In the lower part of the profile, in travertines (*Oc-1*), the malacofaunal assemblage contains a great number of snails typical of open and woodless environments, mainly of the species *Vallonia pulchella* (Müller). Specimens representing eurytopic species, especially *Perpolita radiatula* (Alder), are also fairly common. Nodular tufas (*Oc-2, Oc-3, Oc-4*), in the lower and upper parts of the bed contain a thanatocenose showing equal proportions between ecological groups, yet a slightly higher content of snails from the forest environment, i.e. *Isognomostoma isognomostoma* (Schröter) and *Vitrea crystallina* (Müller). In the middle part of this bed worth noting is the abundance of snails inhabiting very moist environments, the most characteristic of which is *Succinea elegans* (Risso). In two successive samples (*Oc-5, Oc-6*) the composition of the assemblage changes markedly, its dominant component being aquatic molluscs: *Anisus leucostomus* (Millet), *Lymnaea truncatula* (Müller), *Valvata cristata* Müller, and *Pisidium* sp. In the top part of the profile (*Oc-7*) there is again an increase in the number of snails typical of open environments, represented by *Vallonia pulchella* (Müller).

The above succession of mollusc assemblages reflects the evolution of their habitats at the confluence of the Sąspówka and Prądnik valleys during the Holocene. At the time of deposition of travertines, the valley floor was partly woodless whilst the slopes and the plateau surface were covered with mixed and deciduous forests. At the subsequent stage, moist and watery habitats, as well as forest environments, became predominant, which may correspond to the Holocene climatic optimum and partly also to the Sub-Boreal period. The rise of loamy sinters and calcareous silts (upper part of the profile) containing aquatic malacofauna indicates that the valley floor was swamped and partly flooded, whereupon due to the deepening of the stream channel, it dried again and open, woodless habitats developed. This final stage of deposition of tufas and travertines may have been in intimate association with the activities of man, the deforestation of the land, and the intensification of erosion. Such changes took place towards the close of the Sub-Boreal period and in Sub-Atlantic period. Consequently it is inferred that the calcareous sediments in question formed mainly in the Middle Holocene. The succession of beds and malacofaunal assemblages shows close similarity to that from the Racławka valley (Alexandrowicz & Stworzewicz 1983).

SĄSPÓW

In the upper part of the Sąspówka valley, about 1 km SE of Sąspów (*Sp* in Text-fig. 1), there is an autcrop of tufas containing numerous snail shells. It is situated in a scarp on the right bank of the stream, below the "Młynna" klippe. The tufas atain a thickness of 1.5 m, their bottom is not visible, and they are covered with Jurassic limestone debris which forms a fan at the foot of the klippe (Text-fig. 3). The tufas are white and grey-whitish in colour, loose, unbedded. They contain randomly distibuted fragments and blocks of Jurassic limestones of different sizes.

The mollusc assemblage found in the tufas is nearly homogeneous (Table 1). Malacospectra of species (*MSS*) and individuals (*MSI*) reveal a high content, running up to 50%, of forest snails (Text-fig. 3): *Isognomostoma isognomostoma* (Schröter), *Acicula polita* (Hartmann), *Aegopinella pura* (Alder), and the presence of a few species of the family *Clausillidae*. Well represented are also: *Vallonia pulchella* (Müller), *Punctum pygmaeum* (Draparnaud), *Carychium tridentatum* (Risso) and *C.minimum* Müller. Aquatic molluscs are an accessory component. The com-



Fgi. 3. Tufa outcrop at Sąspów (*Sp*) in the Sąspówka valley; symbols the same as in Text-fig. 2

position of malacofauna indicates that the tufas were deposited under the conditions of warm and humid climate at the foot of a slope covered with deciduous forest, on the valley floor occupied by a variety of habitats. The suggested time of their formation is the Atlantic or Sub-Boreal period of the Holocene.

UJAZD

In the Kluczwoda valley, foamy sinters and tufas occur at the village of Ujazd (*Ud* in Text-fig. 1). The valley there is flat and broad, with wide terraces and gently inclined slopes. The outcrop is situated on the northern periphery of the village, on the left bank of the stream.

The tufas are white or grey-whitish in colour, loose, silty or nodular, unbedded, attaining a thickness of 50 cm. They rest on grey and grey-yellowish silty loams containing small pebbles of Jurassic limestones, and are overlain by silts and loess hillwash (Text-fig. 4). The malacofaunal assemblage present in tufas is homogeneous (Table 1), constisting almost entirely of species typical of meadow habitats, euryecological species, aquatic and hygrophilic snails. Malacospectra of species (*MSS*) show equal proportion of these three components whereas malacospectra of individuals (*MSI*) show the marked predominance of aquatic snails (Text-fig. 4), among which *Anisus leucostomus* (Millet) is particularly abundant. Such thanatocenose suggests that the tufas were deposited in a woodless area, on the valley floor partly occupied by marshes and shallow, intensely overgrown water basins. Their deposition presumably took place during the period of progressing deforestation of the Cracow Upland, *i.e.* in the Middle/Upper Holocene.

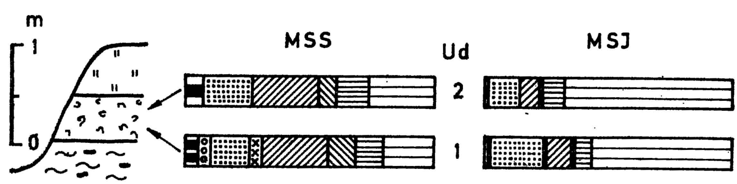


Fig. 4. Tufa outcrop at Ujazd (*Ud*) in the Kluczwoda valley; symbols the same as in Text-fig. 2

Table 1

Mollusc assemblages in profiles and outcrops at Ojców (*Oc*), Sąspów (*Sp*), and Ujazd (*Ud*). The number of mollusc shells in samples: *I* 1—3 specimens, *II* 4—10, *III* 11—31, *IV* 32—100, *V* 101—316, *VI* 317—1000 (*see* Alexandrowicz 1980)
E — symbols of ecological groups (*after* Ložek 1964)

E	Species	Samples: Oc - Ojców 1	2	3	4	5	6	7	Sp-Sąspów 1	2	3	Ud 1	2
1	Acanthinula aculeata					I			II	II	I		
1	Acicula parcenlineata								I		I		
1	Acicula polita		II	I	I	II		II	III	III	III		
1	Aegopinella pura								III	II	III		
1	Cochlodina orthostoma										I		
1	Discus perspectivus								I	I	II		
1	Discus ruderatus							I			I		
1	Iphigena latestriata				I				I		I		
1	Iphigena plicatula								II	II	I		
1	Isognomostoma isognomost.	I	II	I	II	II	I	II	III	II	III		
1	Lacinaria cana							I	I				
1	Orcula doliolum						I		II	I			
1	Oxychilus depressus	I											
1	Ruthenica filograna								II	I	I		
1	Vertigo pusilla				I					I	I		
2	Aegopinella minor								I	II			
2	Bradybaena fruticum		I		I	I		I			I	I	
2	Discus rotundatus	I	I						I				
2	Helix pomatia								I	I	I		
2	Vitrea crystallina	I	III		III	II	I	II	IV	II	III		
3	Iphigena ventricosa				I								
3	Monachoides vicina				I		I		I	I	I		
3	Perforatella bidentata	I	I	I	I	I		I	I	I	I		I
4	Truncatellina cylindrica		I					I	I			I	
5	Pupilla muscorum											II	I
5	Vallonia costata	II	I	I	IV	IV	III	V	II	II	II		
5	Vallonia pulchella	IV	III		I	I	I	II	IV	IV	IV	III	II
5	Vertigo pygmaea								I			I	I
6	Cochlicopa lubricella										I	I	
6	Euomphalia strigella	I											
7	Cochlicopa lubrica	II	II	I	II	II	I	II	II	I	I	I	I
7	Euconulus fulvus	I	I	I	II	II	II	I	I	I		II	I
7	Lacinaria plicata					I							
7	Perpolita radiatula	III	I	I	II	I	I	II				I	I
7	Punctum pygmaeum	I	II		II	I		II	I	II	II	I	I
7	Vertigo alpestris		I							I			
7	Vitrea contracta		I							I	II		
7	Vitrina pellucida	I	I					III	I	I	I		
7	Limacidae	I	I		I	I	I	II	III	II	II	I	
8	Carychium tridentatum	I	II		I	I		II	III	II	II		
8	Columella edentula	II	I		I	I		I	II	I	I		
8	Succinea oblonga				I							I	I
8	Vertigo angustior				I				I	I		I	
8	Vertigo substriata									I			
9	Carychium minimum	I	III	I	III	II	I	II	IV	IV	IV	II	I
9	Succinea elegans	I	II	IV	II	II	I	II				II	II
9	Zonitioides nitidus	I	I	I		II		II					
10	Anisus leucostomus	I	III	I	II	VI	V	IV	I	I	I	IV	IV
10	Armiger crista nautileus											II	II
10	Bithynella austriaca				I								
10	Gyraulus albus					I	II						
10	Lymnaea peregra				I	I	II	I				II	II
10	Lymnaea truncatula	I	II	I	II	II	II	III	I			I	II
10	Valvata cristata		I		I	I	I	III					
10	Pisidium sp.	I		I	II	V	V	IV	I	I	I		

ŁĄCZKI

A tufa layer with inserts of travertines occur in the lower part of the Będkowska valley, near a mill in the village Łączki (*Łk* in Text--fig. 1), in the bottom of the stream and on its left bank. Its thickness varies from 2 to 4 m. In the last century these sediments were very poorly exposed (Zaręczny 1894), and it was only when a small waterfall formed on a travertine layer in the years 1940—1950 (Walczak 1956), and was then dissected that they became accessible. Today they outcrop in a terrace scarp of 1—2 m and in the road below a klippe near the mill (Alexandrowicz 1982). The tufas are white and white-yellowish, silty with intercalations of nodular tufas and sporadic thin lenses of compact, porous travertines.

The mollusc assemblages in these sediments are fairly rich (Table 2). In the lower part of the profile, the dominant are the aquatic molluscs, particularly *Anisus leucostomus* (Millet). Eurytopic snails and species prefering open habitats are also common, being represented by *Perpolita radiatula* (Alder), *Punctum pygmaeum* (Draparnaud), *Euconulus fulvus* (Müller), and *Vallonia costata* (Müller). Forest snails, on the other hand, are a subordinate component of these assemblage (Text-fig. 5). In the middle and upper part of the profile, shells of aquatic snails become scarcer while markedly increases the content of such forest snails as *Acicula polita* (Hartmann), *Isognomostoma isognomostoma* (Schröter), *Discus ruderatus* (Férussac), *Vertigo pusilla* Müller, *Cochlodina laminata* (Montagu), and *Perforatella bidentata* (Gmelin). Meadow snails are represented by *Vallonia pulchella* (Müller) and *V. costata* (Müller). This sequence of assemblages indicates that the tufas formed initially on the moist valley floor, partly in shallow, intensely overgrown and intermittently drying-up water basins. As the stream channel deepened, meadow habitats dried and expanded. The slopes of the valley, which is narrow in this part, were covered with mixed and deciduous forests, and malacofauna inhabiting these forests entered into the composition of the thanatocenose accumulating in the tufas. The sediments in question formed under the condition of warm and humid climate, presumably in the period of the Holocene climatic optimum.

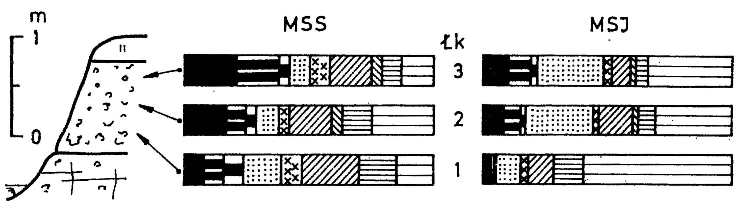


Fig. 5. Tufa outcrop at Łączki (*Łk*) in the Będkowska valley; symbols the same as in Text-fig. 2

WYSOKI WATERFALL

In the middle part of the Będkowska valley, somewhat below the klippes called the Będkowska Gate, a 6-m high waterfall formed on a compact travertine layer. This outcrop of tufas and travertines was described by Lewiński (1913) and Walczak (1956). The waterfall still existed in 1950, when its scarp was dissected. Today calcareous sediments are accessible in several places near the former waterfall, in

(Table 2). Malacospectra of species (*MSS*) show the presence of three equivalent components: forest snails, snails of open environments and euryecological species, as well as aquatic molluscs together with snails having a preference for watery habitat. Malacospectra of individuals (*MSI*) reveal the content of forest snails in the profile increasing markedly upwards, while the number of aquatic mollusc shells diminishes. Snails thriving in open habitats attain a maximum content of about 50% in the middle part of the profile (Text-fig. 6). Among the characteristic

Table 2

Mollusc assemblages in profiles and outcrops at Łączki (*Łk*), Wysoki waterfall in the Będkowska valley (*BP*), and Szeroki waterfall in the Będkowska valley (*BS*); explanations the same as for Table 1

E	Species	Samples:	Łk-Łączki			BP - Będk.val.				BS-Będkowska val.				
			1	2	3	1	2	3	4	1	2	3	4	5
1	Acanthinula aculeata				I		II			I	I		I	I
1	Acicula polita			I	I	III	II	II		I		I	III	II
1	Aegopinella pura			I		I	I			II			II	I
1	Clausilia bidentata											I		
1	Cochlodina laminata				I									
1	Cochlodina orthostoma						I							
1	Discus perspectivus					II	I						I	I
1	Discus ruderatus			II	I	III	III	III	II					
1	Isognomostoma isognomost.		I	I		IV	III	III	II	II	II	I	II	I
1	Orcula doliolum									I			I	I
1	Ruthenica filograna					I		I					I	I
1	Vertigo pusilla				I	I	I	I		I			I	
1	Vestia elata						I							
1	Vitrea diaphana												II	I
2	Aegopinella minor		I		I									
2	Bradybaena fruticum			I	I	I	II	II	I	I				I
2	Cepaea hortensis												I	
2	Discus rotundatus					I				I			I	I
2	Helix pomatia				I	I	II	I	I	I			I	
2	Lacinaria biplicata												II	
2	Vitrea crystallina			II	II	IV	IV	IV	II	III	II	II	III	III
3	Monachoides vicina									I			I	I
3	Perforatella bidentata		I	I	I	II	II	II	I	I				
4	Truncatellina cylindrica					III	III	III	II	I		I	I	I
5	Vallonia costata		II	III	III	IV	III	III	I				IV	III
5	Vallonia pulchella		I	I	III	VI	V	V	III	II	III	II	IV	I
5	Vertigo pygmaea					I								
6	Cochlicopa lubricella		I	I	I								I	
6	Euomphalia strigella				I						I			
7	Clausilia dubia					I			I					
7	Cochlicopa lubrica					III	II	II	I	I	I	I	III	III
7	Euconulus fulvus		I	I	I	II	I	II			I	I	III	I
7	Perpolita radiatula		II	I	I	III	III	II		I	I		II	I
7	Punctum pygmaeum		I	III	I	III	II	I		I	I		II	II
7	Vertigo alpestris											I	I	
7	Vitrea contracta												II	
7	Vitrina pellucida			I	I	IV	III	III		II			III	I
7	Limacidae					II	III	II	II				I	
8	Carychium tridentatum			I	I	III	II	II	I	II		I	II	II
8	Columella edentula					II	I	I					I	
9	Carychium minimum			II	II	IV	III	III	II	II	II	I	IV	II
9	Monachoides rubiginosa												I	
9	Succinea elegans		II	I	I	IV	III	III	II	II	I	I	I	I
9	Succinea putris						I							
9	Vertigo antivertigo					I								
9	Zonitioides nitidus		I	I		III	II	I	I		I	I	II	I
10	Acroloxus lacustris			I										
10	Anisus leucostomus		IV	III	II	VI	III	II	I	I				I
10	Lymnaea peregra		II	II	I	II	I	I			I	I		
10	Lymnaea truncatula			II		II	I					I	I	
10	Valvata cristata			I	III									
10	Pisidium sp.			I		II	I	I	I	II				I

terrace scarps 3—4 m high (*BP* in Text-fig. 1). These are nodular and silty tufas, yellow or grey-whitish in colour. In the lower part of the profile they are grey and contain numerous inserts of loamy sinters, while in the middle and upper parts there occur a few thin lenses of compact, cavernous or friable, porous travertines (Text-fig. 6). All samples collected from these sediments contain abundant snail shells.

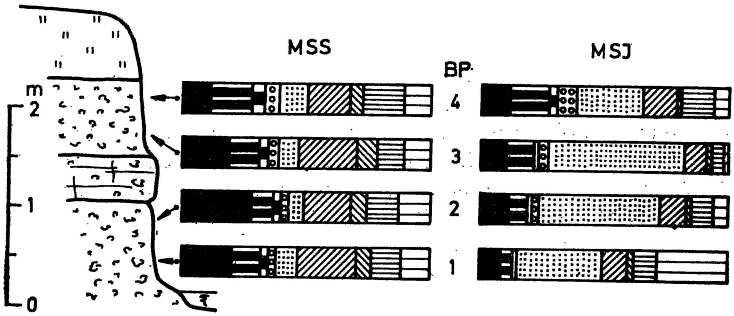


Fig. 6. Profile of tufas and travertines in the Będkowska valley near Wysoki waterfall (*BP*); symbols the same as in Text-fig. 2

The mollusc assemblages are rich and show little variation, particularly in quantitative proportions of species representing the individual ecological groups species present throughout the profile are: ***Discus ruderatus*** (Férussac), ***Isognomostoma isognomostoma*** (Schröter), ***Truncatellina cylindrica*** (Férrusac), ***Perpolita radiatula*** (Alder), ***Vitrina pellucida*** (Müller), and ***Succinea elegans*** (Risso). Worth noting is the presence of ***Vestia elata*** (Rossmässler), reported from the Prądnik valley (Stworzewicz 1973) and the Racławka valley (Alexandrowicz & Stworzewicz 1983).

The tufas and travertines in question represent presumably the middle part of the Holocene, *i.e.* the Atlantic and Sub-Boreal periods. They were deposited on the floor of a fairly wide valley, which was initially very moist and partly occupied by water-meadows and smal water basins. With the lapse of time, the valley floor dried, which promoted the development of meadow habitats. The valley slopes were overgrown with deciduous forests and brushwood, and part of malacofauna found in all samples originated from this environments. The high content of forest snails in the molluscan assemblages may have been due to the progressing afforestation of the country, or to changes in the intensity of hillwash on the plateau surface and on the slopes.

SZEROKI WATERFALL

In the upper part of the Będkowska valley, above the characteristic "Iglica" klippe (*BS* in Text-fig. 1), tufas and travertines are exposed in a waterfall and on the stream banks (Walczak 1956). The waterfall scarp, 3—4 m high, is made up of a compact travertine layer. Below, in scarps on both sides of the stream, a well-exposed profile of calcareous sediments of total thickness of 4 m can be seen (Text-fig. 7). In the lower part, these are grey loamy sinters with tufa intercalations, grading into loose yellow silty tufas. They are overlain by nodular tufas with layers and lenses of compact porous travertines. In the upper part of the profile there occur silty and nodular tufas yellow or grey-whitish in colour, with thin inserts of loamy sinters and calcareous silts. All these sediments abound in mollusc shells.

The mollusc assemblages are rich, showing fairly wide differentiation (Table 2). In the lower part of the profile their principal component is forest snails, their content running up to 50% (*BS-1* in Text-fig. 7). The overlying nodular tufas contain scarce mollusc shells. The content of forest snails is considerably lower in this part of the profile, whereas there is an increase in the number of eurytopic species, particularly those preferring moist and watery environments. The content of meadow snails is also fairly high (*BS-2, BS-3*). In the upper part of the profile the content of forest snails gradually increases, and the assemblages are very rich (*BS-4, B-5*). Malacospectra of individuals (*MSI*) reveal the presence of abundant meadow snails of the genera *Vallonia* and *Truncatellina*.

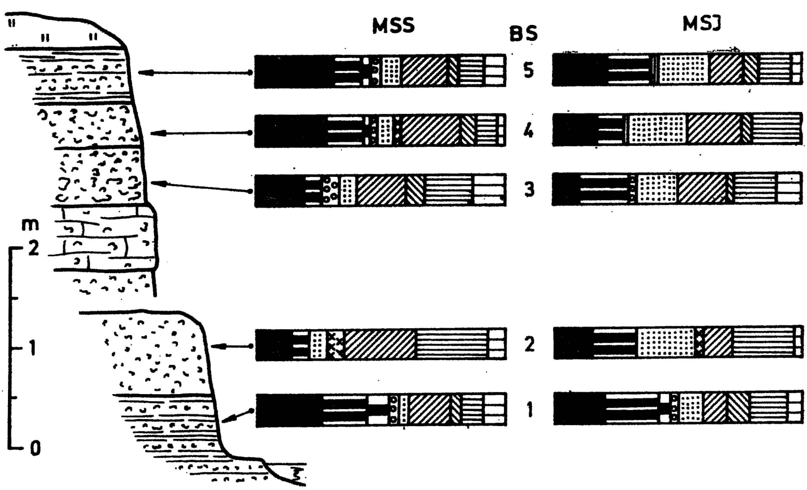


Fig. 7. Profile of tufas and travertines in the Będkowska valley near Szeroki waterfall (*BS*); symbols the same as in Text-fig. 2

The tufas and travertines in question were deposited in the Middle Holocene on the floor of a narrow valley enclosed by steep wooded slopes. The valley floor was initially covered with brushwood and meadows, but in the subsequent period very moist and watery habitats became widespread. At the final stage of formation of tufas, the valley floor dried, which process favoured the development of meadow habitats.

SZKLARY DOLNE

A 6-m thick profile of tufas and travertines, called here Szklary Dolne (*SD* in Text-fig. 1), is exposed in the lower part of the Szklarka valley, 1 km upstream of its confluence with the Racławka valley. In the lower part of the scarp on the left bank of the stream, yellow and grey-whitish nodular tufas with thin inserts of silty tufas are visible. They are overlain by a layer of cavernous and porous compact travertines, on which rest loose yellow nodular tufas with small lenses of friable travertines. The tufas contain two inserts of grey and dark-grey calcareous silts, which are well marked-off in the middle part of the profile. In the upper part of the outcrop there are nodular tufas intercalated by grey-whitish silty tufas (Text-fig. 8).

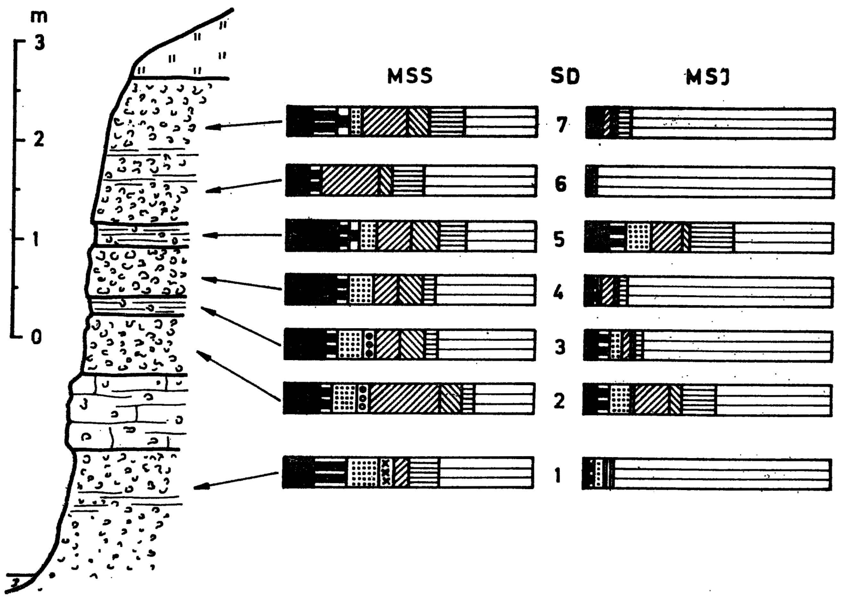


Fig. 8. Profile of tufas and travertines at Szklary Dolne (*SD*) in the Szklarka valley; symbols the same as in Text-fig. 2

Rich malacofauna has been found in these sediments (Table 3). Malacospectra show that the assemblages differ from one another in the amount of snail shells representing the respective ecological groups (*MSI* in Text-fig. 8), while the percentage of species inhabiting particular environments does not virtually show any variation (*MSS* in Text-fig. 8). In the lower part of the outcrop, tufas contain an assemblage of aquatic molluscs with *Acroloxus lacustris* (Linnaeus), *Armiger crista nautileus* (Linnaeus), and *Valvata cristata* Müller. In the tufas overlying the travertine layer the content of aquatic molluscs is not more than 50%, and land snails are represented by all the ecological groups with the quantitative prevalence of mesophile species, e.g. *Euconulus fulvus* (Müller) and *Perpolita radiatula* (Alder). Higher up there appears an assemblage of aquatic molluscs with *Valvata cristata* Müller, and in the upper loamy sinters inserts — a mixed assemblage with a high content of land snails such as *Vitrea crystallina* (Müller), *Vallonia costata* (Müller), *Perpolita radiatula* (Alder), *Punctum pygmaeum* (Draparnaud), and *Carychium minimum* Müller. Aquatic molluscs predominate again in the upper part of the profile (*SD-6*, *SD-7*), especially *Valvata cristata* Müller, *Lymnaea peregra* (Müller), *Armiger crista nautileus* (Linnaeus), and *Anisus leucostomus* (Millet).

The tufas and travertines from Szklary Dolne were deposited in a shallow, intensely overgrown and intermittently drying-up water basin which formed on the floor of the Szklarka valley as a result of the blocking of the stream outflow whereby its level was raised. The higher percentage of land snails in some tufa inserts may be due to the intermittend drying-up of the basin and its filling-up with sediments, as well as to its transformation into watery meadows and swamps. The composition of assemblages may also have been appreciably by the washing of shells from the slopes and the higher part of the valley. The malacofauna found in tufas and travertines of the Szklarka valley indicates that warm and humid climate prevailed at the time of their formation, and the presence of certain snail species suggests that they can be assigned to the Middle Holocene. Their sedimentation may have begun in the Boreal period.

Table 3

Mollusc assemblages in profiles Szklary Dolne (*SD*) and Szklary Górne (*SG*) in the Szklarka valley; explanations the same as for Table 1

E	Species Samples:	SD - Szklarka valley							SG - Szklarka val.				
		1	2	3	4	5	6	7	1	2	3	4	5
1	Acanthinula aculeata		I	I	I	II	I						
1	Acicula polita	I			I	II							III
1	Aegopinella pura												II
1	Cochlodina laminata			II	I	I							
1	Cochlodina orthostoma											I	I
1	Discus perspectivus												I
1	Discus ruderatus	I	II	II					II	II			II
1	Isognomostoma isognomost.		I			I		I	III	II			II
1	Monachoides incarnata					I							
1	Orcula doliolum												I
1	Vertigo pusilla				I	II	II	I	I				I
2	Bradybaena fruticum	I						I	I	I	I		I
2	Lacinaria biplicata												I
2	Vitrea crystallina	I	II	III	II	III	I	II	I				III
3	Monachoides vicina					I						I	
3	Perforatella bidentata							I	I	I			
4	Truncatellina cylindrica												I
5	Pupilla muscorum								I				
5	Vallonia costata	II	III	II	I	III		I	I	III	I	II	III
5	Vallonia pulchella	I	I	I	I	I			IV	V	III	III	V
5	Vertigo pygmaea									I			
6	Cochlicopa lubricella	I	I	I									
7	Clausilia dubia		I	I		I	I						I
7	Cochlicopa lubrica						I	I	III	III		I	I
7	Euconulus fulvus		II			I	I	I	II	III	I	I	II
7	Perpolita radiatula		III	II	II	III	I	I	III	III	I	I	II
7	Punctum pygmaeum	I	I		II	III	II	II	IV	II	I	II	II
7	Vertigo alpestris		I										I
7	Vitrina pellucida								II	II			II
7	Limacidae		I										
8	Carychium tridentatum		II	I		I		I	III	II			II
8	Columella edentula								II	I			I
8	Succinea oblonga								II	II			
8	Vertigo angustior				I	I	I			I			
8	Vertigo substriata		II	I	I	I		I					
9	Carychium minimum	I	III	II	II	IV	II	II	I	II			IV
9	Succinea elegans	I				I	II	II	I		II	I	II
9	Zonitioides nitidus					I	I	I					I
10	Acroloxus lacustris	III	III		I	II	III	I			III		
10	Anisus leucostomus				I	II	II	III		I	IV	II	III
10	Armiger crista cristatus			II		I	I						
10	Armiger crista nautileus	IV	II	IV	III	III	IV	III					
10	Lymnaea auricularia						I						
10	Lymnaea peregra	II		II	II	I	IV	III	I		I		
10	Lymnaea truncatula	I	I	I	I	I	I		II	II	I	I	I
10	Physa fontinalis			I	I		II						
10	Valvata cristata	IV	IV	V	V	IV	VI	V					
10	Pisidium sp.	II	I	III	I	III	III	II	III	II	I		I

SZKLARY GÓRNE

Another profile at Szklary, called here Szklary Górne (*SG* in Text-fig. 1), is exposed about 500 m above the "Brodła" klippe. It is composed of a 3-m thick sequence of tufas and travertines, well visible on the left bank of the Szklarka stream. In the lower part of the outcrop they are white silty and nodular tufas with a thin gravel insert, passing into grey loamy tufas showing parallel bedding. They are overlain by compact cavernous travertines (5.0 m thick), on which there rest white and grey-yellowish nodular tufas with intercalations and lenses of loose porous travertines (Text-fig. 9). These sediments are covered with loess hillwash and sandy silts.

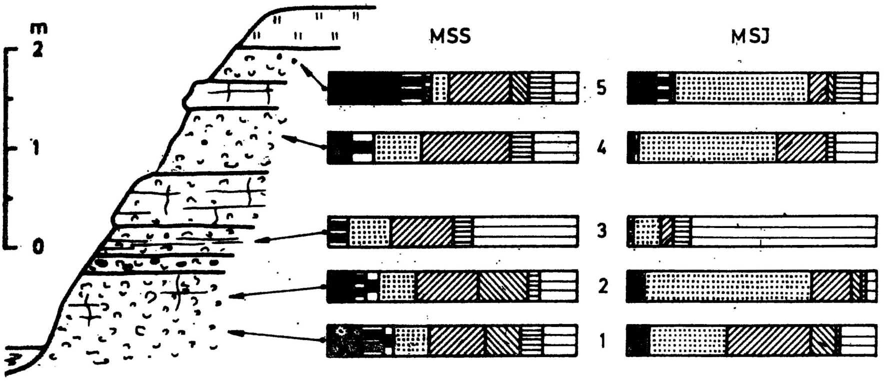


Fig. 9. Profile of tufas and travertines at Szklary Górne (*SG*) in the Szklarka valley; symbols the same as in Text-fig. 2

The mollusc assemblages are rich and widely differentiated (Table 3). In the lower part of the profile they consist of molluscs from a variety of habitats, including abundant shells of *Vallonia pulchella* (Müller) and *Punctum pygmaeum* (Draparnaud). The loamy tufas above the gravel insert contain an assemblage consisting of very few species, with *Anisus leucostomus* (Millet), as the dominant component. In the upper part of the profile, the meadow snails (*Vallonia*) prevail initially, but then the content of forest fauna with *Acicula polita* (Hartmann), *Isognomostoma isognomostoma* (Schröter), *Cochlodina orthostoma* (Menke) and *Vitrea crystallina* (Müller) increases markedly. The species *Discus ruderatus* (Férussac) occurs throughout the whole profile.

The discussed sediments formed in the Lower and Middle Holocene, in the Boreal and Atlantic periods. They were deposited on the flat valley floor where open habitats such as meadows, water-meadows and brushwood prevailed and forest habitats were few. At one time there was a shallow, partly drying-up, intensely overgrown basin there, owing its origin to the temporary blocking of the stream outflow. In the subsequent period of deposition of tufas, meadow environments were dominant again and forest habitats became more widespread, mainly on the valley slopes. The deposition of calcareous sediments was brought to an end by the accumulation of silts and loess hillwash, caused by the progressing deforestation of the plateau surface.

DUBIE

The outcrop of tufas and travertines is situated on the right bank of the Racławka stream near the mouth of the Żary gorge, about 200 m upstream of a forester's lodge at Dubie (*Db* in Text-fig. 1). Fine-grained and nodular yellow silty tufas with inserts of fine- and medium-grained sinters and lenses of compact travertines are exposed in the road scarp. In the lower part of the profile these are unbedded tufas and tufas with

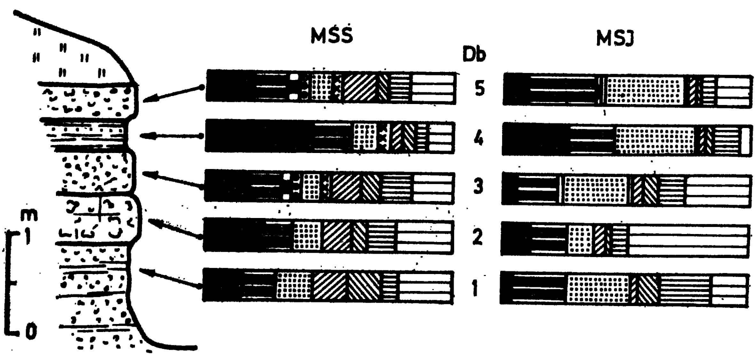


Fig. 10. Profile of tufas, sinters and travertines at Dubie (*Db*) in the Racławka valley; symbols the same as in Text-fig. 2

thin gravel intercalations consisting of pebbles of Paleozoic limestones. They are overlain by a layer of loose travertines, on which there rest cross-bedded fine- and medium-grained sinters intercalated by silty tufas. In the upper part of the outcrop they contain an insert of grey loamy tufas. The sediments in question attain a thickness of 2.5 m.

The mollusc assemblages are fairly rich and show characteristic variation (Table 4). In malacospectra worth notig is the high content of forest snails and the varying amount of aquatic molluscs (Text-fig. 10). In the lower and middle parts of the profile the assemblages contain a large number of snails typical of meadow (*Vallonia*) and moist (*Carychium*) environments. Sporadically there appears malacofauna with abundant *Lymnaee* (sample *Db*-2), pointing the existence of an intermittent water basin. The loamy tufa insert in the upper part of the profile abounds in snails typical of forest habitats: *Acicula polita* (Hartmann), *Aegopinella pura* (Alder), *Cochlodina orthostoma* (Menke), and *Isognomostoma isognomostoma* (Schröter), whereas the top part of the profile again contains a mixed assemblage.

The tufas and travertines at Dubie were deposited on the valley floor, in the part where it is narrow and the slopes are steep and covered with forests. These features were very likely responsible for the high content of forest snails noted in each part of the profile. These sediments may partly owe their origin to the redeposition of sinters which were washed out and eroded in the upper part of the Racławka valley. They presumably represent the middle part of the Holocene, *i.e.* the Atlantic and Sub-Boreal periods. At that time the valley floor was mainly occupied by dry and watery meadows, and there formed intermittent floodplains and shallow, intensely overgrown water basins.

Table 4

Mollusc assemblages in profiles and outcrops at Dubie (*Db*), Paczółtowice (*Pt*), and Czatkowice (*Cz*); explanations the same as for Table 1

E	Species Samples:	Db – Dubie 1	2	3	4	5	Pt-Paczółtowice 1	2	3	4	Cz-Czatk. 1	2	3
1	Acanthinula aculeata		I		I						I	II	
1	Acicula polita	I	I	I	II	II			II	I	II	II	I
1	Aegopinella pura				II	I			II	I	II	II	II
1	Cochlodina orthostoma				I							I	
1	Discus perspectivus	I	I	I	I	I					II	III	I
1	Discus ruderatus			I			I			I			I
1	Helicigona faustina										I		
1	Iphigena latestriata				I								
1	Isognomostoma isognomost.				I			I	I	II	I	I	I
1	Lacinaria cana			I									
1	Monachoides incarnata												I
1	Orcula doliolum										I		
1	Ruthenica filograna											I	
1	Vertigo pusilla		I		I	I			I				
2	Aegopinella minor												I
2	Bradybaena fruticum	II	I	I	I	I						I	I
2	Discus rotundatus											I	
2	Helix pomatia			I								I	I
2	Trichia hispida				I	I							
2	Vitrea crystallina	III	III	III	III	III	I	II	III	III	IV	IV	II
3	Monachoides vicina									I	I		
3	Perforatella bidentata			I		I			I	I	I	I	I
4	Truncatellina cylindrica			I		I							
5	Vallonia costata	II	I	III	III	III	I		I	I	III	III	II
5	Vallonia pulchella	III	II	III	II	III	II	I	III	III	II	II	I
5	Vertigo pygmaea										I	I	I
6	Cochlicopa lubricella			I	I	I							
7	Clausilia dubia									I			
7	Cochlicopa lubrica			I		I				I	II	II	I
7	Euconulus fulvus	I		I		I		I	I	I			
7	Lacinaria plicata												I
7	Perpolita radiatula		I	I		I						I	
7	Punctum pygmaeum	I									I		
7	Vitrea contracta								II	I			
7	Vitrina pellucida											I	
7	Limacidae		I		I		I	I					
8	Carychium tridentatum	II	I	II	I	I		I	II	I	II	II	I
8	Columella edentula	I		I					I	I			
8	Succinea oblonga									I	I		
8	Vertigo substriata												II
9	Carychium minimum	III	II	III	II	II	I	I	III	II	III	IV	III
9	Succinea elegans		I	I			I		I	II			
9	Vertigo antivertigo					I							
9	Zonitioides nitidus			I			I		I	I	I	I	I
10	Acroloxus lacustris									I			
10	Anisus leucostomus		I	I		I			II	II			
10	Armiger crista nautileus									II			
10	Bithynella austriaca												I
10	Lymnaea peregra	II	IV	III	I	II	IV	III	I	II			
10	Lymnaea truncatula	II	I							I			
10	Valvata cristata			II	I	II		I	I	III			
10	Pisidium sp.	I	II	II		I	I	I	I	II	II	II	II

RACŁAWKA

On the left side of the Racławka valley (*Rc* in Text-fig. 1), between the Żary and Stradlina gorges, there exposes a profile of tufas and travertines (8—9 m thick) which is the most complete of all the sections located throughout the Cracow Upland (Zaręczny 1894, Gradziński 1972, Alexandrowicz & Stworzewicz 1983). The lower and middle parts of the profile are made up of white and white-yellowish unbedded nodular and silty tufas with three layers of compact cavernous travertines and two inserts of light-grey tufas and loamy sinters. Above them are grey calcoreous silts intercalated by grey-yellowish loamy and nodular tufas and overlain by sandy silts and loess hillwash (Text-fig. 11).

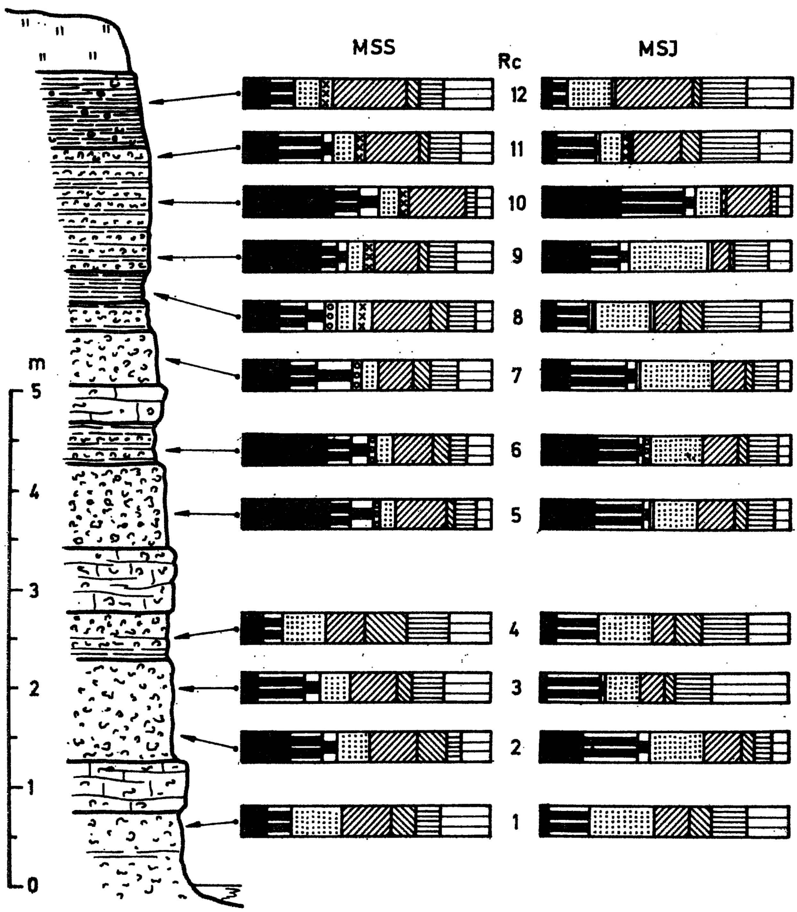


Fig. 11. Profile of tufas and travertines in the Racławka valley (*Rc*); symbols the same as in Text-fig. 2

The composition of malacofauna and its variation was studied on 42 samples collected in three series. Lists of determined taxons and malacospectra were made from 12 selected samples (Text-fig. 11 and Table 5). The profile contains seven distinct mollusc assemblages which form a characteristic sequence.

In the lower layer of nodular tufa (*Rc-1*) the assemblage is poor, including 10 taxons from different ecological groups, with very few forest snails. The tufas overlying the lower travertine layer (*Rc-2*) contain an assemblage having a fairly high content of species inhabiting more or less moist forest. The third assemblage in the sequence (*Rc-3, Rc-4*) is poor, consisting again of mixed malacofauna. In the middle part of the profile (*Rc-5, Rc-6*) there appears a rich mollusc assemblage of a stabilized composition. Among abundant forest snails there occur such species as *Acicula polita* (Hartmann), *Discus perspectivus* (Mühlenfeld), *D. ruderatus* (Férussac), *Cochlodina orthostoma* (Menke), *Iphigena plicatula* (Draparnaud), and *Vestia elata* (Rossmässler). The successive assemblage (*Rc-7, Rc-8, Rc-9*) is enriched in mesophile and hygrophilic species and has a high content of snails typical of meadow habitat (*Vallonia*). Towards the top of the profile, the content of forest

Table 5

Mollusc assemblages in profile of the Racławka valley (*Rc*); explanations the same as for Table 1

E	Species	Samples: Rc – Racławka 1	2	3	4	5	6	7	8	9	10	11	12
1	Acanthinula aculeata					II	I	I		I	I	I	
1	Acicula polita		I	I	I	II	II	II	I	I	I		
1	Aegopinella pura									I	I		I
1	Cochlodina orthostoma					I	I	I					
1	Discus perspectivus					II	I	I			I	I	
1	Discus ruderatus					I	I		I		I		
1	Helicigona faustina											I	I
1	Iphigena latestriata					I				I	I		
1	Iphigena plicatula					I	I						
1	Isognomostoma isognomost.	I	I			II	I	I	I	II	II		
1	Lacinaria cana						I			I	I		
1	Orcula doliolum					I							
1	Ruthenica filograna		I			I							
1	Vertigo pusilla						I		I	I			
1	Vestia elata					I	I			I	I		
2	Bradybaena fruticum		I	II		I	I	I	I	I	I	I	I
2	Discus rotundatus					I							
2	Helix pomatia							I	I		I	I	
2	Lacinaria biplicata			I									
2	Trichia hispida						I					I	
2	Vitrea crystallina	II	II	II	II	III	III	III	III	II	III	II	II
3	Clausilia pumila								I				
3	Iphigena tumida							I					
3	Iphigena ventricosa					I		I					
3	Menachoides vicina					I	I	I	I		I		
3	Perforatella bidentata		I	I		I	I	I		II	I	I	
4	Cepaea vindobonensis							I	I				
4	Truncatellina cylindrica					I	I						
5	Vallonia costata	I	I	I	I	II	I	III	II	II	I	I	I
5	Vallonia pulchella	II	II	II	II	III	III	III	III	III	II	II	II
6	Cochlicopa lubricella								I	I	I	I	I
6	Euomphalia strigella								I				
7	Clausilia dubia					I			I		I		
7	Cochlicopa lubrica	II	I	I	I	II	II	II	I	I	I	I	II
7	Euconulus fulvus					I	I		I	I	I	I	I
7	Lacinaria plicata					I				I			
7	Perpolita radiatula		I	I		II	II	II	II	I	I	II	I
7	Punctum pygmaeum		I			I	I	I	I	I		I	I
7	Vitrina pellucida					I	I	II	I	I	I		I
7	Limacidae	I		I	I				II			II	II
8	Carychium tridentatum				I	II	II	I	III	I		II	I
8	Columella edentula		I					I					
8	Succinea oblonga	I	I	I	I								
8	Vertigo angustior						I		I				
9	Carychium minimum	II	I	II	II	III	III	II	III	II	I	III	III
9	Succinea elegans			I	I	I		I	I	II		I	
9	Zonitioides nitidus					II	I	I	II	I		I	I
10	Anisus leucostomus					I		I		I			
10	Lymnaea peregra			I									I
10	Lymnaea truncatula	II	I	III	I		I	I	III	I	I	II	II
10	Valvata cristata						I	I		II		I	I
10	Pisidium sp.	I	I	I	II	II	I	I	I	I	I	II	II

snails increases markedly again (*Rc-10*), and in the upper part eurytopic, hygrophilic and aquatic species predominate whereas forest snails disappear (*Rc-11, Rc-12*).

The succession of malacofauna shows that the tufas exposed in the lower part of the profile, below the middle layer of travertine, represent presumably the lower part of the Holocene, particularly the Boreal period. They formed on the valley floor occupied by a variety of ecological environments and by an intermittent water basin. Forest habitats were scarce, their number increasing only periodically. Tufas and loamy tufas occurring in the middle part of the profile correspond to the Holocene climatic optimum. They contain an assemblage with numerous species having a preference for mixed and deciduous forest environments, which indicates that forest habitats became more widespread at that time. At the next stage, in the Sub-Boreal period, forest malacofauna gradually diminished in favour of meadow and mesophile species. The beginning of the Sub-Atlantic period is marked by an insert of gray calcareous silts (*Rc-8*); C^{14} dating of this layer is 2475 ± 60 years (communication of J. Szulc at the *Symposium of Speleological Section of the Polish Society of Natural Historians* in 1980). At that time, periods of progressing afforestation alternated with periods of deforestation. These changes, observed in the upper part of the profile, may partly be ascribed to the activities of man, the evidence of which has been found in many localities in the Cracow Upland. The deposition of calcareous sediments was brought to the end by the intensification of erosional processes whereby the valley floor was subject to deep dissection.

PACZÓŁTOWICE

In the middle part of the Racławka valley, near the houses of the village Paczółtowice (*Pt* in Text-fig. 1), tufas and travertines make up a 2-m high terrace on the left bank of the stream. In the lower part of the profile there occur loose, nodular unbedded tufas with poor fauna. Above the tufas there is a layer of compact nodular travertines overlain by white and yellow silty tufas showing fairly distinct parallel bedding. These tufas contain an insert of grey calcareous silts abounding in snail shells (Text-fig. 12).

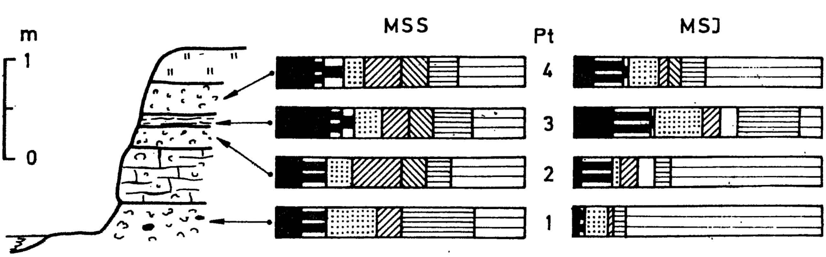


Fig. 12. Profile of tufas and travertines at Paczółtowice (*Pt*) in the Racławka valley; symbols the same as in Text-fig. 2

The mollusc assemblages are poor but show a good deal of variation (Table 4). The assemblage found in the tufas exposed under the travertine layer consists only of 10 taxons representing different ecological groups (*Pt-1*), but the quantitatively dominant component is *Lymnaea peregra* (Müller). The silty and nodular tufas (*Pt-2, Pt-4*) contain an assemblage of a similar composition (see *MSS* in Text-fig. 12), yet the content of aquatic molluscs decreases in favour of forest snails, such as *Isognomostoma isognomostoma* (Schröter) and *Vitrea crystallina* (Müller). A different assemblage was found in the calcareous silts (*Pt-3*). It comprises three components: forest snails, meadow and mesophile snails, and species thriving in very moist and watery environments.

The nature of mollusc assemblages and their sequence indicate that the tufas and travertines from Paczółtowice may be assigned to the Lower and Middle Holocene, to the Boreal and Atlantic periods. They formed on the flat floor of a wide valley, in floodplains, watery meadows and in shallow, overgrown water basins. In the upper part of the profile the content of forest fauna increases, testifying to the expansion of forests, particularly deciduous ones.

CZATKOWICE

In the lower part of the Eliaszówka valley, below the monastery wall, numerous large blocks of porous and cavernous travertines can be found in the stream channel at Czatkowice (*Cz* in Text-fig. 1). A tufa outcrop is situated about 200 m upstream of the confluence of the Eliaszówka and Czernka streams, in terrace scarp 2—3 m in height. The terrace is made up of calcareous gravels and loam containing a large number of pebbles and fragments of Carboniferous limestones. The gravels rest on yellow nodular tufas, fairly compact in places, which pass into loose travertines (Text-fig. 13).

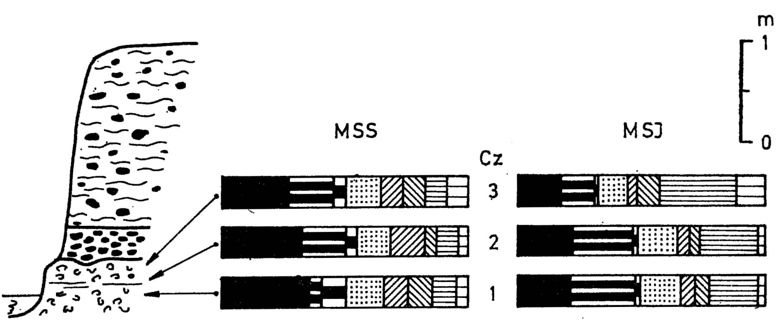


Fig. 13. Outcrop of tufas and travertines at Czatkowice (*Cz*) in the Eliaszówka valley; symbols the same as in Text-fig. 2

The tufas contain rich malacofauna (Table 4). Its major component is forest snails, particularly *Acicula polita* (Hartmann), *Aegopinella pura* (Alder), *Discus perspectivus* (Mühlenfeld), and *Vitrea crystallina* (Müller). Strongly represented are also snails inhabiting open and very moist or watery environments (*Vallonia, Carychium*).

These tufas presumably formed in the period of the Holocene climatic optimum. They were deposited on the valley floor occupied by meadow and watery habitats, surrounded by deciduous forests. As a result of the alternating periods of intensified erosion and deposition, the upper part of calcareous sediments was washed out, removed and replaced by calcareous gravels that now make up a terrace in the Eliaszówka valley.

PSARY

In the slopes of a small gorge in the western part of the village Psary (*Ps* in Text-fig. 1), below a spring flowing out from Lower Triassic dolomites, white tufas are exposed in a few outcrops. They are loose silty tufas with scarce intercalations of nodular tufas and an insert of calcareous silt. Their thickness is 2—3 m, and the are overlain by fine-grained sand (Text-fig. 14).

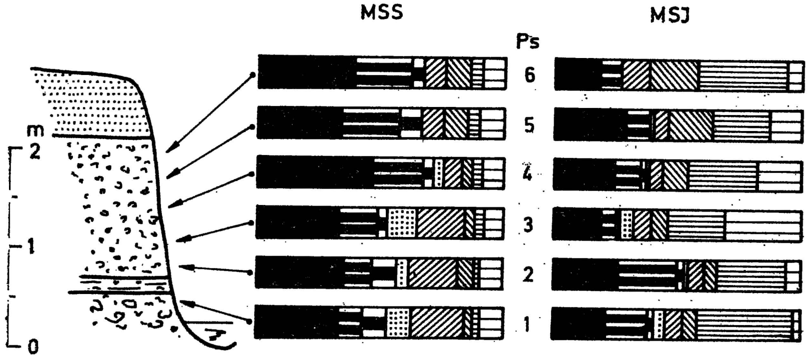


Fig. 14. Profile of tufas at Psary (*Ps*); symbols the same as in Text-fig. 2

The malacofaunal assemblages are very rich but show little variation (Table 6). Malacospectra of species (*MSS*) reveal the presence of two distinct assemblages. In the lower part of the profile the content of forest snails is about 50%, and that of mesofile snails preferring moderately moist habitats — 20%. Praticularly abundant are *Discus perspectivus* (Mühlenfeld), *Orcula doliolum* (Draparnaud), and *Carychium minimum* Müller. In the upper part of the profile forest snails are the dominant component (60—70%). Worth noting is the presence of numerous species representing the family Clausiliidae.

Malacospectra of individuals (*MSI*) show a good deal of variation in the number of specimens belonging in different ecological groups. The percentage of snails inhabiting very moist and watery environments is high and so is the content of aquatic molluscs in some samples (Text-fig. 14).

The succession of mollusc assemblages shows that the tufas of Psary represent mainly the Holocene climatic optimum. This is evidenced by malacofauna typical of deciduos and mixed forests, with a very moist substratum, and brushwood, represented by *Vestia elata* (Rossmässler), *V. turgida* (Rossmässler), *Iphigena plicatula* (Draparnaud), *I. ventricosa* (Draparnaud), *Clausilia pumila* Pfeifer, and *Acanthinula aculeata* (Müller). The sediments in question were deposited in a small valley mostly occupied by watery habitats, in which there existed intermittent floodplains and watery basins. All the surrounding area, now completely deforested, was then covered with forests. The observed variation in the composition of malacofauna provides evidence to suggest that watery and moist environments were more or less widespread during the deposition of tufas.

Table 6

Mollusc assemblages in profiles and outcrops at Psary (*Ps*), Mirów (*Mr*), and Starzyny (*St*); explanations the same as for Table 1

E	Species Samples:	Ps – Psary 1	2	3	4	5	6	Mr – Mirów 1	2	3	4	5	St 1
1	Acanthinula aculeata	III	III	II	I	III	III			II	II	II	
1	Acicula polita	II	III	I	I	I	II	I	I	II	I	III	I
1	Aegopinella nitens							II	II	I			
1	Aegopinella pura	III	IV	III	III	IV		I	II	III	III	III	
1	Cochlodina laminata		I										
1	Cochlodina orthostoma		I							I			
1	Discus perspectivus	III	IV	II	II	II	II	III	III	III	III	II	
1	Discus ruderatus				I					I			
1	Helicigona faustina									I			
1	Iphigena latestriata								I	I		I	
1	Iphigena plicatula	I	I	I	I		I					II	
1	Isognomostoma isognomost.	I	II				I	I	I	I	II	I	I
1	Monachoides vicina						I						
1	Orcula doliolum	II	III	II	I	I	I			I		I	
1	Oxychilus depressus		I										
1	Ruthenica filograna	I	II	I	I			I	I	I	I	I	
1	Trichia unidentata				I	I							
1	Vertigo pusilla	I	II		I	I	I			I	I	I	
1	Vestia elata	I	II	I	I				II		I	I	
1	Vestia turgida							II	I			II	
1	Vitrea diaphana		II						I		I	II	
2	Bradybaena fruticum		I	I	I	I	I	I	I	I	I	I	I
2	Cepaea hortensis					I	I						
2	Discus rotundatus	I	II	I		I	I					I	
2	Helix pomatia				I		I					I	
2	Lacinaria biplicata		I	I	I								
2	Vitrea crystallina	IV	V	II	II	III	III	III	III	I	III	IV	III
3	Clausilia pumila		II			I	I	I					
3	Iphigena tumida	I	I					I	I		I		
3	Iphigena ventricosa	I	II	I				I	I			I	
3	Monachoides vicina	I	II		I	I		I		II	I		
5	Vallonia costata	II	II	II	I			I	I	I	III	II	
5	Vallonia pulchella	I	I	I					II	II	III	II	I
5	Vertigo pygmaea	I		I						III	III		
6	Cochlicopa lubricella									III	III	II	
7	Clausilia dubia	I	I	I				I		I			
7	Cochlicopa lubrica	II	II										I
7	Euconulus fulvus	I	II					II		II	III	II	
7	Lacinaria plicata	I					I					I	
7	Perpolita radiatula		II						I	IV	III	III	
7	Punctum pygmaeum	II	III	II	II	III	III	I		II	II		
7	Vertigo alpestris			I									
7	Vitrea contracta	I	I										
7	Vitrina pellucida		I	II									
7	Limacidae	I	I	I	I	I							I
8	Carychium tridentatum	III	IV	III	III	IV	IV	I	II	IV	III	II	I
8	Columella edentula							I	I	II	III	I	
8	Succinea oblonga							III	III				
8	Vertigo angustior		I			I	I		I	III	II	II	
8	Vertigo substriata		II					I	I	I	II	II	
9	Carychium minimum	V	V	IV	IV	IV	IV	II	II	V	IV	IV	II
9	Succinea elegans							II	II			I	
9	Zonitioides nitidus								I	III	III	II	
10	Anisus leucostomus									III	III	II	
10	Bythinella austriaca	II	IV	IV	III	III	III	V	V			II	
10	Lymnaea peregra		I										
10	Lymnaea truncatula	I	I					III	II	III	IV	III	II
10	Pisidium sp.	I	I	I	I	I	I	II	II	III	III	II	I

MIRÓW

In the valley of a small affluent of the Regulice stream near Mirów (*Mr* in Text-fig. 1), there is an outcrop of white unbedded silty tufas containing locally inserts and lenses of nodular tufas. They overlie fine-grained sands and attain a thickness of 1—2 m (Text-fig. 15).

The malacofauna found in the tufas is rich but shows little variation (Table 6). The content of forest snails in all samples runs up to 50%, and best represented are the Clausillidae: *Iphigena latestriata* (Schmidt), *I. tumida* (Rossmässler), *I. ventricosa* (Darapamaud), *Ruthenica filograna* (Rossmässler), *Vestia turgida* (Rossmässler) and *V. elata* (Rossmässler). In the lower part of the profile very common are *Bythinella austriaca* (Frauenfeld), while the upper part abounds in *Carychium minimum* Müller.

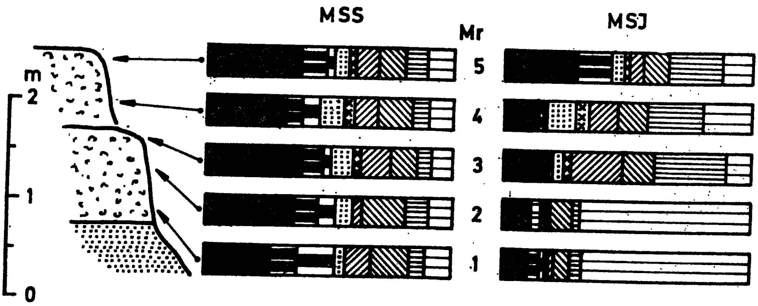


Fig. 15. Profile of tufas at Mirów (*Mr*); symbols the same as in Text-fig. 2

The tufas formed in a period particularly favourable to the growth of deciduous forests, presumably in the Middle Holocene. They were deposited on the floor of a small watery valley, in the immediate vicinity of a spring and in the midst of watery meadows and forests.

STARZYNY

The outcrops of travertines at Starzyny near Płaza (*cf.* Zaręczny 1894, Siedlecki 1952) are situated near the spring of a small affluent of a stream, a few dozen metres upstream of its bifurcation (*St* in Text-fig. 1).

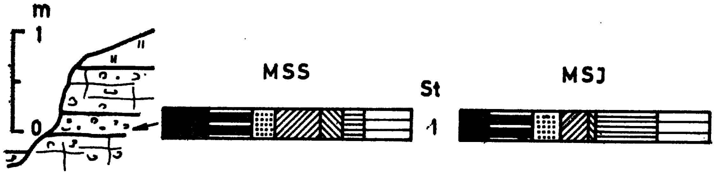


Fig. 16. Outcrop of travertines at Starzyny (*St*); symbols the same as in Text-fig. 2

The travertine layer with an insert of gray-yellowish nodular tufa (Text-fig. 16) contains here scarce molluscs. Their assemblage is poor and shows a little variation (Table 6); it yields *Vitrea crystallina* (Müller), *Carychium minimum* Müller, and *Lymnaea truncatula* (Müller). These tufas and travertines were deposited in a valley covered with forests and brushwood with a very moist, partly watery substrate.

MOLLUSC ASSEMBLAGES

The Holocene tufas and travertines of the Cracow Upland contain rich and varied malacofaunal assemblages, differing from one another in the number of taxons, the number of specimens and its composition. Variable is the content of species preferring certain ecological environments, especially forest, meadow and water habitats. This diversity reflects the variety of local conditions under which the calcareous sediments were deposited in the valleys of the Cracow Upland.

The number of mollusc species present in individual samples varies over a wide range. Poor assemblages contain 10—20 taxons. Most common are samples containing 20—28 snail species, and these make up 30% of the whole material collected (*Tx* in Text-fig. 17). Rich and very rich assemblages consist of 28—40 species, but such were found in some profiles only.

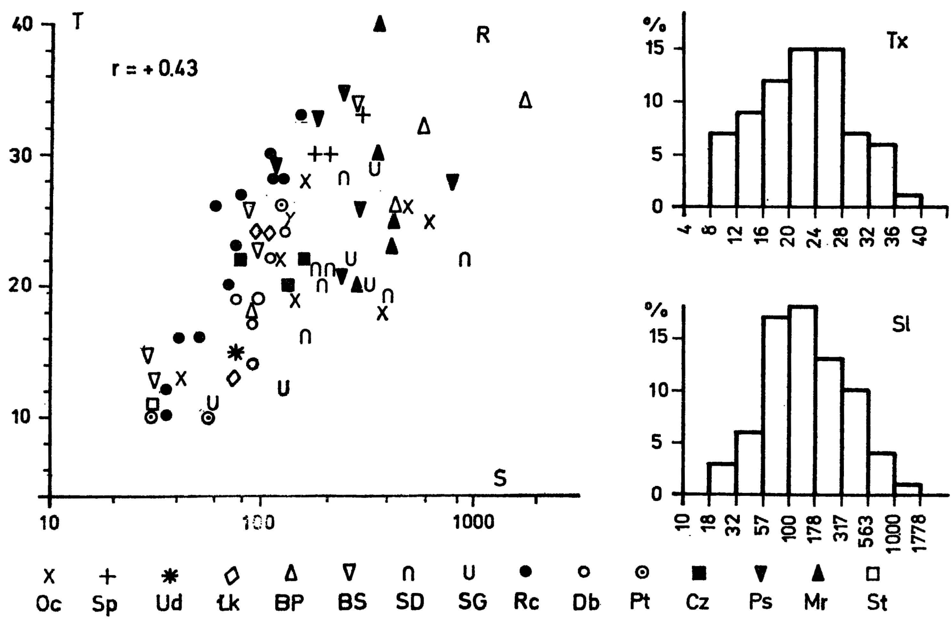


Fig. 17. Distribution of the number of taxons and specimens in malacofaunal assemblages

R — correlation between the number of taxons (*T*) and the number of specimens (*S*) in samples; **Tx** — distribution of the number of taxons, **Sl** — distribution of the number of specimens; symbols of the investigated profiles and outcrops (*Oc*, *Sp*, *Ud*... the same as in Text-figs 2—16

The number of mollusc shells in the samples is variable, and the particular assemblages generally consist of 50—200 specimens (35% of samples). There are, however, many assemblages containing a greater number of shells (200—500), whereas in few samples only there were less than 50 specimens (*SL* in Text-fig. 17).

The richest mollusc assemblages comprising a large number of taxons and having simultaneously a high content of shells, come from the profiles at Psary, Mirów, Ojców, Sąspów, and from the Będkowska and Szklarka valleys. Assemblages including many taxons generally abound in species typical of forest environments and also in mesophile snails. Those containing an exceptionally great number of specimens are enriched in aquatic species and in species inhabiting meadow and woodless environments.

In the whole set of samples there is a correlation between the number of taxons in the assemblages and the number of specimens. It is expressed by the correlation coefficient $r = +0.43$, which for the number of samples $n = 72$ is significant at a confidence level of .05 and .01 (R in Text-fig. 17). This correlation has different values in respective profiles. For example, it is very distinct at Racławka but non-existent at Ojców or Szklary Dolne. The observed differences may be primarily due to the varying percentage of aquatic, and partly also of meadow snails, among which there occur single species represented by a great number of specimens, e.g. *Anisus leucostomus* (Millet), and *Vallonia pulchella* (Müller). In the profiles abounding in such snails, the correlation between the number of taxons and the number of specimens is very weak and statistically insignificant, in contrast to the profiles with forest and mesophile malacofauna.

A characteristic feature of the malacofaunal assemblages is the quantitative dominance of certain taxons, indicative of the degree of their specialization or variation. In this respect, two types of assemblages can be distinguished: oligomictic and polymictic, defined respectively by Evans (1972) as specialized and generalized. The former are characterized by the presence of one or two species represented by a great number of specimens (at least 30—50% of the assemblage), while the contents of the other species are a few per cent each or less. In polymictic assemblages the quantitative distribution of components is nearly even, the content of most numerous species being not more than 10—20%.

In the tufas and travertines described in this paper, both types of malacofaunal assemblages are present (Text-fig. 18). Oligomictic associations contain a large number of aquatic, hygrophilic or meadow snails. These are, for example, the assemblage with *Bythinella austriaca* from Mirów (sample *Mr-2*), the assemblage with *Carychium minimum* from Psary (sample *Ps-1*), and the assemblage with *Vallonia pulchella* and *Anisus leucostomus* from the Będkowska valley (sample *BP-1*). Polymictic assemblages are characterized by the presence of many taxons, the most numerous of which do not predominate quantitatively. They have a high content of mesophile snails (sample *Oc-2*), forest snails (sample *Rc-5*), or snails assigned to different ecological groups but having no preference for any particular one (sample *Db-3*).

The analysis of malacospectra was the basic method used to determine the depositional conditions of the calcareous sediments of the Cracow Upland. The spectra were prepared according to the ecological groups distinguished by Ložek (1964, 1969). Malacospectra of species (*MSS*) characterize well the composition of malacofauna inhabiting the valleys and depressions in which tufas and travertines were deposited. They permit an assessment of the distribution of main types of habitats and vegetation both on the floor of each valley and on its slopes, but first of all show the degree of afforestation of the area. Malacospectra of individuals (*MSI*) reflect primarily the nature of habitats associated with streams or water basins in which calcareous sediments were deposited, and with its closest surroundings.

Malacospectra of species (*MSS*) show a good deal of variation, and several types of mollusc assemblages have been distinguished:

(*i*) Assemblages with forest snails as the dominant component (40—60%), occurring at Mirów, Psary, and in some samples from Racławka, Dubie and the Będkowska valley;

(*ii*) Assemblages with a high content of forest snails (25—35%) accompanied by fairly numerous mesophile and aquatic species, found at Ojców, Racławka valley, Dubie, Czatkowice, and the Będkowska valley;

(*iii*) Assemblages having a high content of aquatic molluscs (20—40%) and mesophile and meadow snails, found mainly in the Szklarka and Kluczwoda valleys;

(*iv*) Assemblages of mixed fauna in which all the ecological groups are equally represented, none of them being obviously dominant; they can be found in single samples derived from different profiles.

Malacospectra of individuals (*MSI*) also show a great deal of variation. It is possible to distinguish on their basis asemblages with a high content of forest snails (Racławka), ones with the dominant content of snails typical of open, woodless and unshaded habitats (Będkowska and Szklarka valleys, Dubie), and assemblages with very abundant shells of aquatic molluscs (Ojców, Ujazd, Szklarka valley, Paczółtowice). Many profiles also contain assemblages of mixed fauna, which do not show any quantitative prevalence of molluscs inhabiting a definite type of environment.

The results of the variation analysis of malacofauna were generalized by joining the ecological groups representing similar types of environments, and by grouping them into three main elements. They comprise the following ecological types distinguishedd by Ložek (1964, 1969).

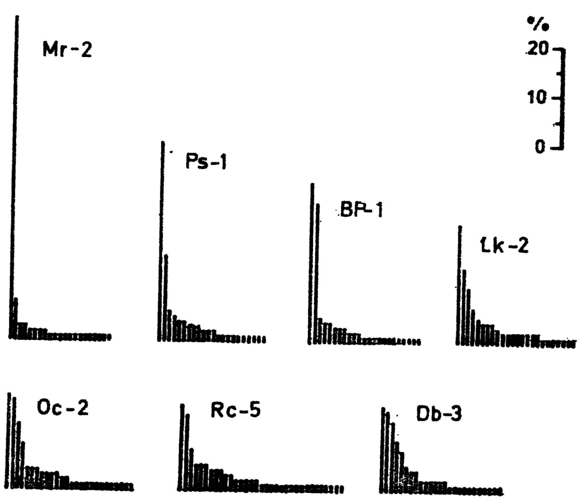


Fig. 18. Types of malacofaunal assemblages: oligomictic and polymictic, in selected samples; each bar represents the percentage of one taxon in a sample (for symbols of samples *see* Text-figs 2—16)

A — snails of forest environments: ecological groups *1, 2, 3*;
B — snails of woodless environments: ecological groups *4, 5*;
C — mesophile snails: ecological groups *6, 7, 8*;
D — hygrophilic and aquatic molluscs: ecological groups *9, 10*.

The percentage of mollusc shells in each sample was presented (Text-fig. 19) in a ternary system, comprising the ecological types *A*, *B+C*, *D*. In the triangular diagram, seven types of malacofaunal assem-

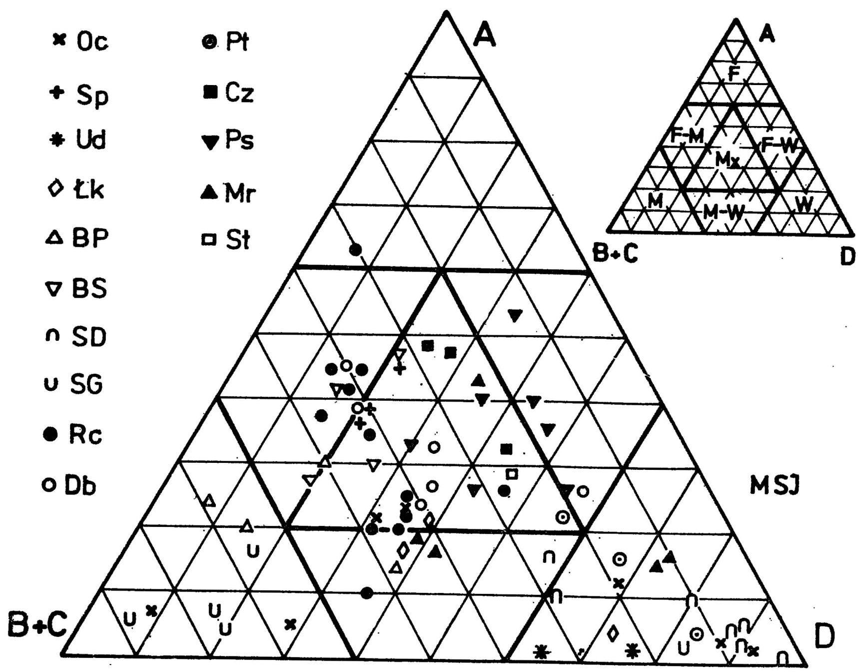


Fig. 19. Ecological types of Holocene malacofauna in the Cracow Upland: **A** — forest species, **B** — species of woodless environments, **C** — mesophile species, **D** — aquatic species

TYPES OF ASSEMBLAGES: *F* forest, *M* meadow and mesophile, *W* aquatic, *F-M* forest-meadow, *F-W* forest-water, *M-W* meadow-mesophile-aquatic, *Mx* — mixed; symbols of outcrops and profiles the same as in Text-figs 2—16

blages can be distinguished. Three of them are assemblages with a dominant content of molluscs from a specific environment: *W* — water *M* — meadow and mesofile, *F* — forest. The three successive assemblages are mixed ones, composed ot two elements: *M—W*, *F—M* or *F—W*. One assemblage includes all three components in equal quantitative proportions (*Mx*).

The commonest type of malacofaunal association is mixed three-component assemblages (29 samples). They occur in 12 profiles and failed to be found only in the Szklarka and Kluczwoda valleys. Amply represented are assemblages of aquatic fauna (17 samples). They are particularly characteristic of the profiles at Szklary and Ujazd, but were also found in some other outcrops (*e.g.* Ojców and Mirów). Assemblages of meadow and mesophile snails were identified in 8 samples derived from three profiles (Ojców, Będkowska and Szklarka valleys), where they are accompanied mainly by mixed assemblages. An assemblage showing the quantitative predominance of forest snails is represented only by one sample from the Racławka valley. The remaining assemblages are represented by 5 or 6 samples each, and can be found in some profiles only, for example the *F—M* type in the Racławka valley, the type *F—W* at Psary (Text-fig. 19).

The considerable variation of malacofauna present in the Holocene tufas and travertines of the Cracow Upland is a feature characteristic of this type of sediments. It is pronounced both in Pleistocene and postglacial travertines and in those accumulating at present. Calcareous sediments of similar form contain mollusc assemblages with a dominant content of species inhabiting water basins, watery, very moist, meadow, woodless, as well as forest environments. Equally numerous are tufa and travertine outcrops with mixed fauna (Ložek 1955, 1961a, b; Schneider 1968; Fuhrmann 1973; Zeissler 1980). This variety of assemblages implies that the sediments in quesiton may have formed under different conditions. The most suitable conditions for their deposition were in wide flat-floored valleys intensely overgrown with vegetation and partly watery, with shallow water basins that intermittently dried up, and became filled up with sediments and overgrown (Steiner 1979).

ZOOGEOGRAPHIC STRUCTURE OF MALACOFAUNA

The discussed mollusc assemblages consist of species which have various geographic ranges. Nearly all the cited taxons live at present in southern Poland, the Cracow Upland including (Urbański 1947, 1977; Berger 1961; Dzięczkowski 1972).

The zoogeographic structure of Holocene malocofauna is regarded according to the division presented by Ložek (1955, 1956, 1964) and other authors (Urbański 1939, 1948, 1957; Berger 1961; Piechocki 1981). This simplified scheme comprises widerspread species (Holarctic, Palearctic, European), Central European species (inhabiting Central, Central and Eastern, as well as Central and Western Europe), mountain species typical of the Carpathians and the Alps (Carpathian, Alpine-Carpathian, Alpine, Boreal-mountain), South-European species, Eurosiberian species, and North-European species (Text-fig. 20).

Widespread species (*WS*) are the commonest zoogeographic element of the malacofauna discussed, their content running up to 41%. They are represented by *Cochlicopa lubrica* (Müller), *Vallonia costata* (Müller), *V. pulchella* (Müller), *Acanthinula aculaeata* (Müller), *Cochlodina laminata* (Montagu), *Vitrea crystallina* (Müller), and by most aquatic snails.

Central European species make up the next, strongly element (*ME* — 27%). In this group belong snails inhabiting mainly Central Europe (*Me* — 12%), such as *Acicula polita* (Hartmann), *Lacinaria plicata* (Draparnaud), *Clausilia dubia* (Draparnaud), *Iphigena ventricosa* (Draparnaud), snails living in Central and Eastern Europe (*Ee* — 11%): *Clausilia pumila* Pfeifer, *Ruthenica filograna* (Rossmässler), and *Perforatella bidentata* (Gmelin), as well as snails widespread throughout Central and Western Europe (*We* — 4%), e.g. *Discus rotundatus* (Müller).

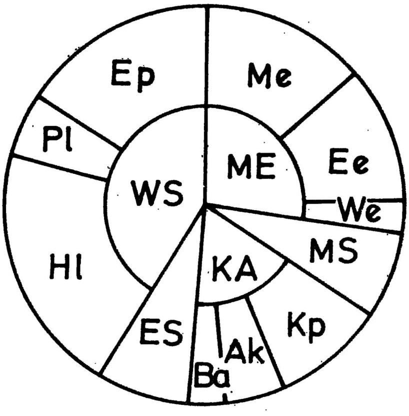


Fig. 20

Zoogeographic structure of Holocene malacofauna in the Cracow Upland
COMPONENTS: *WS* widespread species, *Ep* European, *Pl* Palearctic, *Hl* Holarctic, *ES* Eurosiberian, *KA* mountain, *Ba* Boreal-mountain, *Ak* Alpine-Carpathian, *Kp* Carpathian, *MS* South-European, *ME*, *Me* Central-European, *Ee* Central-East European, *We* Central-West European

The third major zoogeographic element are the molluscs occurring mainly in the mountains of Central Europe — the Alps and the Carpathians (*KA* — 17%). To this group belong typical Carpathian species (*Kp* — 9%): *Iphigena latestriata* (Schmidt), *Vestia turgida* (Rossmässler), *V. elata* (Rossmässler), and *Monachoides vicina* (Rossmässler), as well as species widespread throughout the western Carpathians and the Alps, or mainly in the Alps (*Ak* — 5%), e.g. *Isognomostoma isognomostoma* (Schröter) and *Bythinella austriaca* (Frauenfeld). The few Boreal-mountain species (*Ba* — 3%), such as *Vertigo substriata* (Jeffreys) and *Clausilia cruciata* Studer, have also been assigned to this group.

The two subordinate components of malacofauna are represented by Eurosiberian element (*ES* — 8%) e.g. *Succinea oblonga* Draparnaud, *Vertigo antivertigo* (Draparnaud), *Acroloxus lacustris* (Linnaeus) and by South-European species (*MS* — 7%), *i.e.* snails inhabiting South-Eastern Europe and the Mediterranean, and partly also Central Europe, e.g. *Orcula doliolum* (Bruguière) and *Helix pomatia* Linnaeus.

The presented zoogeographic structure of Holocene malacofauna is the result of changes in the range of species and the migration of many species during Quaternary climatic cycles (Ložek 1976). It is feasible that some species inhabited the Cracow Upland already in the Eemian Interglacial and survived the last glaciation utilizing suitable ecological niches, especially slopes and klippes with a southern exposure. The amount of such Eemian relicts is difficult to evaluate, but in Urbański's opinion (1948, 1977), it is substantial. Some taxons, found both in Holocene tufas and in present-day assemblages, were reported from rock-shelters in the Würm sediments near Ojców (Kowalski & *al.* 1965, 1967; Stworzewicz 1973), viz. *Clausilia dubia* (Draparnaud), *Cochlodina laminata* (Montagu), *Vallonia costata* (Müller), and *Euconulus fulvus*

(Müller). Other species live at present in environments with climatic conditions close to those prevailing in the Cracow Upland during the last glaciation. They are reported from the high mountains, for example the Tatra Mts, from the zone of the upper timberline and above, the zone of fells and crags, living at altitudes of 1200—1800 m and even more than 2000 m (Urbański 1962, 1977; Ložek 1955, 1963, 1964). These species are represented by *Pyramidula rupestris* (Draparnaud) and *Vertigo alpestris* Alder, and partly also by *Cochlicopa lubrica* (Müller), *Perpolita radiatula* (Alder), and *Vitrea crystallina* (Müller).

Towards the close of the Würm and at the beginning of the Holocene, as the climate became warmer, a great number of snail species migrated northwards. The intense migration attended the progressive changes in the distribution of vegetation, especially the expansion of mixed forests and multi-species deciduous forests. These changes reached their climax in the Holocene climatic optimum. At the time, in the southern part of the Cracow Upland there appeared rich and widely diversified mollusc assemblages with the abundant Clausillidae, including Carpathian species: *Vestia elata* (Rossmässler), *V. turgida* (Rossmässler), *Iphigena latestriata* (Schmidt), and *I. tumida* (Rossmässler); Alpine species, e.g. *Isognomostoma isognomostoma* (Schröter); and the South-European species *Helix pomatia Linnaeus*. Some of them became extinct with the Upper Holocene, e.g. *Vestia elata* (Rossmässler) and *Iphigena tumida* (Rossmässler), whilst other persisted until the present times.

In the Upper Holocene a pronounced change in the composition of malacofauna occurred in Central Europe. It was brought about by human activity, and specifically by the rapid deforestation of vast areas and the artifical expansion of open environments, meadows and fields. This change, very pronounced in the Holy Cross Mts in Central Poland (Piechocki 1977, 1981), involves the considerable impoverishment of assemblages and the elimination of many forest species. As a consequence, the relative content of eurytopic species of wide geographic ranges (Holarctic and Palearctic) increased so that in the present-day malacofaunal assemblages this zoogeographic element is positively dominant. In the Cracow Upland its content is more than 70% (Berger 1961), *i.e. about* 30% more than in the older Holocene. Yet in wooded areas, where the original vegetation has been preserved (*e.g.* in the Ojców National Park), the content of this element is a little more than 40% (Dzięczkowski 1972), which means that it has not changed for the past five thousand years.

AGE OF TUFAS AND TRAVERTINES

The stratigraphic ranges of some snail species and some mollusc assemblages characteristic of the Holocene sediments of Central Europe have already been recognized in several countries (Danilovski 1955;

Ložek 1964, 1969; Fuhrmann 1973; Mania 1973; Piechocki 1977). The Lower Holocene sediments contain mixed fauna, consisting mainly of mesophile snails of steppe and meadow habitats, with an admixture of forest snails. In the Boreal the content of forest snails increased, and *Discus ruderatus* (Férussac), widespread in Central Europe at that time, is regarded as the index species (Dehm 1967). In the Lower Holocene sediments Fuhrmann (1973) distinguished the *"Ruderatus-Vallonia association"* and the *"Ruderatus-Vallonia-Crystallina association"*.

The Middle Holocene was a period of the maximum expansion of mixed and deciduous forests. In the older part of the Atlantic there appeared abundant Clausillidae, *Discus rotundatus* (Müller), *D. perspectivus* (Mühlenfeld), and other species (Piechocki 1977). According to Fuhrmann (1973), it is the *"Ruderatus-Rotundatus-Crystallina-Carychium association"*. In the younger part of the Atlantic, the thermo- and hygrophilic species became widespread again, and the assemblage were the richest (Ložek 1964, Piechocki 1977); it is the *"Rotundatus-Carychium association"* of Fuhrmann (1973). The same type of association persisted into the older part of the Sub-Boreal (Epi-Atlantic period of Jäger & Ložek 1973), but the assemblages were poorer and showed more variation as a result of climatic changes and the human activities (deforestation). Towards the close of the Sub-Boreal (Sub-Boreal period *s.s.* of Jäger & Ložek 1968) there was an increase of snails inhabiting woodless areas and mesophile species. In the Upper Holocene, as vast expanses of land were brought into cultivation, the mollusc assemblages became poorer (Mania 1973, Piechocki 1977). The gradual cooling of the climate and the progressing disappearance of forest habitats resulted in changes in the range of many snail species and their abundance.

The most abundant data on the age of tufas and travertines of the Cracow Upland were yielded by the profile of the Racławka valley, as recognized recently by J. Szulc. Palynologic analysis of the bottom of tufas points to the Boreal, whereas C^{14} dating of charcoals derived from the upper part of the profile (near sample *Rc-8*, see Text-fig. 11) has determined their age at 2475 ± 60 years BP. Malacofauna found in this profile reflects environmental changes occurring during the Holocene, from the Boreal to the Sub-Atlantic (Alexandrowicz & Stworzewicz 1983). The malacologic analysis also permits a determination of the age of calcareous sediments in all the other profiles described in this paper (Text-fig. 21).

In the lower parts of some profiles mollusc assemblages are poor, consisting mainly of eurytopic species and a small amount of forest snails: *Vallonia costata* (Müller), *V. pulchella* (Müller), *Vitrea crystallina* (Müller), *Cochlicopa lubrica* (Müller), *Perpolita radiatula* (Alder), *Succinea oblonga* Draparnaud, *Carychium minimum* Müller. In places, they contain aquatic snails: *Acroloxus lacustris* (Linnaeus), *Armiger crista* *nautileus* (Linnaeus), and *Valvata cristata* Müller. Sporadically there also appear *Discus ruderatus* (Férussac) and *Bradybaena fruticum* (Müller). These assemblages are typical of the Boreal prior to the wide expansion of deciduous and mixed forests. They occur both in the Szklarka valley (*SD* — Szklary Dolne, *SG* — Szklary Górne) and in the Racławka valley (*Rc* — between Żary and Stradlina, *Pc* — Paczółtowice).

A higher stratigraphic position in the four profiles is occupied by sediments containing very rich mollusc assemblages, characterized by the presence of abundant forest snails thriving in warm and moist biotopes: *Acanthinula aculeata* (Hartmann), *Isognomostoma isognomostoma* (Schröter), *Discus rotundatus* (Müller), *Aegopinella pura* (Alder), *Iphigena latestriata* (Schmidt), *I. plicatula* (Draparnaud), *I. tumida* (Rossmässler), *Ruthenica filograna* (Rossmässler), *Cochlodina orthostoma* (Menke), and *Vestia elata* (Rossmässler). They are generally accompanied by hygrophilic species, such as *Carychium minimum* Müller and *Succinea*

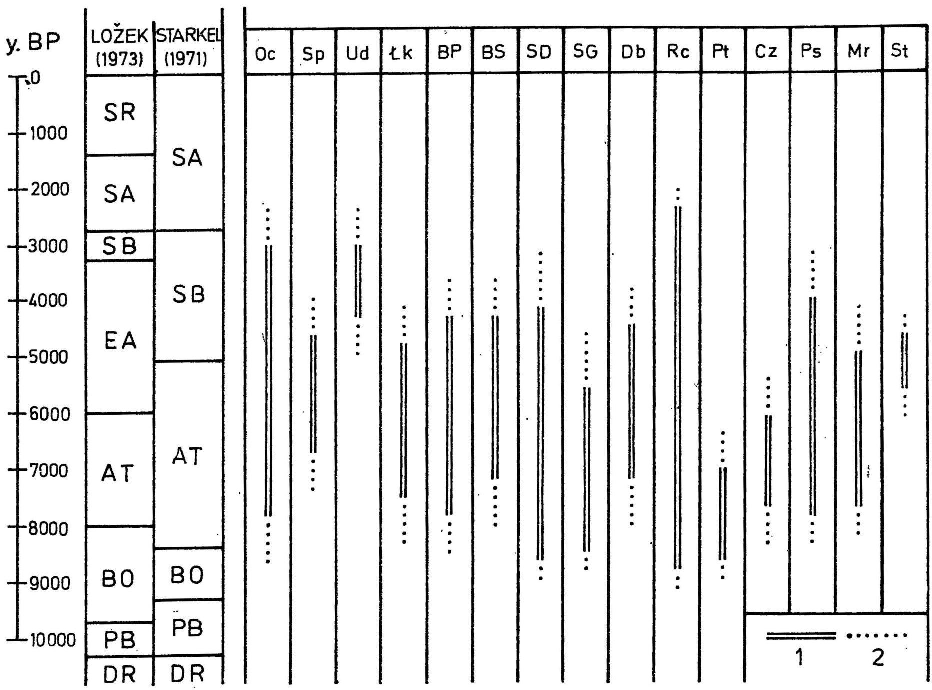


Fig. 21. Stratigraphy of Holocene tufas and travertines of the Cracow Upland (age scale in years BP)

Stratigraphic division of the Holocene: **DR** — Dryas, **PB** — Pre-Boreal, **BO** — Boreal, **AT** — Atlantic, **EA** — Epi-Atlantic, **SB** — Sub-Boreal, **SA** — Sub-Atlantic, **SR** — Sub-Recent; profiles and outcrops according to symbols used in Text-figs 2—19

1 age interval of calcareous sediments in a profile or outcrop, *2* admissible extension of age interval *elegans* (Risso), as well as by aquatic snails *Anisus leucostomus* (Millet) and *Valvata cristata* Müller. Similar assemblages occur in the ten other profiles, and the differences between them consist mainly in the varying amounts of aquatic and mesophile species, and sometimes also of meadow snails. This type of malacofauna represents the climatic optimum, *i.e.* the Atlantic (Text-fig. 21). The common occurrence of such assemblages indicates that conditions favouring the formation of tufas and travertines prevailed in the Cracow Upland at that time.

In the upper parts of several profiles, a progressive change in the composition of malacofauna is noted, involving a decrease in the number of taxons and the disappearance of some species. The malacofaunal assemblages are poorer, and contain scarce Clausillidae, whilst the amount of forest snails is limited or unstable. Simultaneously the content of mesophile and meadow snails and aquatic molluscs increases. Worth noting is the appearance of scarce specimens representing the family Helicidae: *Helix pomatia* Linnaeus, *Cepaea hortensis* (Müller) and *C. vindobonensis* (Férussac). Such malacofauna is known from Ojców, the Racławka and Będkowska valleys, Psary, and Ujazd, being characteristic ot the Sub-Boreal period of the Holocene (Text-fig. 21). It shows considerable variation which reflects the progressing differentiation of habitats, brought about by climatic changes and man's impact on the natural environment.

HISTORY OF SEDIMENTATION

The discussed tufas and travertines formed over a time span embracing the Lower and Middle Holocene. Their deposition was preceded by intensified erosional activity that took place in the Late Glacial. The evidence of this activity is found all over the area of southern Poland, both in the Carpathians and their foreland, in the Cracow Upland and in the Holy Cross Mts (Starkel 1968, 1977; Klatka 1968; Jersak 1965, 1977). At that time valleys were deepened, and the bulk of Pleistocene sediments that filled them up was destroyed and removed (Walczak 1965). They were mainly silts, loesses of valley and slope facies, rewashed loesses and loess hillwash. These sediments are still preserved in some valleys between Krzeszowice and Ojców, and they contain characteristic malacofauna with *Succinea oblonga elongata* Sandberg, *Pupilla muscorum* (Linnaeus), *P. loessica* Ložek, *Vallonia pulchella* (Müller), *V. tenuilabris* (Braun), and *Helicopsis striata* (Müller). This malacofauna is typical of valley loesses deposited during the last glaciation and in its final stage, and indicates that the climatic conditions were milder than those prevailing in the pleniglacial period (Ložek 1964).

A new stage of the accumulation of sediments began in the Lower Holocene, precisely in the Boreal. Erosional processes were than brought to an end, and the expansion of forests prevented loams and loesses covering the plateau surfaces from being washed out. Due to the land configuration and profuse vegetation, the surface runoff was limited while the bulk of rainfall infiltrated into the ground and recharged the ground water circulation through karstic system developed in Jurassic and Paleozoic limestones. Under these conditions, the washing out and displacement of terrigenous material did not play any significant role, in contrast to chemical denudation, which was extremely intense. The profuse vegetation and the decomposition of organic matter favoured the formation of humic acids and carbonic acid, whereas rainwater enriched in these compounds dissolved calcium carbonate and enabled their circulation. As a consequence of these processes, karst phenomena developed in the limestones of the Cracow Upland, accompanied by the deposition of tufas and travertines.

Simultaneously, the decalcification of Quaternary covers took place at the plateau surfaces. As a result of the slow infiltration of rainwater through porous loesses, silty loams and sands containing fine calcareous grains (*e.g.* snail shells and shell fragments), the carbonates subjected to intense leaching. Owing to this, the ground water was substantially enriched in calcium bicarbonate even before it reached Mesozoic and Paleozoic limestones occurring in the basement. The scale of this process and its significance are well ilustrated by Quaternary calcareous sediments that formed in zones of ground water seepage, near springs and in stream valleys in areas entirely devoid of karstifying rocks. Such Holocene tufas and travertines were also found in the Sudetic foreland (Kowaliński & *al.* 1972), in the south-eastern part of the Holy Cross Mts (Walczowski 1975), and in the Fore-Carpathian Depression (Alexandrowicz & Gerlach 1983), in places of occurrence of non-calcareous crystalline and terrigenous rocks covered with silty loams and loess. It is feasible that both in these localities and in the Cracow Upland the bulk of carbonates from which tufas and travertines formed owes their origin to the decalcification of loesses, whereas the remaining part derives from limestones and dolomites subject to kartification.

The cessation of erosional activity and intense chemical denudation at the plateau surface promoted the precipitation of calcium carbonate in valleys. At that time these were flat-floored and overgrown with profuse vegetation. The streams carried very little sediment in suspension and did not show any tendency to incision. Their channels were braided and poorly individualized; in places where the valleys widened the drying-up swamps and floodplains have formed. During periodic floods, the logjams could have stranded in narrow parts of valleys, obstructing the outflow. The profuse vegetation and the warming of slowly flowing water caused a decrease in carbon dioxide, due to which calcium carbonate could precipitate. This process took place under various conditions. Flat watery meadows were generally areas of the deposition of loose tufas and calcareous silts, whilst in places where the water outflow was obstructed, compact porous travertines accumulated. As a result of the local washing out, displacement and redeposition of these sediments, the silts and calcareous sands showing distinct cross-bedding were deposited (*e.g.* at Dubie).

The formation of travertines gave rise to natural dams that divided the valleys. The profiles to streams was then disturbed, the dams assumed the role of waterfall scarps, and flooplains, swamps and even intermittent or perennial water basins formed upstream. Such three-levelled system of scarps made up of travertines and basins filled up with tufas occurs in the Będkowska valley (Walczak 1956), and similar forms have been reported from Ojców in the Saspówka valley, from the Szklarka valley between Dubie and Szklary, and from the Racławka valley between Dubie and Paczółtowice.

The conditions suitable for the precipitation of calcium carbonate and the deposition of tufas abounding in malacofauna also existed near springs, especially in floodplains and small water basins in which water outflow was hampered. Sediments of such origin are known from Psary and Mirów.

Variation in the local conditions of deposition of tufas and travertines are well reflected in the composition of malacofauna. On this basis, several types of sedimentary environments can be distinguished:

(*i*) Wide flat-floored valleys occupied by meadows, watery meadows and brushwood; the malacofaunal assemblages are of mixed composition, showing a high content of mesophile and meadow snails (most profiles);

(*ii*) Water basins and intermittent floodplains formed in valleys divided by travertine dams; aquatic molluscs are dominant in the tufas, and the assemblages are oligomictic (Szklarka valley, Ujazd, Ojców);

(*iii*) Narrow valleys with the slopes covered with forests; the malacofaunal assemblages are polimictic and display a high content of forest snails (*e.g.* Sąspów, Racławka, Czatkowice);

(*iv*) Swamps, intermittent water basins and deciduous forests with a very moist substrate near springs and zones of water seepage (Psary, Mirów); the malacofauna is rich, abounding in forest and aquatic snails, with particularly numerous *Bythinella austriaca* (Frauenfeld).

There is no sharp division between these types of environments, so they often exhibit transitional featur . The individual profiles reflect changes in the depositional conditions of calcareous sediments during their formation, such as the expansion of forests throughout the surrounding areas, the appearance of water basins, swamps and watery meadows, or the progressing deforestation. This local evolution of habitats and their marked differentiation were responsible for the variation of malacofauna, which at present is very pronounced in the Cracow Upland (Medwecka-Kornaś 1977).

On the basis of the distribution of malacofauna classed according to the ecological groups and taking into consideration the seven types of assemblages discussed (Text-fig. 19), the variation in sedimentary environments and mollusc assemblages can be presented. In the profiles of tufas and travertines, two types of facies sequence can be distinguished (Text-fig. 22). One of them, showing the prevalence of mesophile and

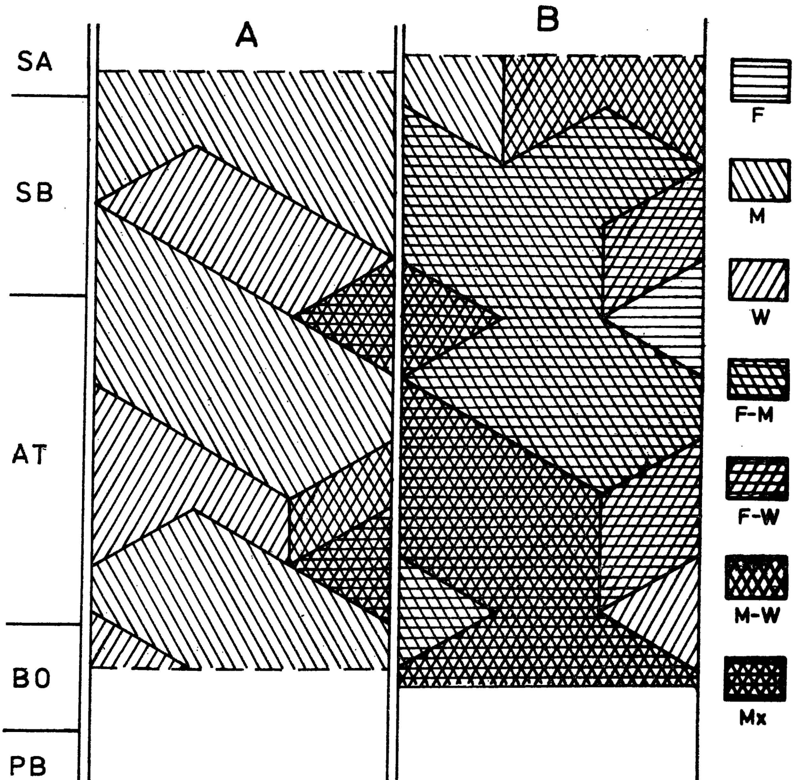


Fig. 22. Evolution of malacofauna in Holocene tufas and travertines of the Cracow Upland

Periods of the Holocene: **PB** — Pre-Boreal, **BO** — Boreal, **AT** — Atlantic, **SB** — Sub-Boreal, **SA** — Sub-Atlantic (comp. Text-fig. 21)

A — facies sequence of open (woodless) habitats, **B** — facies sequence of forest habitats

Types of malacofaunal assemblages: *F* forest, *M* meadow and mesophile, *W* aquatic, *F-M* forest-meadow, *F-W* forest-aquatic, *M-W* meadow-mesophile-aquatic, *Mx* mixed

aquatic snail assemblages (*W* and *M*), occurs mainly in the Prądnik and Szklarka valleys, whilst the other, characterized by the presence of mixed molluscan assemblages (*Mx*, *M—F*, *W—F*, *M—W*), appears at Racławka, Psary and Mirów.

Tufas and travertines deposited in wide-floored valleys, water basins and watery meadows (sedimentary environments *i* and *ii*) represent the former type of facies sequence (*A* in Text-fig. 22). In the Boreal and at the beginning of the Atlantic, assemblages showing the prevalence of mesophile and meadows snails (*M*), and locally of aquatic molluscs (*W*), or mixed assemblages (*Mx*) were positively dominant. During the subsequent sedimentary episode a periodic expansion of water environments (*W*, *M—W*) took place, whereupon habitats suitable for the development of mesophile and meadow snails (*M*) became again prevalent. In the late period of the climatic optimum, the malacofauna of mixed composition (*Mx*) appeared locally, characterized by a high content of forest snails. In the Sub-Boreal, the assemblages of mesophile and meadow snails (*M*) prevailed, alternating with aquatic malacofauna (*W*).

The other type of facies sequence (*B* in Text-fig. 22) is associated with tufas and travertines that were deposited in narrow wooded valleys and in intermittent water basins amidst forest (sedimentary environments *iii* and *iv*). In the Boreal and in the lower part of the Atlantic, the most widespread became multi-component assemblages (*Mx, M—F, W—F*), and locally assemblages of aquatic malacofauna (*W*). In the upper part of the Atlantic, the content of forest snails increased, and the commonest type of malacofaunal association was the assemblage of forest and mesophile snails (*M—F*), and locally only of forest species (*F*). In the Sub-Boreal, the open habitats, favouring the development of mesophile and meadow species, were gradually more widespread, but it was only at the final stage of the deposition of calcareous sediments that these snails became the principal component of malacofauna (*M*, *M—W*).

The variation of sedimentary environments is not paralleled by the lithologic features of calcareous sediments. Tufas containing abundant aquatic malacofauna do not differ from those abounding in meadow, mesophile or forest snails, whilst the same or very similar malacofauna can be found in the different lithologic varieties of tufas (silty, fine- or coarse-nodular, bedded or unbedded). The thickness of sediments being formed depended on local conditions (*e.g.* on the height of travertine dams dividing the valleys) and varies therefore over a wide range.

The formation of calcareous sediments in the interglacial periods and in the Holocene was primarily controlled by climatic changes and was a cyclic process. Jäger & Ložek (1968) distinguished four stages of this cycle and showed that the cold period, in which calcareous sediments were not deposited (stage *1*), was followed by a stage of intense deposition and accumulation of these sediments (stage *2*), whereupon the process gradually slackened (stage *3*), and finally was brought to the end (stage *4*). In the Holocene the sedimentation of tufas and travertines began in the Boreal, reaching its climax in the period of climatic optimum, whereas in the Epi-Atlantic and Sub-Boreal it gradually came to the end. In the Sub-Atlantic period, the calcareous sediments did not form any more but were commonly dissected and eroded. The main determinants of the course of this cycle were temperature and humidity, especially the average summer temperature and the annular quantity of precipitation (Jäger & Ložek 1968; Starkel 1977, Text-fig. 140).

The formation of tufas and travertines in the Cracow Upland proceeded according to the presented cycle. It is worth noting, however, that the stage of optimum depositional conditions was somewhat longer, embracing the Atlantic and particularly the lower part of the Sub-Boreal (Epi-Atlantic period). In some localities the sediments were still being deposited in the first part of the Sub-Atlantic.

The progressive climatic evolution, the expansion of human settlements and the deforestation of plateau surfaces were responsible for intensification of erosional processes whereby loesses and loams were washed out, and the amount of sediments in suspension transported by streams increased markedly. Tufas containing a substantial admixture of terrigenous material and calcareous silts were then deposited in water basins and flooded meadows existing in valleys. At Racławka and Ojców such sediments end the depositional cycle of calcareous sediments.

In the Sub-Atlantic, a pronounced change in sedimentary conditions occurred in the Cracow Upland. Due to the marked increase in humidity and the amount of precepitation, as well as the progressing deforestation of the land, erosion began to play a dominant role. This tendency was widespread throughout the area of southern Poland, and its effects were observed in the Carpathians (Starkel 1968), the Fore-Carpathian Depression and in loess-covered areas of the Central Polish Uplands (Jersak 1965, 1977; Klatka 1968). Due to intense bottom erosion operating in the valleys of the Cracow Upland, travertine dams, waterfall scarps and tufas deposited beyond them were dissected. The depth of this dissection depended on the position of local base level. The cuts were generally a few metres deep, but in some places they attained a depth of 10 m, forming large outcrops of calcareous sediments (Racławka and Szklarka valleys).

The processes of dissection of waterfall scarps and the rise, evolution and disappearance of steep-sided gorges in Holocene tufas and travertines still continue up to the present times. A good example of these events is offered by Wysoki Waterfall in the Będkowska valley. In 1940—1950 its scarp was 5—6 m high (Walczak 1956), but over the following decade it was completely destroyed, and today there are only outcrops in scarps along the stream which incises to a depth of 2—4 m into the valley floor.

Institute of Geology and Mineral Deposits,
University of Mining and Metallurgy,
Al. Mickiewicza 30,
30-059 Kraków, Poland

REFERENCES

ALEXANDROWICZ S. W. 1980. Early Holocene molluscan assemblages from Podgrodzie on the Wisłoka river, Poland. *Roczn. PTG (Ann. Soc. Géol. Pologne)*, **50** (3—4), 391—408. Kraków.

— 1981. Malacofauna of the Late Quaternary lacustrine deposits in the Krosno Depression. *Bull. Acad. Polon. Sci., Sér. Sci. Terre*, **28** (4), 243—255. Warszawa.

— 1982. Zespoły mięczaków w holoceńskich martwicach wapiennych doliny Będkowskiej. *Spraw. Pos. Kom. Nauk. PAN*, **24**. Kraków.

— & GERLACH T. 1983. Holocene travertine from Moszczenica near Bochnia. *Studia Geomorph. Carp.-Balk.*, **16**. Kraków.

— & STWORZEWICZ E. 1983. Molluscan fauna from Holocene tufa in the Racławka near Krzeszowice. *Acta Zool. Cracov.*, **26** (8). Kraków.

— & WILK Z. 1962. Geologic structure and springs of the Prądnik Valley in the Ojców National Park. *Ochr. Przyr. (Prot. of Nature)*, **28**, 187—210. Kraków.

ALEXANDROWICZ Z. & ALEXANDROWICZ S. W. 1976. Przyroda nieożywiona Ojcowskiego Parku Narodowego — Zarys budowy geologicznej. *Studia Naturae*, **B-28**, 33—49. Warszawa.

BUKOWY S. 1956. Geology of the area between Cracov and Korzkwia. *Biul. Inst. Geol.*, **108**, 17—82. Warszawa.

BERGER L. 1961. Molluscs in the transition zone of Great Poland, Silesia and the Cracow—Wieluń Jura. *Prace Kom. Biol. Pozn. Tow. Przyj. Nauk*, **25** (1), 1—123. Poznań.

DANILOVSKI I. W. 1955. Opornyi litologo-stratigrafitcheskyi razrez otlozenyi skandinavskogo oledenenija russkoi ravniny i rukovodiashche chetviertichnye molluski. *Trudy Bses. Nautch.-Issl. Geol. Inst.*, **9**, 1—202. Moskva.

DEHM R. 1967. Die Landschnecke *Discus ruderatus* im Postglazial Süddeutschlands. *Mitt. Bayer. Staats. Pal. Hist. Geol.*, **7**, 135—155. München.

DZIĘCZKOWSKI A. 1972. Quantitative researches of gastropods in the beech forests of south-western Poland. *Prace Kom. Biol. Pozn. Tow. Przyj. Nauk*, **35** (5), 1—89. Poznań.

EVANS J. G. 1972. Land Snails in Archaeology. *Seminar Press*; London.

FUHRMANN R. 1973. Die spätweichselglaziale und holozäne Molluskenfauna Mittel- und Westsachsens. *Freib. Forch.*, **C-278**, 1—121. Leipzig.

GOŁĄB J. 1949. Short characteristic of hydrogeological conditions on north-west from Cracow. *Biul. Inst. Geol.*, **58**, 18—22. Warszawa.

GRADZIŃSKI R. 1972. Przewodnik geologiczny po okolicach Krakowa. *Wyd. Geol.*; Warszawa.

JÄGER K. D. & LOŽEK V. 1968. Beobachtungen zur Geschichte der Karbonatdynamik in der Holozänen Warmzeit. *Českoslov. Krac.*, **19**, 7—22. Praha.

JERSAK J. 1965. Stratigraphie et genese des loess aux environs de Kunów. *Acta Geogr. Lodz.*, **20**, 1—121. Łódź.

— 1977. The late Pleistocene and Holocene deposits in side valleys of the Kunów region. *Folia Quater.*, **40**, 15—21. Kraków.

KLATKA T. 1968. Holocene land-forming processes in the Świętokrzyskie Mts. *Folia Quater.*, **29**, 89—96. Kraków.

KÖRNIG G. 1966. Die Molluskengesellschaften des mitteldeutschen Hügellandes. *Malakol. Abhandl.*, **2** (1), 1—112. Leipzig.

KOWALIŃSKI S., LISZNAR S., DROZD J. & LICZNAR M. 1972. Soils in the Reserve Muszkowicki Las Bukowy. *Ochr. Przyr. (Prot. of Nature)*, **37**, 67—87. Kraków.

KOWALSKI K., KOZŁOWSKI J. K., KRYSOWSKA M. & WIKTOR A. 1965. Investigation of sediments of the Puchacza Skała Cave in Prądnik Czajowski, Olkusz District. *Folia Quater.*, **20**, 1—44. Kraków.

KOWALSKI K., KOZŁOWSKI J. K., KRYSOWSKA-IWASZKIEWICZ M., PAWLIKOWA B. & WIKTOR A. 1967. A study of the deposition of the rock-shelters in Żytnia Skała (Bębło, Kraków District). *Folia Quater.*, **25**, 1—48. Kraków.

LEWIŃSKI J. 1913. Die diluvialen Ablagerungen der Umgegend von Ojców. *Spraw. Pos. Tow. Nauk. Warsz.*, **6** (9), 819—849. Warszawa.

LOŽEK V. 1955. Měkkýši Československého kvartéru. *Rozpr. Ústř. Úst. Geol.*, **17**, 1—510. Praha.

— 1956. Klíč československých Měkkýšu. *Slov. Akad. Vied.*; Bratislava.

— 1961a. Stratigrafický výzkum travertinu u Skřečoně. *Antropoz.*, **9**, 35—44. Praha.

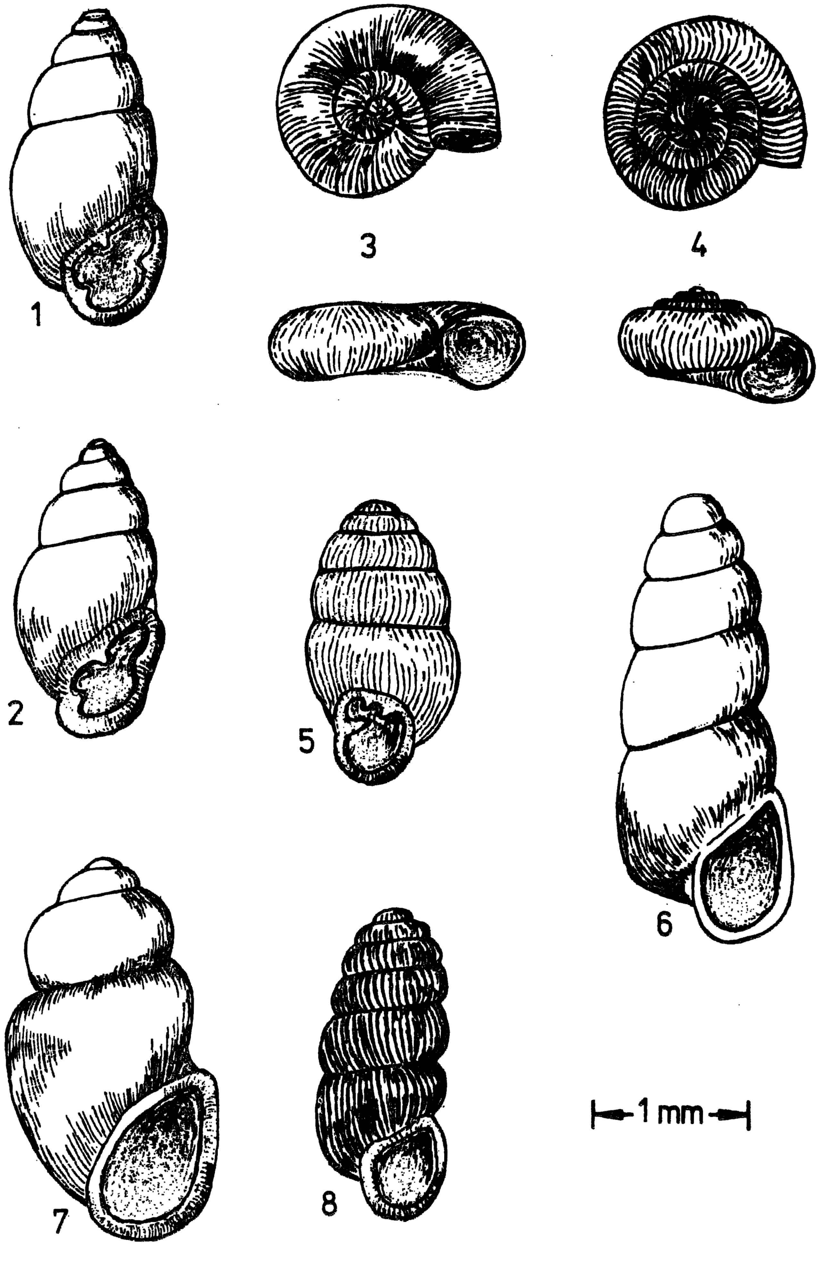
— 1961b. Stratigrafický výzkum ložiska sypkých sintru a slatin u Dluhonic na Přerovsku. *Antropoz.*, **9**, 65—74. Praha.
— 1963. Malakozoologický významna území Slovenska z hlediska ochrany přírody. *Českoslov. Ochr. Přír.*, **1**, 76—113. Bratislava.
— 1964. Quartärmollusken der Tschechoslowakei. *Rozpr. Ústř. Úst. Geol.*, **31**, 1—374. Praha.
— 1969. Znatshenije molluskov dla izutshenia kontinentalnogo holocena. *VIII Kongr. INQUA — Holocen*, 58—78. Moskva.
— 1973. Příroda ve čtvrtohorach. *Akademia*; Praha.
— 1976. Klimaabhängige Zyklen der Sedimentation und Bodenbildung während des Quartärs im Lichte malakozoologischer Untersuchungen. *Rozpr. Českoslov. Akad. Věd*, **86** (8), 1—97. Praha.
MANIA D. 1973. Paläoökologie, Faunenentwicklung und Stratigraphie des Eiszeitalters im mittleren Elbe-Saalegebiet auf Grund von Molluskengeselschaften. *Geologie, Beihf.*, **78—79**, 1—175. Berlin.
MEDWECKA-KORNAŚ A. Przyroda Ojcowskiego Parku Narodowego — Zespoły roślinne. *Studia Naturae*, **B-28**, 199—235. Kraków.
PIECHOCKI A. 1977. The Late Pleistocene and Holocene Mollusca of the Kunów region (N-E Margin of the Świętokrzyskie Mts). *Folia Quater.*, **49**, 23—36. Kraków.
— 1981. Recent and subfossil Mollusca of the Świętokrzyskie Mts (Central Poland). *Acta Univers. Lodz.*, 1—138. Łódź.
PUISSÉGUR J. J. 1976. Mollusques continentaux quaternaires de Bourgogne. *Mem. Geol. Univ. Dijon*, **3**, 1—241. Paris.
SCHNEIDER J. 1968. Eine Waldschneckenfauna aus dem holozänen Travertin von Schwarza bei Blankenheim in Thüringen. *Malakol. Abhandl.*, **2** (2—3), 119—125, Leipzig.
SIEDLECKI S. 1952. Utwory geologiczne obszaru pomiędzy Chrzanowem a Kwaczałą. *Biul. Inst. Geol.*, **60**, 1—230. Warszawa.
STARKEL L. 1968. The processes of fluvial erosion and accumulation in the Holocene. *Folia Quater.*, **29**, 109—117. Kraków.
— 1977. Paleogeografia holocenu. *Państw. Wydaw. Nauk.*; Kraków.
STEINER W. 1979. Der Travertin von Ehringsdorf und seine Fossilien. *Ziemsen Verl.*, 1—200. Wittenberg-Lutherstadt.
STWORZEWICZ E. 1973. The fossil land snails (Gastropoda) of rock-shelter above Niedostępna Cave in the Ojców region (South Poland). *Acta Zool. Cracov.*, **18** (12), 301—309. Kraków.
URBAŃSKI J. 1939. Die Molluskenfauna der Pieninen. *Prace Kom. Mat.-Przyr. Pozn. Tow. Przyj. Nauk*, **9** (3), 1—240. Poznań.
— 1947. Revue critique des Mollusques en Pologne. *Annal. Univ. Marie Curie-Skłod.*, **C-2**, 1—35. Lublin.
— 1948. Relict mollusks in Poland and in some of the adjacent lands. *Ochr. Przyr.* (*Prot. of Nature*), **18**, 66—95. Kraków.
— 1957. Krajowe ślimaki i małże. *Państw. Zakł. Wydaw. Szkol.*; Warszawa.
— 1962. Mięczaki — Tatrzański Park Narodowy. *Zakł. Ochr. Przyr. PAN, Wyd. Popul.-Nauk.*, **21**, 473—484. Kraków.
— 1977. Przyroda Ojcowskiego Parku Narodowego — Mięczaki. *Studia Naturae*, **B-28**, 299—318. Kraków.
WALCZAK W. 1956. Quaternary deposits and morphology of the southern part of the Cracow Jura in the Będkówka and Kobylanka basin. *Biul. Inst. Geol.*, **100**, 419—461. Warszawa.
WALCZOWSKI A. 1976. Occurrence of calcareous sinter under the loesses in the environs of Bogoria. *Annal. Univ. Marie Curie-Skłod.*, **B-30/31**, 99—110. Lublin.
WILK Z. 1958. Investigations on the tectonics of the Libiąż Hills (Upper Silesia). *Zesz. Nauk. AGH, Geologia*, **2**, 47—63. Kraków.
ZARĘCZNY S. 1894. Mapa geologiczna okolic Krakowa i Chrzanowa. *Atlas Geol. Galic.* Kraków.
ZEISSLER H. 1980. Neue Bearbeitung der Konchylienfaunen aus dem interglazialen Travertin des Aufschlusses „An der Klippe" in Mühlhausen (Thüringen). *Malakol. Abhandl.*, **6** (19), 241—266. Dresden.

S. W. ALEXANDROWICZ

MALAKOFAUNA HOLOCEŃSKICH MARTWIC WAPIENNYCH WYŻYNY KRAKOWSKIEJ

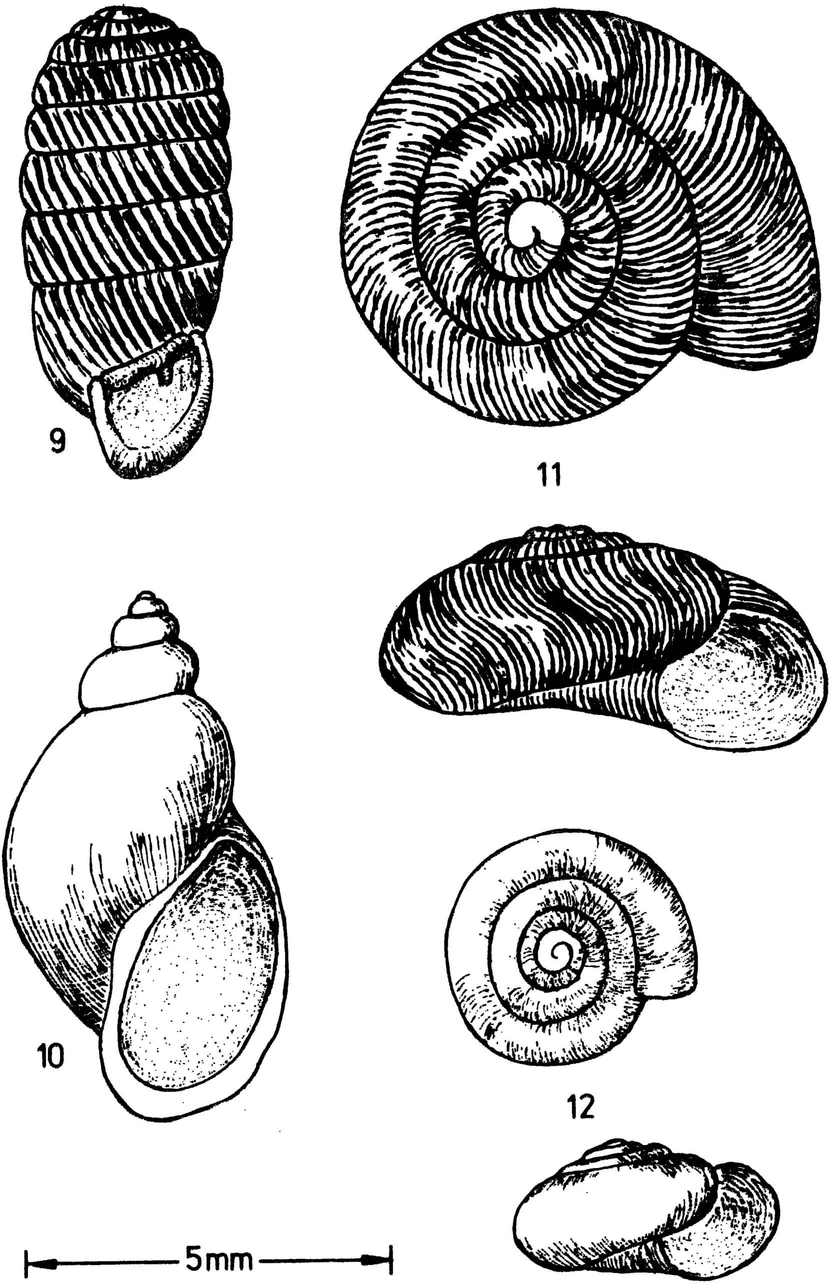
(Streszczenie)

Martwice wapienne występujące na Wyżynie Krakowskiej utworzyły się w dolnym i środkowym holocenie. Odsłonięte są one głównie w północnej części Wyżyny (fig. 1), gdzie najlepsze profile dostępne są w dolinach Sąspówki, Szklarki i Racławki (fig. 2—16). Martwice zawierają bogate zespoły mięczaków (patrz pl. 1—3), które wskazują na zróżnicowanie i ewolucję siedlisk, wywołane zmianami klimatycznymi oraz wpływem działalności człowieka (fig. 17—19 oraz tab. 1—6). W początkowej fazie powstawania martwic malakofauna była mało charakterystyczna. W czasie atlantyckiego optimum klimatycznego zaznaczył się wyraźny wzrost ilości ślimaków leśnych, a następnie udział ich stawał się coraz mniejszy, co wiązało się z postępującym wylesianiem Wyżyny. Struktura zoogeograficzna omawianej malakofauny w porównaniu ze współczesną fauną zasiedlającą ten obszar wykazuje mniejszy udział gauntków o szerokim rozprzestrzenieniu (palearktycznych, holarktycznych i europejskich), jest natomiast zbliżona do zespołów występujących w nieznacznie zmienionym przez człowieka, naturalnym środowisku Ojcowskiego Parku Narodowego (fig. 20). Tworzenie się martwic, poprzedzone intensywną erozją późnoglacjalną, rozpoczęło się w fazie borealnej. Główne nasilenie procesu narastania osadów wapiennych miało miejsce w fazie atlantyckiej i w pierwszej części fazy subborealnej (faza epiatlantycka), zaś zakończenie tego procesu nastąpiło z początkem fazy subatlantyckiej (fig. 21). W opisanych profilach wyróżnić można dwa typy sekwencji facjalnych, zawierające zespoły mięczaków o różnym składzie. Jeden z nich odznacza się dominacją gatunków preferujących siedliska wilgotne, łąkowe i słabo zalesione. W drugim typie sekwencji występują gatunki charakterystyczne dla rozmaitych środowisk ze znacznym udziałem ślimaków dobrze rozwijających się w siedliskach zacienionych (fig. 22). Martwice wapienne osadzały się na płaskich dnach dolin, wśród wilgotnych i podmokłych łąk, zarośli i lasów, a także w drobnych zbiornikach wodnych, powstających w wyniku okresowego zatamowania potoków przez narastające groble trawertynowe. W fazie subatlantyckiej wzrosła intensywność procesów erozyjnych; w konsekwencji tworzenie się osadów wapiennych uległo przerwaniu, zaś dna dolin zostały rozcięte i pogłębione do stanu dzisiejszego.



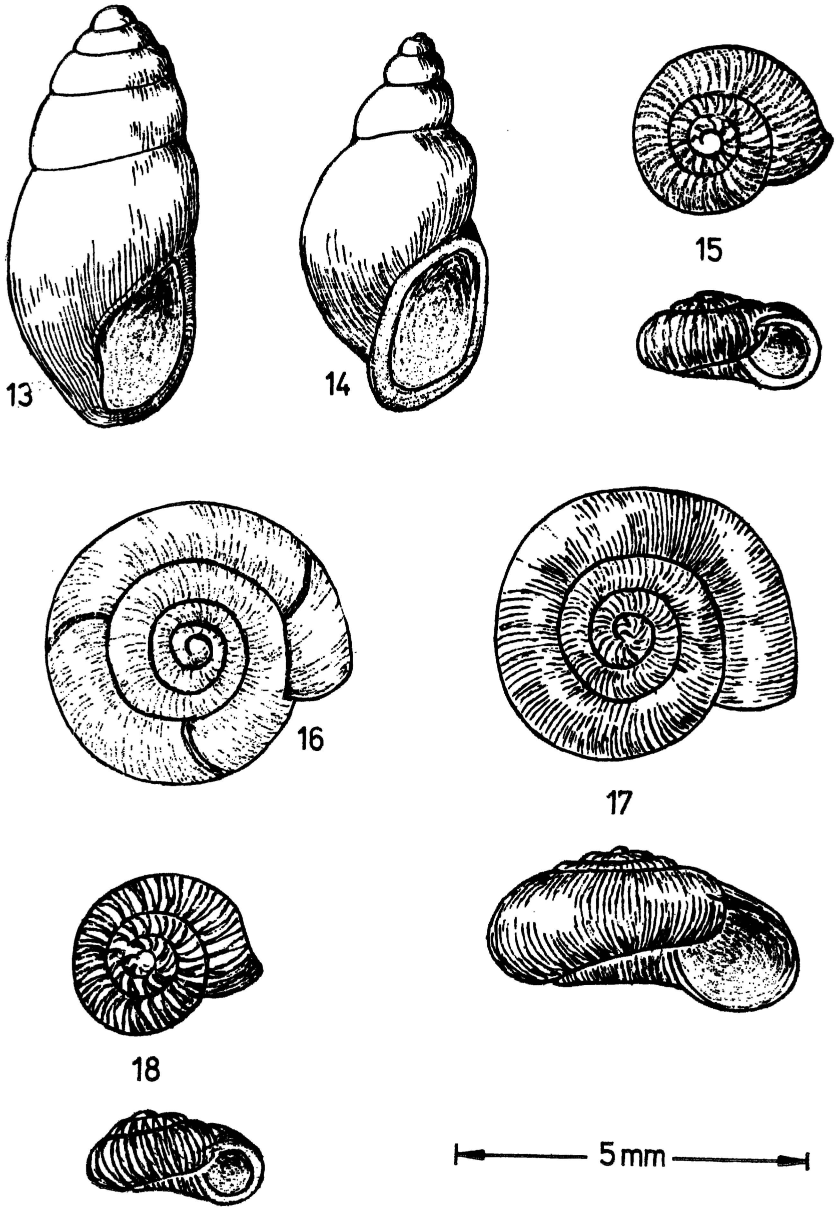
Typical gastropod species of Holocene calcareous tufas from the Cracow Upland

1 — *Carychium tridentatum* (Risso), 2 — *C. minimum* Müller, 3 — *Valvata cristata cristata* Müller, 4 — *Punctum pygmaeum* (Draparnaud), 5 — *Vertigo angustior* Jeffreys, 6 — *Acicula polita* (Hartmann), 7 — *Bythinella austriaca* (Frauenfeld), 8 — *Truncatellina cylindrica* (Férussac)



Typical gastropod species of Holocene calcareous tufas from the Cracow Upland (*cnt'd*)

9 — *Orcula doliolum* (Bruguière), **10** — *Lymnaea truncatula* (Müller), **11** — *Discus ruderatus* (Férussac), **12** — *Vitrea crystallina* (Müller)



Typical gastropod species of Holocene calcareous tufas from the Cracow Upland (*cnt'd*)

13 — *Cochlicopa lubrica* (Müller), **14** — *Lymnaea truncatula* (Müller), **15** — *Vallonia pulchella* (Müller), **16** — *Anisus leucostomus* (Millet), **17** — *Perpolita radiatula* (Alder), **18** — *Vallonia costata* (Müller)