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Malacofauna evolution of the Lake Peţea (Püspökfürdő), Oradea region, Romania

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Abstract. In the area of Püspökfürdő a geological section was elaborated by the Prospect Geo 2000 S.R.L. from Oradea, from which 42 pieces of sediment samples from every 20 cm of the section were handed over for malacological examinations. After dual flotation and sorting, the samples yielded 10,945 specimens of 10 species and the upper 40 samples yielded more than 100 specimens (statistically accepted). Only the lower two contained less than 100 specimens but these samples were remarkably fit to the malacological changes of the lower part, thus they were usable during the assessment. As a result of the malacological, paleoecological and statistical examinations 3 paleoecological zones can be separated, each of them showing different environmental conditions. The first paleoecological zone (by faunal composition) indicates a shallow, 15-23°C temperature stream-system, formed during the ice age, probably during the Würmian glaciation. Then, during the second half of the Würmian glaciation, it transformed into a 2-3 metre deep, oligomesotrophic lake system. In this temperate, lime-salt-rich, clean, well trans-illuminated water the SE-European *Fagotia acicularis*, evolved during the Middle Pleistocene, was the sole ruler, its dominance being over 80% in each sample. This species is thermophilous as like as *Theodoxus prevostianus*: based on the presence of both species the examined

area was a refuge of SE-European and Pannonian species at the end of the ice age, due to the relatively mild local environment. Simultaneously, the ice age water environment could be unbalanced, probably because of the shortness of the growth season, i.e. the rate of juvenile specimens in the examined fauna was high (between 50-70%), and therefore the mortality and the selection among the juvenile specimens was significant. A characteristic peak in diversity appeared at the beginning of the Holocene, after which *Fagotia acicularis* was driven into the background and soon disappeared, and parallel with that *Melanopsis parreyssii* appeared and became dominant (over 80%) as *Fagotia acicularis* was during the Pleistocene. The morphological changes among the parts of the genealogical line suggest that *Melanopsis parreyssii* is an eco-form of *Fagotia acicularis*, adapted to the 28-32°C warm thermal conditions. As a result of the genetic analyses on recent snail-shells (Smolen & Falniowski, 2009) it is just possible that this eco-form established itself and started a speciation process during the Holocene. As reflected in the composition of the fauna, the thermal hydro-geological system choked up and the temperature of the thermal water, broken out along tectonic fault lines, slightly increased, to over 30°C . In parallel the area and the water level of the Ice Age origin lake system decreased, and a warm water, eutrophic lake was formed in the examined area. Probably a gully established at the extensive, deeper, Ice Age origin lake system. Thus the lacustrine conditions could only remain at the deepest parts, near the tectonic fault lines of the territory, where the thermal water rush up in a cornet-like shape. This is the model that, in 1863, the Austrian geologist Heinrich Wolf described for the Püspökfürdő lake system, which explains the decrease in the level and mass of the water. Our data prove that the protected, Pannonian endemic mollusc species evolved and survived in this lake, thus the protection of the territory could have been fundamental, but unfortunately, because of the recent hotel constructions, the thermal and the ground water level dangerously decreased, and this is the reason why *Theodoxus prevostianus* became extinct and *Melanopsis parreyssii* is on the brink of extinction.

Introduction

Within the framework of Hungarian-Romanian bilateral collaboration, the members of the consortium elaborated an 8.4 m deep section in the area of the thermal lake Băile 1 Mai, in the area of Püspökfürdő, Oradea (Nagyvárad) region (Fig. 1). The samples were taken in the range of 20 cm for malacological examinations. According to the conditions of the application, they were delivered to the Department of Geology and Palaeontology, University of Szeged, in May, 2012, where detailed quartermalacological examinations were performed. The results of the malacological investigations are shown in this paper.

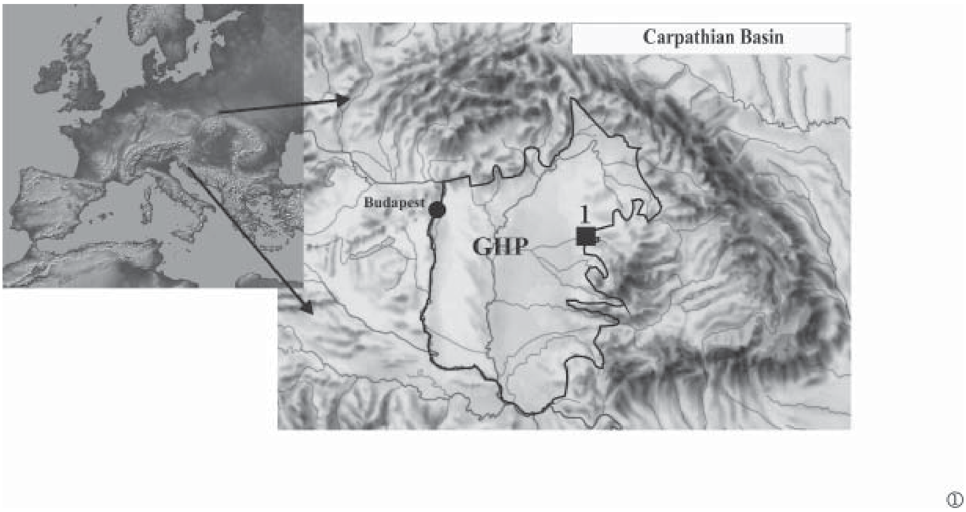

Fig. 1 – Location of the Lake Peţea in the Carpathian Basin (Băile 1 Mai, Oradea, Romania). 1=location of the lake, GHP=Great Hungarian Plain

Material and methods

The samples were wet-screened with dual meshes of 5 and 0.5 mm. Then the snail shells were assorted from the remains and the identified shells and the remaining sediment were packed up and sent back to Oradea.

Accepted identification handbooks were used for the malacological identification (Soós, 1943; Grossu, 1981-1987; Glöer, 2002; Horváth, 1950, Kerney et al., 1983; Glöer & Sîrbu, 2005; Sîrbu, 2006). The identified species were divided into paleoecologic and biogeographic groups (Soós, 1943; Sparks, 1961; Ložek, 1964; Evans, 1972; Sümegi & Krolopp, 2002, Sümegi, 2001, 2003, 2005) (Table 1). During the paleoecological classification, the species' water-cover-demands and dissolved-salt-bearing attributes were identified, and for the terrestrial species the habitat, climate and humidity demands were identified as well (Table 1).
Besides the identification, the abundance and dominance values and the rate of broken/intact and juvenile/adult shells for one litre unit were defined (Table 2a,b; 3a,b). During the malacological analysis, Shannon's diversity values were used (Table 2) and during the biometric analyses only the shells' length and width were identified (Fig. 2).

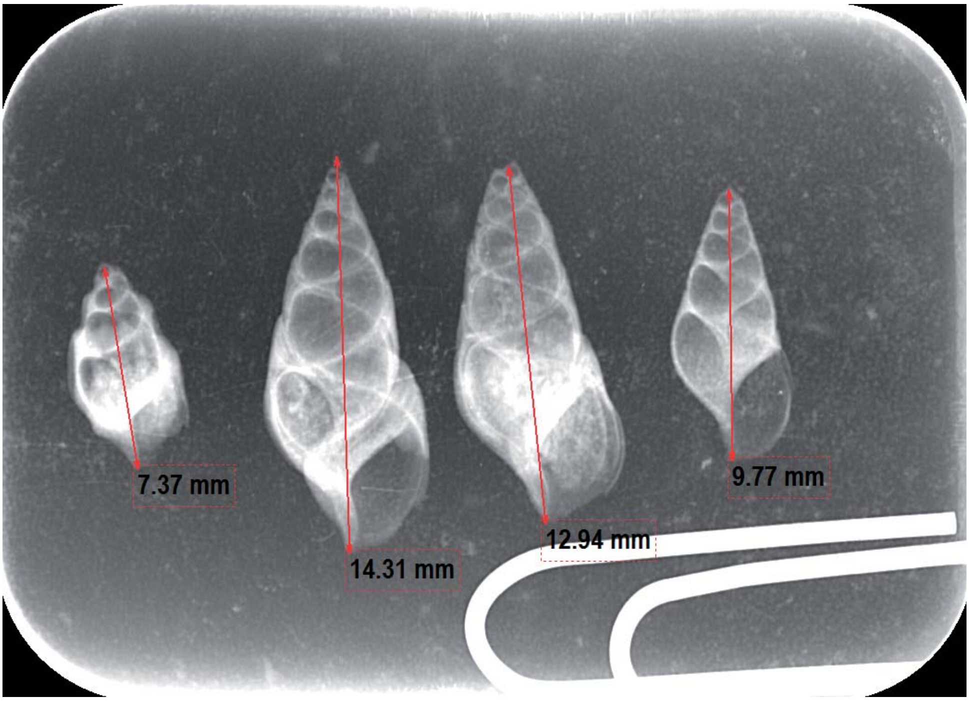

Fig. 2 – The X-ray snapshot used in biometric analysis (from left to right: *Melanopsis parreyssii, Fagotia acicularis* f. *thermalis, Fagotia acicularis* f. *sikorai, Fagotia acicularis* standard form*)*

Paleoecologic changes in the malacofauna, statistical evaluation

The changes of the fauna are shown by its dominance-changes (Sümegi & Krolopp, 2002) and were represented by the Psimpoll software-kit (Bennett, 1992), used mainly in the paleoecological domain (Table 3a and 3b, Fig. 5). Statistical analyses were made by using the malacofauna data, based on Podani's classification and ordination operation which was drawn up for comparison of mollusc faunas (Podani, 1978 and 1979).

The cluster analysis was fulfilled by Bray-Curtis method (Southwood, 1978), for the series-formation the Orlóci-Ward operation applied (Fig. 3). For the similarity and the series-formation analyses the NUCOSA software-kit was used, as designed by Tóthmérész (1993, 1997).

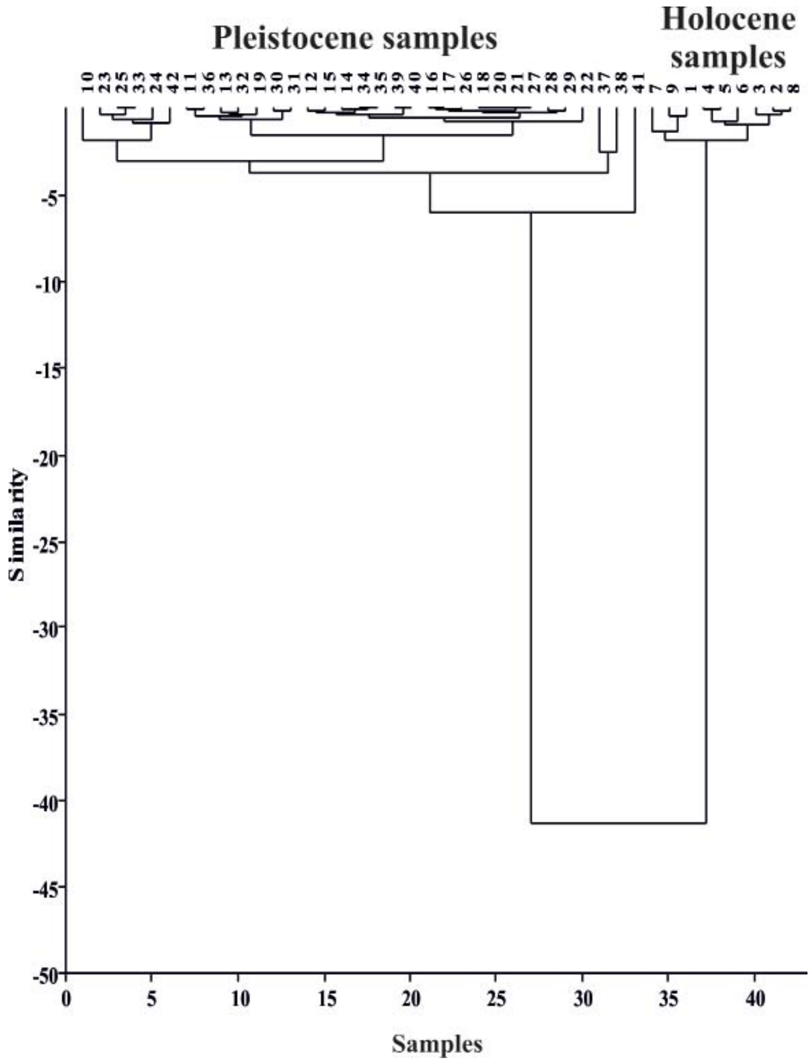

Fig. 3 – Results of malacological examinations on the Püspökfürdő, Băile 1 Mai samples: the cluster diagram of the samples based on the Beta-diversity a.k.a. Bray-Curtis similarity index

Statistical multi-variable biplot correspondence analyses were made on the samples to show the termination of malacological zones and the malacological-based reconstruction of paleoenvironment (Rousseau, 1990; Podani, 1993) (Fig. 4). From this analysis, the termination of samples deposited in the same environmental conditions could be perceptible, as well as which species were the key factors in paleoecological aspect. These bio-indicator elements were analysed particularly and a comprehensive paleoecological and paleobiographic evaluation is shown below.

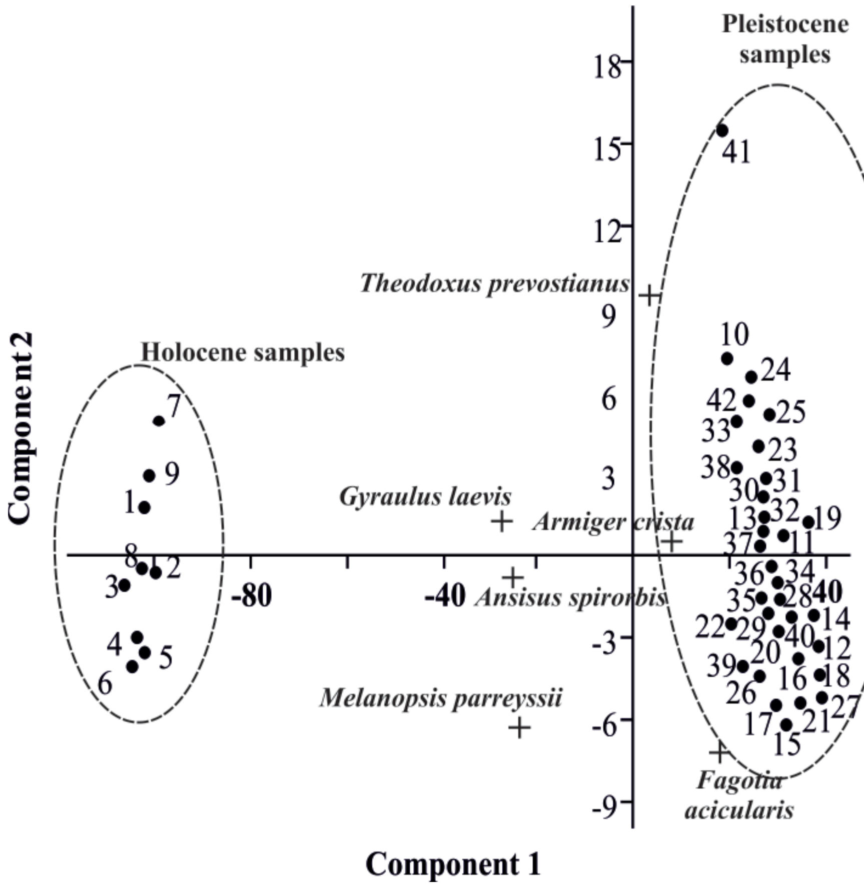

Fig. 4 – Results of malacological examinations on the Püspökfürdő, Băile 1 Mai samples: results of biplot correspondence analysis

Table 1 – Paleoecological classification of mollusc data according to ecological, biogeographic and paleoclimatologic groups

Paleoecological groups	*1. Theodoxus prevostianus*	*2. Fagotia acicularis*	*3. Melanopsis parreyssii*	*4. Planorbis planorbis*	*5.Anisus spirorbis*	*6. Gyraulus laevis*	*7. Armiger crista*	*8. Succinea putris*	*9. Vallonia pulchella*	*10.Perforatella rubiginosa*
Ditch species	+	+	+	+		+	+			
Slum species					+					
Alkaline water resistant species					+					
Spring water environment preferring species	+	+								
Thermal water environment preferring species			+							
Water bank species								+	+	+
Thermophilous species	+	+	+							
Cold-resistant species										+
Xerophilous species										
Hygrophilous species								+	+	+
Holarctic species				+		+			+	
Palearctic species					+		+			
Eurosiberian species								+		+
Pontic species		+								
Pannonian endemic species	+		+							

Table 2a – Abundance of the mollusc fauna from 1 litre sample unit of the Püspökfürdő, Băile 1 Mai profile

Sample number	Depth (cm)	*Theodoxus prevostianus*	*Fagotia acicularis*	*Melanopsis parreyssii*	*Planorbis planorbis*	*Anisus spirorbis*	*Gyraulus laevis*	*Armiger crista*	*Succinea putris*	*Vallonia pulchella*	*Perforatella rubiginosa*	**Total abundance**	**Number of species**	**Shannon-index**
		pcs	pcs	pcs	pcs	pcs	pcs	pcs	pcs	pcs	pcs	pcs	pcs	
1	0 - 20	17	0	121	0	0	0	0	0	0	0	138	**2**	**0,37**
2	20 - 40	38	0	334	1	0	3	0	0	0	0	376	**4**	**0,38**
3	40 - 60	18	0	176	0	0	4	0	0	0	0	198	**3**	**0,40**
4	60 - 80	22	0	251	0	1	4	0	0	0	0	278	**4**	**0,36**
5	80 - 100	24	0	273	0	0	5	0	0	0	0	302	**3**	**0,35**
6	100 - 120	22	0	267	0	0	0	0	1	0	0	290	**3**	**0,28**
7	120 - 140	42	0	253	0	1	7	0	0	0	0	303	**4**	**0,52**
8	140 - 160	21	0	185	0	0	3	0	0	0	0	209	**3**	**0,39**
9	160 - 180	52	0	347	0	1	2	0	0	0	0	402	**4**	**0,42**
10	180 - 200	34	319	9	3	0	1	0	2	0	0	368	**6**	**0,50**
11	200 - 220	10	296	0	0	0	0	0	0	0	0	306	**2**	**0,14**
12	220 - 240	3	268	0	0	0	0	0	0	0	0	271	**2**	**0,05**
13	240 - 260	11	251	0	0	0	0	0	0	0	0	262	**2**	**0,17**
14	260 - 280	5	369	0	1	0	0	0	0	0	0	375	**3**	**0,08**
15	280 - 300	2	327	0	1	0	0	0	0	0	0	330	**3**	**0,05**
16	300 - 320	1	204	0	0	0	0	0	0	0	0	205	**2**	**0,02**
17	320 - 340	1	191	0	0	0	0	0	0	0	0	192	**2**	**0,02**
18	340 - 360	0	179	0	0	0	0	0	0	0	0	179	**1**	**0,00**
19	360 - 380	5	146	0	1	0	0	1	0	0	0	153	**4**	**0,21**
20	380 - 400	0	127	0	0	0	0	0	0	0	0	127	**2**	**0,00**
21	400 - 420	0	126	0	0	0	0	0	0	0	0	126	**4**	**0,00**

Table 2b – Abundance of the mollusc fauna from 1 litre sample unit of the Püspökfürdő, Băile 1 Mai profile

Sample number	Depth (cm)	*Theodoxus prevostianus*	*Fagotia acicularis*	*Melanopsis parreyssii*	*Planorbis planorbis*	*Anisus spirorbis*	*Gyraulus laevis*	*Armiger crista*	*Succinea putris*	*Vallonia pulchella*	*Perforatella rubiginosa*	**Total abundance**	**Number of species**	**Shannon-index**
		pcs	pcs	pcs	pcs	pcs	pcs	pcs	pcs	pcs	pcs	pcs	pcs	
22	420 - 440	1	123	0	0	0	2	0	0	0	0	126	**3**	**0,11**
23	440 - 460	9	124	0	0	0	0	0	0	0	0	133	**2**	**0,24**
24	460 - 480	31	312	0	0	0	0	0	0	0	0	343	**2**	**0,30**
25	480 - 500	31	371	0	0	0	0	0	0	0	0	402	**2**	**0,26**
26	500 - 520	1	373	0	0	0	0	0	0	0	0	374	**2**	**0,01**
27	520 - 540	0	337	0	0	0	0	0	0	0	0	337	**2**	**0,00**
28	540 - 560	0	377	0	0	0	1	1	0	0	0	379	**3**	**0,03**
29	560 - 580	0	441	0	0	0	1	3	0	0	0	445	**3**	**0,05**
30	580 - 600	21	385	0	0	0	0	1	0	0	0	407	**3**	**0,21**
31	600 - 620	19	351	0	0	0	0	3	0	0	0	373	**3**	**0,24**
32	620 - 640	16	352	0	0	0	0	2	0	0	0	370	**3**	**0,20**
33	640 - 660	30	356	0	0	0	0	0	0	0	0	386	**2**	**0,27**
34	660 - 680	6	354	0	0	0	0	0	0	0	0	360	**2**	**0,08**
35	680 - 700	6	342	0	0	0	0	0	0	0	0	348	**2**	**0,08**
36	700 - 720	9	247	0	0	0	0	0	0	0	0	256	**2**	**0,14**
37	720 - 740	1	119	0	7	0	0	0	0	1	1	129	**5**	**0,33**
38	740 - 760	2	101	0	13	0	0	0	0	1	0	117	**4**	**0,47**
39	760 - 780	1	104	0	1	0	0	0	0	0	0	106	**3**	**0,09**
40	780 - 800	1	103	0	1	0	0	0	0	0	0	105	**3**	**0,09**
41	800 - 820	1	5	0	0	0	0	0	0	0	0	6	**2**	**0,45**
42	820 - 840	4	48	0	1	0	0	0	0	0	0	53	**3**	**0,35**

Table 3a – Dominance values of the mollusc fauna from 1 litre sample unit of the Püspökfürdő, Băile 1 Mai profile

Sample number	Depth (cm)	*Theodoxus prevostianus*	*Fagotia acicularis*	*Melanopsis parreyssii*	*Planorbis planorbis*	*Anisus spirorbis*	*Gyraulus laevis*	*Armiger crista*	*Succinea putris*	*Vallonia pulchella*	*Perforatella rubiginosa*	**Total dominance**
		%	%	%	%	%	%	%	%	%	%	%
1	0 - 20	12,32	0,00	87,68	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**100,00**
2	20 - 40	10,11	0,00	88,83	0,27	0,00	0,80	0,00	0,00	0,00	0,00	**100,00**
3	40 - 60	9,09	0,00	88,89	0,00	0,00	2,02	0,00	0,00	0,00	0,00	**100,00**
4	60 - 80	7,91	0,00	90,29	0,00	0,36	1,44	0,00	0,00	0,00	0,00	**100,00**
5	80 - 100	7,95	0,00	90,40	0,00	0,00	1,66	0,00	0,00	0,00	0,00	**100,00**
6	100 - 120	7,59	0,00	92,07	0,00	0,00	0,00	0,00	0,34	0,00	0,00	**100,00**
7	120 - 140	13,86	0,00	83,50	0,00	0,33	2,31	0,00	0,00	0,00	0,00	**100,00**
8	140 - 160	10,05	0,00	88,52	0,00	0,00	1,44	0,00	0,00	0,00	0,00	**100,00**
9	160 - 180	12,94	0,00	86,32	0,00	0,25	0,50	0,00	0,00	0,00	0,00	**100,00**
10	180 - 200	9,24	86,68	2,45	0,82	0,00	0,27	0,00	0,54	0,00	0,00	**100,00**
11	200 - 220	3,27	96,73	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**100,00**
12	220 - 240	1,11	98,89	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**100,00**
13	240 - 260	4,20	95,80	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**100,00**
14	260 - 280	1,33	98,40	0,00	0,27	0,00	0,00	0,00	0,00	0,00	0,00	**100,00**
15	280 - 300	0,61	99,09	0,00	0,30	0,00	0,00	0,00	0,00	0,00	0,00	**100,00**
16	300 - 320	0,49	99,51	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**100,00**
17	320 - 340	0,52	99,48	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**100,00**
18	340 - 360	0,00	100,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**100,00**
19	360 - 380	3,27	95,42	0,00	0,65	0,00	0,00	0,65	0,00	0,00	0,00	**100,00**
20	380 - 400	0,00	100,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**100,00**
21	400 - 420	0,00	100,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**100,00**

Table 3b – Dominance values of the mollusc fauna from 1 litre sample unit of the Püspökfürdő, Băile 1 Mai profile

Sample number	Depth (cm)	*Theodoxus prevostianus*	*Fagotia acicularis*	*Melanopsis parreyssii*	*Planorbis planorbis*	*Anisus spirorbis*	*Gyraulus laevis*	*Armiger crista*	*Succinea putris*	*Vallonia pulchella*	*Perforatella rubiginosa*	**Total dominance**
		%	%	%	%	%	%	%	%	%	%	%
22	420 - 440	0,79	97,62	0,00	0,00	0,00	1,59	0,00	0,00	0,00	0,00	**100,00**
23	440 - 460	6,77	93,23	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**100,00**
24	460 - 480	9,04	90,96	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**100,00**
25	480 - 500	7,71	92,29	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**100,00**
26	500 - 520	0,27	99,73	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**100,00**
27	520 - 540	0,00	100,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**100,00**
28	540 - 560	0,00	99,47	0,00	0,00	0,00	0,26	0,26	0,00	0,00	0,00	**100,00**
29	560 - 580	0,00	99,10	0,00	0,00	0,00	0,22	0,67	0,00	0,00	0,00	**100,00**
30	580 - 600	5,16	94,59	0,00	0,00	0,00	0,00	0,25	0,00	0,00	0,00	**100,00**
31	600 - 620	5,09	94,10	0,00	0,00	0,00	0,00	0,80	0,00	0,00	0,00	**100,00**
32	620 - 640	4,32	95,14	0,00	0,00	0,00	0,00	0,54	0,00	0,00	0,00	**100,00**
33	640 - 660	7,77	92,23	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**100,00**
34	660 - 680	1,67	98,33	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**100,00**
35	680 - 700	1,72	98,28	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**100,00**
36	700 - 720	3,52	96,48	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**100,00**
37	720 - 740	0,78	92,25	0,00	5,43	0,00	0,00	0,00	0,00	0,78	0,78	**100,00**
38	740 - 760	1,71	86,32	0,00	11,11	0,00	0,00	0,00	0,00	0,85	0,00	**100,00**
39	760 - 780	0,94	98,11	0,00	0,94	0,00	0,00	0,00	0,00	0,00	0,00	**100,00**
40	780 - 800	0,95	98,10	0,00	0,95	0,00	0,00	0,00	0,00	0,00	0,00	**100,00**
41	800 - 820	16,67	83,33	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**100,00**
42	820 - 840	7,55	90,57	0,00	1,89	0,00	0,00	0,00	0,00	0,00	0,00	**100,00**

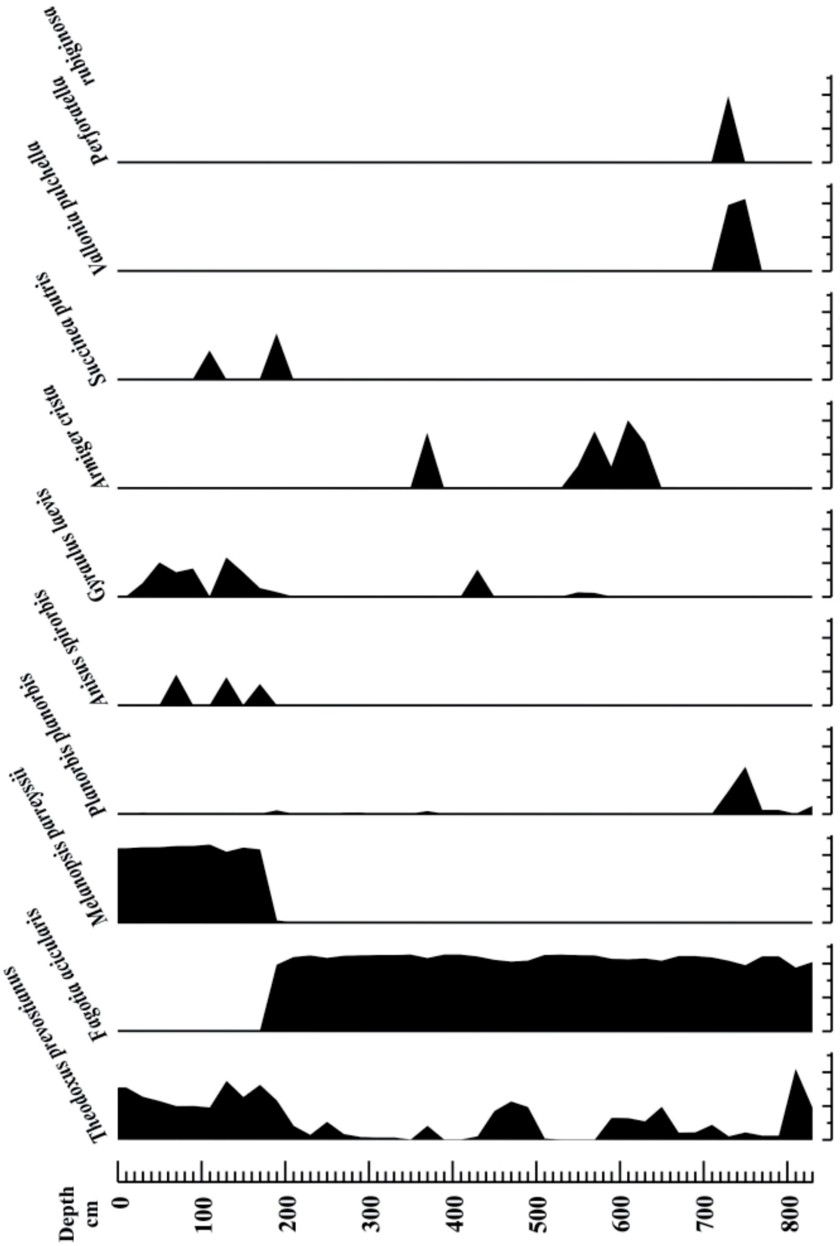

Fig. 5 – Dominance relations of the mollusc fauna from Püspökfürdő, Băile 1 Mai profile previous examinations

Prior examinations

The very first report about the *Melanopsis* species in the Püspökfürdő area was made by the Austrian geologist, Franz Bregrath Ritter von Hauer (Hauer, 1852). On the other hand, according to Phillippi, the finder of *Melanopsis parreyssii* (Phillippi, 1847) (Fig. 6), the found specimen was ensued from Hungary, and the collector was the Austrian naturalist, von Mühlfeld. Unfortunately Phillippi neither mentioned the specimen's exact locality nor when and where von Mühlfeld visited Hungary. Currently it can't be proved but not impossible that the first described specimens of this taxa were from Püspökfürdő, because the shells of that species can be easily found there on the ground, and then this area was a part of Hungary.

Fig. 6 – *Melanopsis parreyssii*, the first report from Philippi's monograph (Philippi, 1847)

The first geological series of the Püspökfürdő area, with the *Melanopsis* taxa in the layers, was published by an Austrian geologist, Heinrich von Wolf (Wolf, 1863). The published series contained a barely formed humic horizon in the immediate vicinity of the thermal lake (Wolf, 1863) (Fig. 7.). Unfortunately, Wolf used neither a compass, a scale nor a map, and because of the significant environmental changes of the past 150 years his description can hardly be used. But some parts of his published series-description could be found in the elaborated sections and boreholes. Thereafter these mollusc species were mentioned during the comprehensive geological analysis of the Oradea region (Szontagh, 1890) and also in the borehole for water layer-series by Béla Zsigmondy.

Regardless of these investigations, the Hungarian natural scientist Mihály Tóth was the first who reported the Quaternary malacofauna of the Püspökfürdő area in the 25th Hungarian Itinerary Congress of Doctors and Naturalists in Oradea, in 1890. He gave a detailed account of the Quaternary malacofauna, and among other things the changes of the *Melanopsis* species. In his work he reported the mollusc fauna he obtained by layer-rarefying from an approx. 2 m high section. According to the changes of the various *Melanopsis* species, he described an intense development-process with many *Melanopsis* species during the Quaternary. He considered that the thermal lake was formed earlier than the Holocene, and derived the various *Melanopsis* species from a Tertiary common ancestor which survived the glacial period.

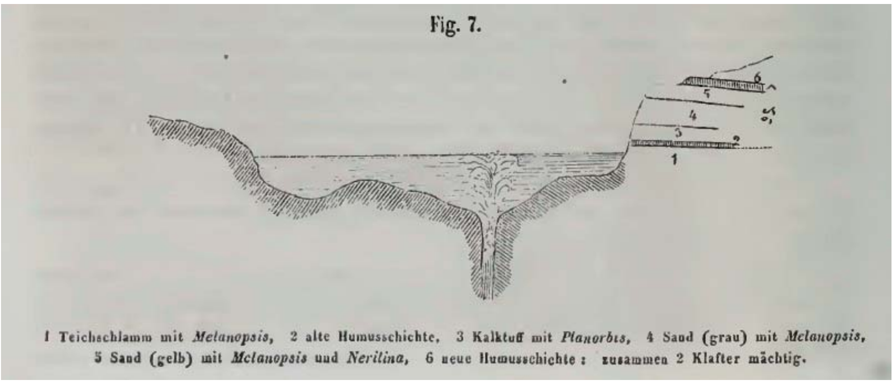

Fig. 7 – The first sketch of the Lake Peţea in Püspökfürdő (Wolf, 1863*)*

Beside Mihály Tóth's work, Spiridon Brusina and Tivadar Kormos examined the Quaternary malacofauna of the Püspökfürdő area, among others the *Melanopsis* and the *Theodoxus* species (Brusina, 1902; Kormos, 1903a,b; 1905a,b). Brusina made no elaborated sections or boreholes, but he made taxonomic investigations only from ground shells and from Tóth's shell-collection (Brusina, 1902). In his work he determined eight taxa, including *Melanopsis parreyssii* as well as 23 varieties of it. Unfortunately, he made no figures nor detailed description for the taxa, only a short word in Latin for each of them (Brusina, 1902). Based on an earlier work of the paleobotanist Móric Staub (Staub, 1892), Brusina considered that the *Melanopsis* taxa are remains of a Tertiary subtropical oasis which survived the glacial period due to the thermal lake in Püspökfürdő.

Tivadar Kormos, based on Zsigmondy's and Mihály Tóth's results, mapped the area's geological and morphological attributes and elaborated an 11 meter high, combined section-borehole layer series. Beside the detailed geological and stratigraphic investigations, Kormos made a detailed examination on the

Theodoxus and *Melanopsis* specimens described by Brusina (Kormos, 1903a,b, 1905a,b). Kormos also examined other ground sections, published maps and geological layer-series and marked his and Mihály Tóth's section as well.

This was the base work for us when we began the examinations on the development of the *Theodoxus* and *Melanopsis* taxa as well as the geological and chronologic development of the Püspökfürdő area. The main conclusions of Kormos were that the *Melanopsis* and *Theodoxus* taxa can be traced back to a Tertiary common ancestor. The recent malacofauna of the thermal lake of Püspökfürdő has a relict, subtropical survivor character, and is evolutionary and genealogically related to the late Tertiary Slavonian malacofauna.

Simultaneously, Kormos noticed that the *Melanopsis* specimens from Püspökfürdő can be genealogically related to the taxa of *Fagotia*: *Fagotia acicularis* and *F. esperi* (Kormos, 1905a). Some researchers consider the latter species, *Esperiana (Microcolpia) daudebartii acicularis* (Fèrussac, 1823) and *Esperiana (Fagotia) esperi* (Fèrussac, 1823), are Pontic (Fehér et al., 2004), but the cyclic appearance of these species in the Carpathian Basin was clearly determined during the Quaternary interglacial periods, not the Tertiary (Krolopp, 1973, 1983).

The basis of the malacological investigations of Kormos was a botanical occurrence in the thermal lake, the Egyptian white water-lily (*Nymphaea lotus thermalis*). The thermal lake was considered a subtropical oasis, a relict of an older geologic age (Kerner, 1887, Simonkai, 1890, Staub, 1903). The Egyptian white water-lily was considered as a Quaternary taxon by the majority of botanists, and this is why Kormos also considered the same age for the other relicts, notwithstanding that several botanists made mentions about the origin of the water-lily of the thermal lake (Borbás, 1894, Richter, 1897). Kormos considered an Egyptian origin both for *Melanopsis* and the Egyptian white water-lily, and noticed that they lived together there, this is why he considered *M. parreyssii* is a Quaternary taxon, and based on the presence of the water-lily at Püspökfürdő, he thought the thermal lake is a subtropical relict area.

Results of paleoecological analyses

All of the 42 examined samples contained a statistically rateable amount of mollusc shells (Table 1, 2a, 2b, 3a and 3b). From the upper 40 samples, the abundance of shells was over the 100 pcs/sample, so the statistical minimum was exceeded (Krolopp, 1983); the lower samples' (no. 41 and 42) abundance was below the statistical minimum, nevertheless they were suitable for characterizing the environmental changes of Püspökfürdő area.

The investigated mollusc fauna contained a total amount of 10,945 specimens of 10 species (Table 2a and 2b). Thus every sample was suitable to describe its abundance and dominance value (Table 2a, 2b, 3a and 3b; Fig. 5), diversity-index (Table 2a and 2b), cluster and biplot analyses (Fig. 3 and 4).

Based on the statistical report, the examined samples represent material accumulated in three radically different environmental situations. From the base of the section (samples no. 37-42; from 720 to 840 cm) terrestrial, mainly riparian elements came to light, mostly the cold-resistant, Eurosiberian *Perforatella rubiginosa* and the mesophilous, Holarctic *Vallonia pulchella* (Fig. 5). Besides the terrestrial species, the abundance and dominance of the eutrophic shallow water preferring, Holarctic *Planorbis planorbis*, and the thermal water preferring, Pannonian endemic *Theodoxus prevostianus* are significant (Table 2a, 2b, 3a and 3b). Although the dominance value of the Pontic *Fagotia acicularis* is outstanding, the presence of the other bio-indicator elements refers to the evolution of a maximum 1-2 m deep, organic-material-rich lake environment.

The temperature of the water could be between 15°C and 23°C (Vásárhelyi, 1956), based on the presence of permanent and mild water temperature and lime-salt-rich water preferring *Theodoxus prevostianus* and *Fagotia acicularis*. The hydrologic system could have consisted of shallow, slow running water and probably that time the thermal-water containing stream-system (Pece-stream) incised into the area. The base mudstone layer eroding stream-system unambiguously developed during the Ice Age.

The second malacological zone was formed between the samples no. 10 and 36 at depths between 200 and 720 cm. This horizon is characterized by the absolute dominance (over 80%) of *Fagotia acicularis* (Fig. 5). The presence of *Armiger crista* signals the Ice Age fauna-horizon, because based on recent malacological examinations this species can be linked to Ice Age layers (Sümegi et al., 2012).

Moreover, the thermal form of *Fagotia acicularis*, the taxonomically non-valid thick-shelled *Fagotia acicularis* f. thermalis appeared beside the standard form in this horizon. This form of *Fagotia acicularis* appears in the colder thermal water (between 15°C and 20°C) in Holocene sediments and also in Riss-Würmian interglacial sediments (Krolopp, 1985). It is also known that the thick-shelled form appears in higher temperature water which is rich in Mg^{+} cations; the Mg^{+} cations infiltrate into the shell and determine its thickening (Sümegi, 2012). Besides the *Fagotia acicularis*, present with high dominance, the Pannonian endemism *Theodoxus prevostianus* appeared in a ratio between 4 and 8 percent. The composition of the mollusc fauna indicates an oligo-mesotrophic lake system with higher water depth (minimum 1.5 m, maximum 3-4 m), a water temperature of about 15-23°C and a significant content of dissolved carbonate. The examined section probably originated in the deepest point of the former lake-system, this is why the absolute dominance (over 96%) of the branchiate species occurs in every sample (Fig. 5). The pulmonates *Gyraulus laevis* and *Armiger crista* sporadically appeared from this Ice Age malacological horizon (Fig. 5), and their common dominance didn't reach 4% in every sample, so this horizon is characterized by the dominance of branchiate snails (*Theodoxus prevostianus* and *Fagotia acicularis*). Since quite few species appeared in this horizon (mainly two species – *Fagotia acicularis* and *Theodoxus prevostianus*), the diversity values were the lowest in the section. This is quite characteristic of the substrate region of Ice Age oligo-mesotrophic lakes even if the water temperature was optimal: the high level of dissolved Ca^{+} and Mg^{+} cations, the slow running water, the low level of dissolved organic matter and the ancillary water flora predestined a homogenous fauna composition.

Besides the low Shannon-index values, the other characteristic of the Ice Age fauna is the high ratio of juvenile specimens of the malacofauna: for *Fagotia acicularis* (ratio of juvenile specimens between 52% and 71%) and also *Theodoxus prevostianus* (between 53% and 61%). Based on the high rate of juvenile species it could be said that the length of the growth season could rapidly change during the Würmian glacial, thus the surviving chances of the juvenile specimens were quite limited.

This means that the high juvenile rate in the Ice Age samples indicates rapid changes in the environment: because of the shorter growth season the mortality rate was high (and caused extraordinary selection). Unfortunately, this kind of examinations was not previously performed (or not published), but mainly in loessy sediments. Hence the Ice Age fauna is compared here with the Holocene fauna's adult/juvenile ratio of the same section.

The boundary between the ice age (Pleistocene) and our age (Holocene) could have occurred at the 10th sample because this sample contains both *Melanopsis parreyssii* and *Fagotia acicularis*. *Melanopsis parreyssii* alone appeared from the upper 9 samples, while *Fagotia acicularis* was driven into the back (Fig. 5). The change and the formation of a transitional zone of the above mentioned taxa, included in the *Melanopsidae* family is not casual, i.e. the evolution of *Melanopsis parreyssii* is derived from *Fagotia acicularis* by both classic morphologic (Sümegi et al. 2012), and modern genetic analyses (Smolen & Falniowski, 2009).

The disjunction of the two species can be placed in the Holocene. From a paleontological point of view it is quite problematic, partly because the disjunction is remarkably young (maximum 10 ka), and partly because the transitional forms of the two taxa were believed to be connectives between them (by the 100 year-old malacological notion) (Tóth, 1891, Brusina, 1902, Kormos, 1905a,b).

Simultaneously, it is well-known that the morphological changes are not unambiguous (Pauca, 1937), the transitional forms are rather connected with the environmental changes: the non-stable genetic background was influenced by the thermal water system's dissolved lime-salt concentration and the considerable intake of the Mg^{+} cation (Sümegi et al. 2012).

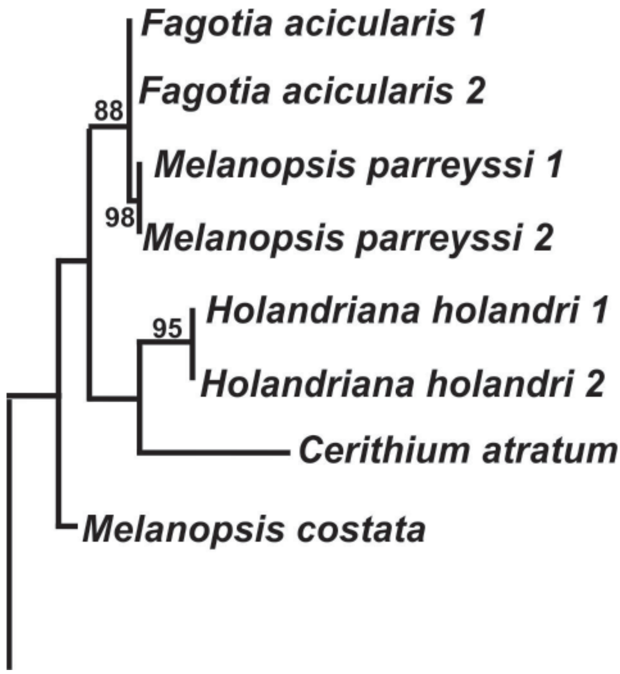

Fig. 8 – Results of genetic analyses on the 18S mitochondrial series of recent Melanopsidae taxa; hypothetic phylogenetic ramifications by the molecular watch (Smolen & Falniowski, 2009)

The genetic analyses (Smolen & Falniowski, 2009) only show the changes of the genetic watch, or the geological time of the probable disjunction, not the real genetic disjunction. Thus the taxonomic classification of *Fagotia acicularis*, *Melanopsis parreyssii* and all previously described species, forms and varieties (Tóth, 1891, Brusina, 1902, Kormos, 1903a,b, 1905a,b) is entirely doubtful, because the spiral markings and stepped shell forms of the freshwater *Melanopsidae* taxa in thermal water could have been formed because of environmental causes (Krolopp, 1985). Thus the taxonomical segregation of the Pleistocene aged *Fagotia acicularis* and the Holocene aged *Melanopsis parreyssii* is debatable in the future: there is reason for the species-disjunction, as much as for the environmental-effected varieties formation (Sümegi et al. 2012). This is supported by the genetic analyses of the recent *Melanopsidae* 18S mitochondrial series (Fig. 8), which clearly prove the least genetic (geological) time difference between the *Melanopsis parreyssii* and the *Fagotia acicularis* of Püspökfürdő. Despite that, it is arguable that the major morphological differences between *Melanopsis parreyssii* and *Fagotia acicularis* can be found in the *Melanopsidae* taxa of Püspökfürdő (Tóth, 1891, Brusina, 1902, Kormos, 1903a,b, 1905a,b).

Simultaneously, the segregation of *Melanopsis parreyssii* from the considered original ancestor (so-called father group), Late-Tertiary evolved, Minor Asian and Middle Eastern ranged *Melanopsis costata* is quite significant and even quite similar to the *Fagotia acicularis* (Fig. 8), so the genealogical relationship between *Fagotia acicularis* and *Melanopsis parreyssii* is unequivocal.

Thus it is not accidental that the geological and paleontological analyses on the *Melanopsis* shells, connected with the 2012 application, clearly supported the close genealogical relationship between *Fagotia acicularis* and *Melanopsis parreyssii* and their (incipient) disjunction during the last 10,000 years in the Holocene.

For the solving of the taxonomical problems there were two opportunities: *Melanopsis parreyssii* may be considered as a form (eco-morphological taxon) of *Fagotia acicularis* adapted to 32-34 °C thermal water conditions, or it may be a separate species which adapted and established itself in thermal water. Either version is considered as benchmark, the dimension and the geological time of the disjunction are minimal. If the taxa disjunction is the benchmark, it can be said that this species is the youngest endemism which evolved in the historic times in the Carpathian Basin, in the paleobiogeographical Pannonicum (Sümegi, 2012). This means that this species is one of the youngest endemism, which evolved in front of our eyes and unfortunately, because of its isolated and polluted biotope, could become extinct in front of our eyes (Sümegi, 2012).

Furthermore, as proved by our examinations, the ecosystem acted as a temperate refuge (or oasis) during the last glaciation, not as a subtropical one, as stated in previous publications (Kerner, 1887, Simonkai, 1890, Straub, 1892, 1903, Tóth, 1891, Brusina, 1902, Kormos, 1905a,b), because the Tertiary considered *Theodoxus prevostianus* and *Fagotia acicularis* evolved during the Middle-Pleistocene (between 800 and 200 ka) after splitting from the Early-Pleistocene ancestral group (Krolopp, 1973). Therefore, by the presence of these species, the refuge cannot be inferred as a subtropical, Tertiary one, but a temperate one, formed during the last glaciation (Sümegi, 1999).

Thus the character of the Tertiary refuge cannot be consistent with the presence of *Fagotia acicularis*, but the lake is a temperate refuge-like area dating from the late Middle-Pleistocene interglacial (Sümegi, 1999). Beside *Fagotia acicularis* the presence of *Theodoxus prevostianus* shows that the examined territory was not a subtropical oasis, but a temperate refuge formed by the heat-surplus of the thermal water. In this temperate refuge at Püspökfürdő in the S-SE of the Carpathian Basin, thermophilous mollusc species, such as the freshwater *Theodoxus prevostianus*, *Fagotia acicularis*, *Fagotia esperi* and the terrestrial *Helicigona (Chliostoma) banatica*, could survive during the coldest periods of the ice age (Sümegi, 1999).

Above the both *Melanopsis parreyssii* and *Fagotia acicularis* containing, Pleistocene-Holocene boundary indicating level, an another level with high (over 80%) *Melanopsis parreyssii* dominance was formed. Beside this species, the secondary dominance of *Theodoxus prevostianus* (between 6-10%) is noticeable in the Holocene lake sediment. Beside these taxa the following species appear in this level: the shallow alkaline water preferring *Anisus spirorbis*, the organic-matter-rich water preferring *Gyraulus laevis* and the coastal area preferring *Succinea putris*, which lives on the stems of water plants (reed and bulrush).

In the transitional Holocene-Pleistocene level shows a maximum of diversity assets, because both the retreating Pleistocene taxa and both the expanding Holocene species are present. Considering this, the diversity assets decreased (Table 2a,b) but still remained higher than the Pleistocene assets. A cause for the increased diversity assets could be the congenial Holocene environmental conditions for the molluscs.

Based on the composition of the fauna, the lake system was transformed in the beginning of the Holocene: the water temperature particularly increased (over 28-30°C degrees), and the water-dissolved organic matter content, in-washed from the coastal area, strongly increased. Based on the presence of the shallow water preferring species, the water level decreased, and a shallow, thermal, water plant-covered, eutrophic lake was formed.

The background of this change was the increased amount of rainfall in the end of the ice age, thus the area's hydrological system soon choked up, and for this reason the amount and the temperature of the thermal water, broken out along tectonic fault lines, suddenly rose. The temperature of the lake system was strongly influenced by the deep waters' temperature and the Holocene air temperature conditions: the increased durations of frostless period, vegetation period and growth season. The changed length of growth season is clearly visible for instance in the change of the ratio of adult/juvenile specimens: the ratio of *Melanopsis parreyssii* juvenile specimens decreased below 40% during the Holocene and was between 26-40% during the last 10,000 years.

This juvenile ratio, compared with the Pleistocene 50% above, is a quite significant change. Similar changes occurred in *Theodoxus prevostianus*: the Pleistocene juvenile ratio (between 50-60%) decreased between 27-32% in the Holocene samples. Thus the mortality rate of the juvenile species strongly decreased during the Holocene, probably due to the increased length and balanced environmental conditions of the growth season.

Following these hydro-geological and climate changes, a eutrophic thermal lake was formed in the second half of the Holocene, where protected endemic species, like Egyptian white water-lily (*Nymphaea lotus thermalis*), *Theodoxus prevostianus*, *Melnanopsis parreyssii*, could establish. This organic matter-rich, thermal system remained up to the present, but because of the anthropic disturbation and pollution, the survival of this unique system is quite problematic. The survival of the ecosystem can be ensured only by initiating strict nature protection orders and setting up a hydro-geological and biological buffer zone in the whole Peţea-valley.

Description of the main mollusc species

Theodoxus prevostianus (C. Pfeiffer, 1928)

Endemic species which evolved in the Middle Pleistocene and remained in some remote streams in the Carpathian Basin (Krolopp, 1973; Sümegi, 1999). Known localities in the Carpathian Basin: Bad Vöslau and Bad Fischau (Austria), Bušeča vas (Slovenia) and Kács (Hungary). This species was eurytopic in the Püspökfürdő area (Wolf, 1863; Kormos, 1903a,b, 1905a,b), and the last living specimens were collected by Sándor Mocsáry in the 1870s. But the species was widespread from the 19th century till 2007 in the Răbăgani region southeast of Oradea (Kimakowicz, 1883-1884; Grossu, 1936; Jurcsák, 1969; Sîrbu & Benedek, 2005). The last Romanian population has become extinct because of a construction in Răbăgani (Sîrbu & Benedek, 2009). In the Püspökfürdő area the destiny of recent specimens is unknown, i.e. no one had found recent specimens after Sándor Mocsáry in the area (Sîrbu, 2006). Thus the extinction of the local population can be estimated in the second half of the 19th century or the beginning of the 20th century.

Fagotia acicularis (Fèrussac, 1823)

Pontic species which spread in the southern part of the Carpathian Basin via the River Danube and its tributaries and is also known from mild and cold streams. By our results *Fagotia acicularis* become extinct from the Püspökfürdő area during the Holocene and this is supported by the recent examinations by Sîrbu (2006). It is presently known from the Răbăgani, the catchment area of River Black-Kőrös (Clessin, 1887), but because of the irrigation of the area the survival of the species is doubtful (Sîrbu, 2006).

Melanopsis parreyssii (Philippi, 1847)

Endemic species, the only known locality is the thermal lake Băile 1 Mai, Püspökfürdő. By the results shown above and the genetic analyses (Smolen&Falniowski, 2009) the hundred-year-old statement of Tivadar Kormos can be proved: *Melanopsis parreyssii* is a sort of differentiated sister-taxon (species or thermal water preferring eco-form) of *Fagotia acicularis*. The length of fossil adult shells was below the values of recent shells (15.52 mm mean vs. 18 mm mean), and the mean width of fossil *Melanopsis parreyssii* shells was 6.81 mm.

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