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The Forest Refugium of the Bükk Mountains, Hungary—Vegetation Change and Human Impact from the Late Pleistocene

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Abstract: The Rejtek I. Rock Shelter in the Bükk Mountains of the inner Western Carpathian region plays an important role in the Late Pleistocene and Holocene environmental historical analyses. The investigations of the cave sediment accumulated from the end of the Pleistocene and the recovered paleontological finds, together with the archaeological artefacts, provided an opportunity to develop stratigraphic classifications. In addition, by comparing archaeostratigraphic, lithostratigraphic and biostratigraphic data, it was possible to link environmental and prehistoric events. The importance of the site is shown by both the mollusc and floral cold- and warm-tolerant species that were present in the area during the Late Pleistocene. The early expansion of thermophilous species indicates the presence of a refuge already during the Late Pleistocene. Based on the documents of the excavation, the previous works, the sediment sequence, as well as the sediment samples and the filling material of the mollusc shells, together with the new chronology, we were able to clarify the relative order of the excavated layers and the description of the sediment types in the Rejtek I. Rock Shelter.

Keywords: rock shelter; anthracology; vertebrata analysis; malacology; refuge; environment history

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1. Introduction

The European Extra-Mediterranean forest refugia of the Late Pleistocene were theorized by de Lattin [1], but the first Extra-Mediterranean forest refugium of the Late Pleistocene based on concrete paleoecological data was presented by József Stieber (1921–2001), a Hungarian anthracologist [2]. In an exemplary rock shelter excavated by the vertebrate palaeontologist Dénes Jánossy (1926–2005) [3], Stieber revealed the presence of thermos-mesophilous species from Pleistocene layers [2,4–6]. Unfortunately, his anthracological results and hypothesis were rejected in Hungary and further research on the late glacial Extra-Mediterranean forest refugia theory has been relegated. In the 1990s an Anglo-Hungarian project led by Professor Keith David Bennett started. In this joint work Professor Baroness Katherine Jane Willis, a palynologist, investigated the radiocarbon dated pollen material of the Bátorliget bog [7], the Kelemér bog [8], and as a result of the radiocarbon dated charcoal samples from loess layers [9] she finally confirmed the existence of deciduous forest patches (oases, refugium) in the late glacial coniferous forest.

In this way, the vegetation picture of the Carpathian Basin, which had been described as a cold tundra desert at the end of the Pleistocene has been disproved, and it supported the hypotheses of József Stieber on the glacial forest refugia, independently of him. Together with the charcoal assemblage, very rich vertebrate skeletal and mollusc material was recovered and allowed the chronological control of the late glacial forest refugium presented by Stieber [4,5].

Since only a short French and German summary has been published about the anthracological results of the Rejtek I. Rock Shelter excavation [5], we present Stieber's results and the examinations and evaluation of our own chronological, sedimentological and malacological investigations.

The Rejtek I. Rock Shelter is located in the Bükk Mountains, Hungary, near Répáshuta (Figure 1). It is in the south-facing 500–800 m elevation region of the inner Western Carpathian Bükk Mountains where forest refugia surviving the most significant glacial cooling events have been modelled [10].

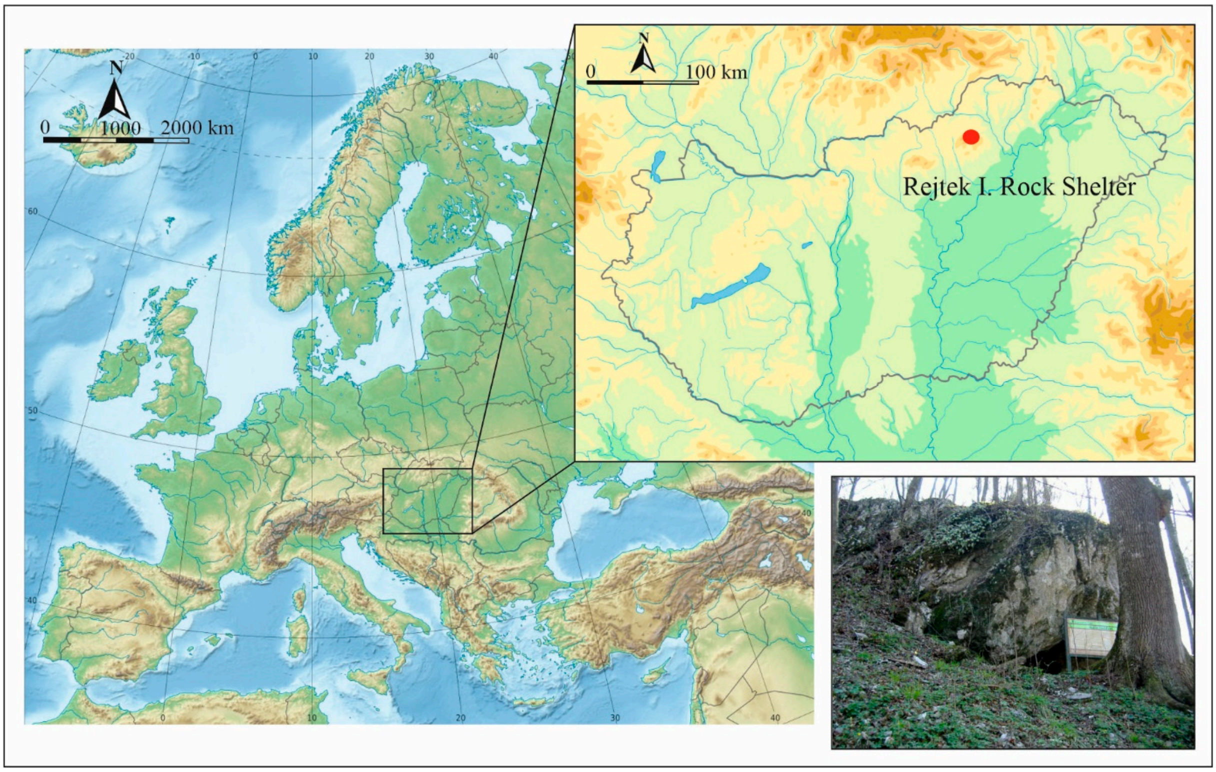

Figure 1. The location of Rejtek I. Rock Shelter.

The excavation lasted from 1957 to 1959. As a consequence of the stone blocks and a large amount of debris, the section was revealed and sampled in three blocks (Table 1; [3]). Very significant archaeological finds [11], vertebrate fauna fragments [3,12–14], a significant amount of charcoal [2,4–6] and a very briefly described, species-rich mollusc fauna (without evaluation) were excavated and identified later. The malacological material and documents of the section were handed over by Endre Krolopp (1935–2010), a quarter-malacologist, for further evaluation and publication. This site is of great significance for the understanding of the environmental changes in the Carpathian Basin and has had a decisive influence on the Hungarian geological, environmental and archaeological specialists in terms of their views on the temporal appearance of the various Quaternary cultures and the environmental changes. In addition, one of the first Mesolithic blades of the Tardonasian culture, with a clear stratigraphic position was found here. Surprisingly, however, isotope geochemical (radiocarbon) and sedimentological studies have not been carried out to allow a correct comparison with other sites of similar age, or to provide a chronological clarification of the archaeological, palaeontological, prehistoric and environment historical horizons.

Table 1. Sampling of the blocks and the re-numbering of samples (based on [11,12,15]). Blue: Block II/2 and Block III/3 represent more or less the same age and sediment.

	BLOCK II.			BLOCK III.			BLOCK III. Northern Part, Sporadic Finds		
Depth (cm)	**Original Sample Number 1957**	**Renumbered 1962**	**Renumbered 1976**	**Original Sample Number 1957**	**Renumbered 1962**	**Renumbered 1976**	**Original Sample Number 1957**	**Renumbered 1962**	**Renumbered 1976**
0–30	II/1		5						
30–60	II/2	1	6						
60–90	II/3		7						
90–120 (140)	II/4 "Neolithic"	2	8				block III. northern part at 1.10 m/110–140 cm	3 (110–140 cm)	13 (at 110 cm)
direct continuity of layers between Blocks II. and III. is lacking [13]									
140–160				BLOCK III. 140–160	4	9			
160–180				BLOCK III. 160–180	5	10			
180–200				BLOCK III. 180–200	6	11			
200–220				BLOCK III. 200–220	7	12			

We aimed to clarify the stratigraphic position of the excavated layers using radiocarbon analysis, to accomplish the sedimentological analysis, to re-identify the mollusc fauna of the cave sequence and to compare these data with previously published palaeontological results.

2. Materials and Methods

The study site is located in Northern Hungary in the Bükk Mountains near Répáshuta, on the western side of Szarvaskő Hill at 534 m above sea level. The rock shelter is about 900 cm long in a north-south direction, 250 cm wide and 220 cm deep. It was filled with sediments before the excavations.

During the excavation (1957–1959), three blocks (block I. /test sampling—side-niche/, II., III.) were formed (Table 1) and sediment samples were taken from them [3,12,13,15].

The entire sediment sequence was excavated, extracted and samples were taken at 30/20 cm intervals. These were then wet-sieved using a 0.5 mm diameter sieve [3,12,13,15]. Only a few decagrams of sediment per sample were submitted for further analysis. The stratigraphic sequence was reconstructed based on the publications of Dénes Jánossy [3,12,13,15] (Table 1). Reassessing the sedimentological description, the categories of Troels-Smith [16] were used, and the Munsell colour chart [17] for dry sediment colour description. The remaining sediment samples of the original excavation (20 cm sampling intervals, occasionally 30 cm) were used for sedimentological, magnetic susceptibility, loss on ignition, organic and carbonate content determination.

Sedimentological analysis was carried out using Easy Laser Particle Sizer 2.0. Laser Sediraph after proper sample preparation [18]. We used a Bartington MS2 Magnetic Susceptibility Meter for magnetic susceptibility measurements for both field and laboratory testing at 2.7 MHz [19]. Three measurements were conducted on each sample and the values obtained were averaged. The carbonate and organic material content were determined using the loss on ignition (LOI) method of Dean [20].

Radiocarbon measurements were carried out on Mollusca shells at the Poznan Radiocarbon Laboratory to reassess the section from anthracological, vertebrate fauna and malacological points of view. The bones extracted from the horizon of the Holocene, from 140 cm towards the surface, were burnt through and did not contain enough collagen for the analyses [21], thus shell remains were used for the radiocarbon analyses. In addition, the effect of fire could not be detected in the snail shells extracted from the section [22], so these proved suitable for radiocarbon measurements. Following this, a stratigraphic, environmental and prehistoric evaluation of the section was carried out, including a complete geochronological study.

3. Results

3.1. Lithological Observations and Analysis

A significant amount of coarse debris was embedded in the sedimentary sequence [3,12,13,15]. The sharp sediment facies shifts suggested that a sediment deficit may have developed in the sequence [22,23]—similar to other Hungarian cave deposits [11]. These data and observations suggest caution and it is assumed that this (probably incomplete) stratigraphic sequence is unusable for sedimentation rate determination. Unfortunately, samples could only be excavated in blocks and not in a single stratigraphic sequence because of the debris material and stone blocks (Table 1).

Based on the sediment fill found in the aperture of Mollusca shells and the leftover sediment material, the following layers could be revealed.

Between 220 and 180 cm there is a significant amount of coarse, slightly carbonate, yellowish-brown, clayey silt (Figure 2). Based on its evolution, this horizon can be considered as a so-called "cave loess" [24], a variety of surface loess accumulated in a cave or a rock shelter.

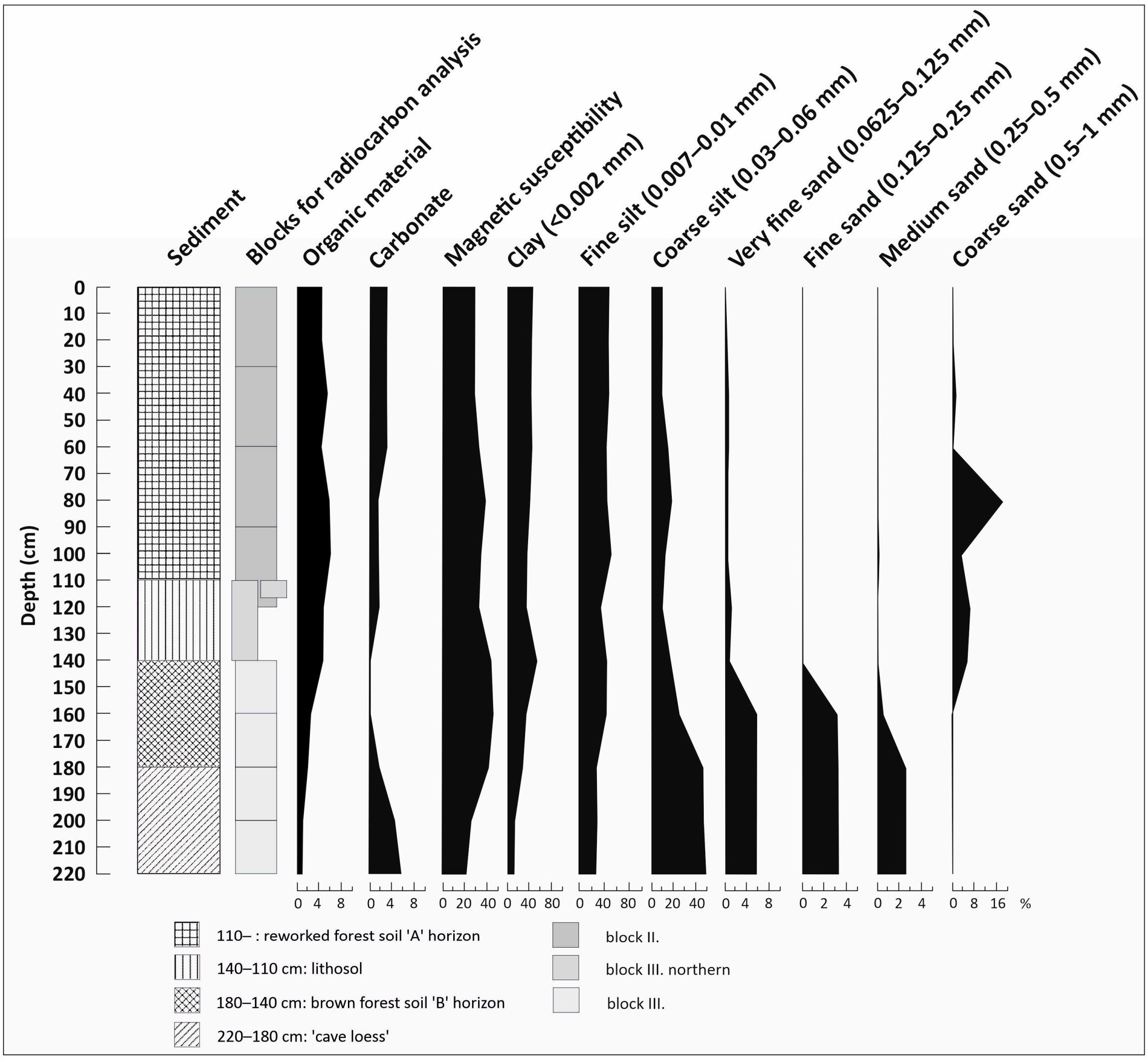

Figure 2. Results of grain size analysis.

Between 180 and 140 cm, a reddish-brown, carbonate-free, clay horizon developed with minimal coarse silt content. It is best understood as the 'B' level of an overlay of brown forest soil.

Between 140 and 110 cm, a black silty clayey with high organic material and carbonate content developed. It can be perceived as a poorly developed lithosol formed on carbonate bedrock, a secondary (reworked) rendzina soil, or a highly disturbed forest soil.

From 110 cm to the surface, a blackish-brown clay with aleurit with varying carbonate and organic material content evolved. It may originate from the reworked 'A' level of forest soil [3,12,15]. The development of the layer confirms weathering and soil formation under very significant vegetation cover.

3.2. Radiocarbon Analysis and Archaeological Finds

According to radiocarbon measurements (Table 2, Figure 3), the sediment layers of the Rejtek I. Rock Shelter accumulated from 15,000 cal BP until the end of the Middle Ages and the beginning of the Modern Ages.

Table 2. Results of radiocarbon analysis with uncalibrated, calibrated BP and calibrated BC/AD ages.

Depth (cm)	Uncal BP	+/−	Cal BP	+/−	Range Cal BP	Cal BC/AD	+/−	Range Cal BC	Lab Code
0–30	480	25	520	20	500–540	1431 AD	20	1411–1451 AD	Poz-7881
30–60	2470	30	2887	172	3059–2715	593 BC	172	765–421 BC	Poz-7880
60–90	4265	35	4803	152	4955–4651	2804 BC	152	2956–2652 BC	Poz-7887
90–120	4675	35	5431	116	5547–5315	3714 BC	116	3830–3598 BC	Poz-7877
110–117	5160	40	5876	123	5999–5753	3927 BC	123	4050–3804 BC	Poz-7879
110–140	5630	40	6400	89	6489–6311	4451 BC	89	4540–4362 BC	Poz-7872
140–160	8970	50	10,072	163	10,235–9909	8019 BC	159	8169–7869 BC	Poz-7876
160–180	9790	40	11,217	45	11,262–11,172	9268 BC	45	9313–9223 BC	Poz-7878
180–200	12,260	50	14,425	377	14,802–14,048	12,476 BC	377	12,853–12,099 BC	Poz-7963
200–220	12,530	50	14,812	326	15,138–14,486	12,835 BC	326	13,161–12,509 BC	Poz-7975

Late Glacial Epipalaeolithic and Early Holocene Mesolithic finds are present in the stratigraphic sequence. The original findings [11,25] were prehistoric, featureless pottery from the Neolithic through the Bronze Age; at the same time pottery of the Late Neolithic, Early Copper Age and probably Bronze Age (Table 3) occurred as well. Radiocarbon data indicate that the development of the sequence was not continuous.

Sediment accumulation ceased between approximately 14,000 and 11,200 cal BP (Table 1) and coarse rock debris had fallen into the rock shelter.

3.3. Paleobotanical Analysis

The paleobotanical analysis was based on charcoal samples from the sediment material [2,4–6].

The first paleobotanical horizon developed between 220 and 180 cm (Figure 4, Table 4). The remains of coniferous trees dominated, which evolved between 15,000 and 14,000 cal BP, with spruce (*Picea* sp.) accounting for more than 50% of all charcoal remains, and Scots pine (*Pinus sylvestris*) for 25%. The spruce (*Picea* sp.) and larch (*Larix* sp.) remains could not yet be separated from each other at the technical level of the time [2,4–6]. József Stieber therefore introduced Picea—Larix as an anthracological taxon, as the wood anatomical picture of these species are very similar to each other. However, Edina Zita Rudner, an anthracologist, clarified by SEM microscopy analyses that these remains belong to the spruce (*Picea*) taxon [26,27]. In addition to coniferous elements, the presence of thermo-mesophilous deciduous trees is detectable in the charcoal assemblage.

Table 3. Calibrated radiocarbon data and recovered archaeological findings in the Rejtek I. Rock Shelter.

Depth (cm)	Cal BP (Range)	Cal BC/AD (Range)	Archaeological Finds [11,12,15]
0–30	500–540	1411–1451 AD	coin from 18th century
		hiatus	
30–60	3059–2715	765–421 BC	-
		hiatus	
60–90	4955–4651	2956–2652 BC	Prehistoric (Neolithic-Bronze Age) ceramics pieces
90–120	5547–5315	3830–3598 BC	Prehistoric (Neolithic-Bronze Age) ceramics pieces
110–117 (sample 13)	5999–5753	4050–3804 BC	Prehistoric (Neolithic-Bronze Age) ceramics pieces
110–140 (sample 13)	6489–6311	4540–4362 BC	Prehistoric (Neolithic-Bronze Age) ceramics pieces
		hiatus	
140–160	10,235–9909	8169–7869 BC	Mezolithic (Tardonasien) trapezoid blade
160–180	11,262–11,172	9313–9223 BC	
		hiatus	
180–200	14,802–14,048	12,853–12,099 BC	Epipaleolit (?) finds
220–200	15,138–14,486	13,161–12,509 BC	Epipaleolit (?) finds

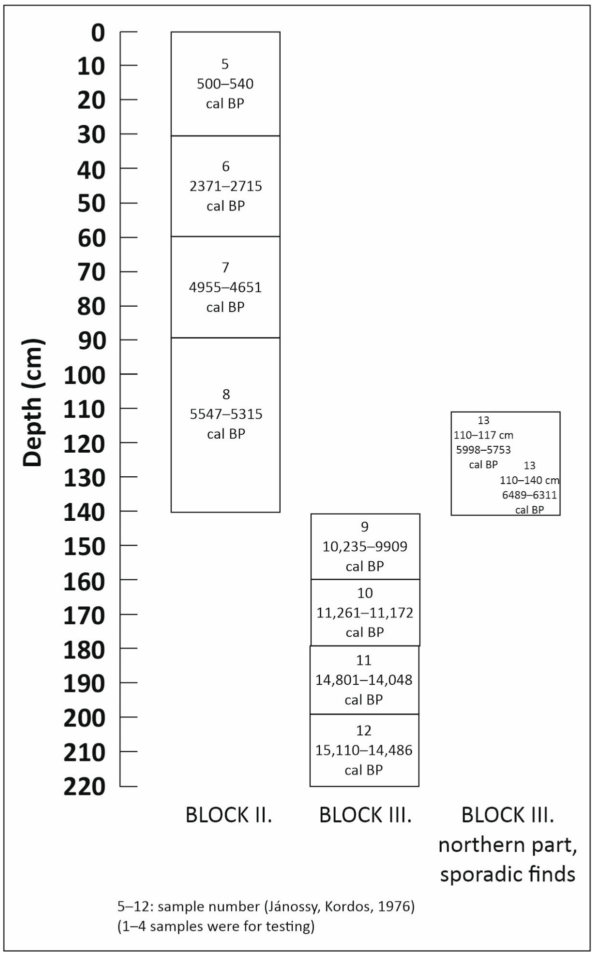

Figure 3. The location of sampling blocks [13] with the calibrated radiocarbon data (range).

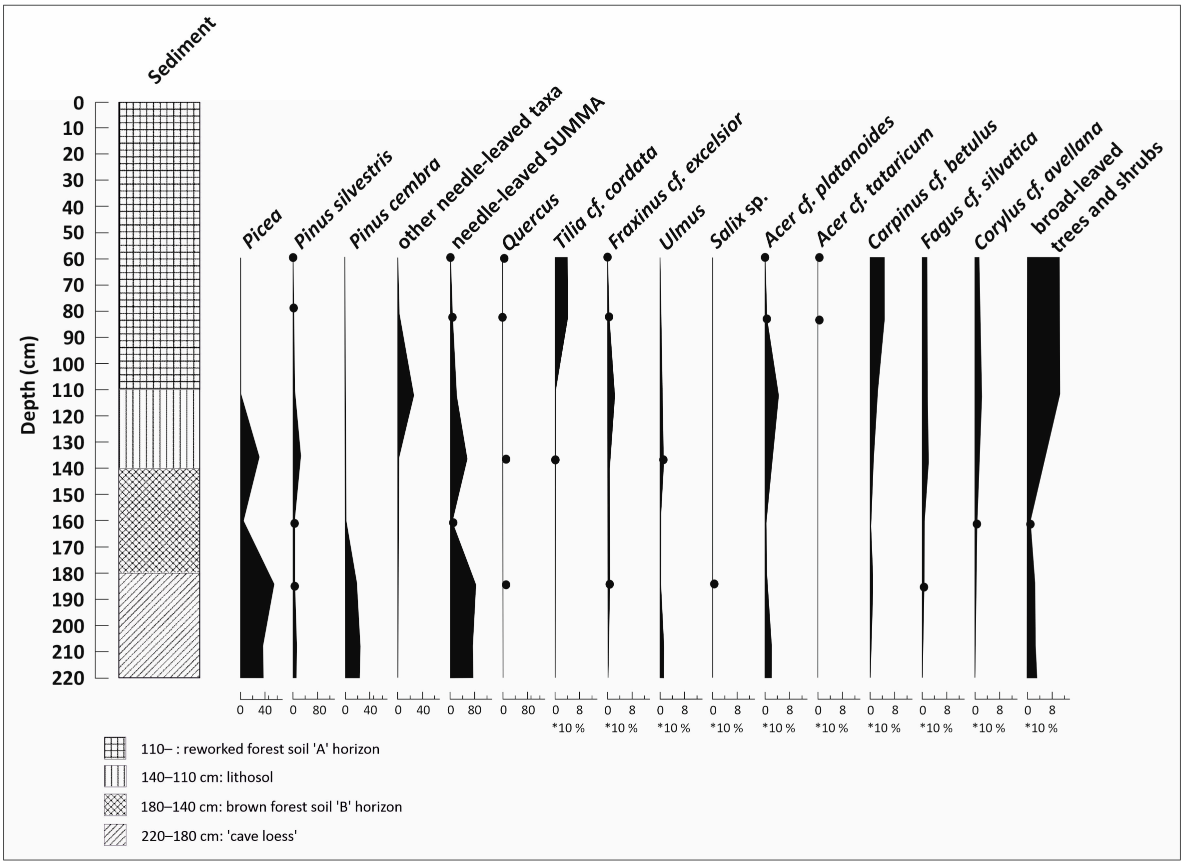

Figure 4. Results of anthracological analysis [4–6].

Table 4. Charcoal remains from Rejtek I. Rock Shelter [4–6].

Sample Number [13]	**12**	**11**	**10**	**9**	**13**	**8**
cal BP years	15,138–14,486	14,802–14,048	11,262–11,172	10,235–9909	6489–6311	5547–5315
Depth (cm)	220–200 cm	200–180 cm	180–160 cm	160–140 cm	140–110 cm	90–120 cm
Charcoal taxa	number of pieces	number of pieces	number of pieces	number of pieces	number of pieces	number of pieces
Picea (original *Picea-Larix*)	5	26	1	30		
Pinus sylvestris	1	1	1	16		1
Pinus cembra	2	5				
Needle-leaf tree	6	32	2	46		1
Quercus sp.		1		4		2
Tilia cf. *cordata*				2		25
Fraxinus cf. *excelsior*		1			2	4
Ulmus cf. *campestre*	1			4		
Salix sp.		1				
Acer cf. *platanoides*	2	2		15	5	4
Acer cf. *tataricum*						2
Carpinus cf. *betulus*		2		4	2	31
Fagus cf. *sylvatica*		1		11	1	8
Corylus cf. *avellana*			1	8	2	10
Broad leaf trees and shrub	3	8	1	48	14	84
SUMMA	11	40	3	94	14	85

In the next horizon between 180 and 140 cm, i.e., between 11,300 and 9900 cal BP years, during the Early Holocene, deciduous trees, mainly oak (*Quercus* sp.), linden (*Tilia* sp.), elm (*Ulmus* sp.), beech (*Fagus* sp.), maple (*Acer* sp.), and hazel (*Corylus* sp.) dominated, while Scots pine (*Pinus sylvestris*) and spruce (*Picea* sp.) charcoal were only secondary.

The third paleobotanical horizon evolved between 140 and 80 cm. The proportion of coniferous trees decreased and the number of deciduous trees has become absolutely dominant in the profile.

3.4. Malacological Analysis

Based on the composition of the Mollusca fauna, four malacological zones could be distinguished (Table 5, Figure 5).

Table 5. Results of malacological analysis.

Sample Number [13]	**12**	**11**	**10**	**9**	**13**	**8**	**7**	**6**	**5**
cal BP years (range)	15,138–14,486	14,802–14,048	11,262–11,172	10,235–9909	6489–6311	5547–5313	4955–4651	3059–2715	540–500
Depth (cm)	220–200	200–180	180–160	160–140	140–110	120–90	90–60	60–30	30–0
Piece (i = individual)	i	i	i	i	i	i	i	i	i
Acicula polita				1					
Carychium tridentatum		1		7					
Cochlicopa lubricella		1							
Chondrina clienta		1		1					
Granaria frumentum		1		2	1				
Orcula dolium		1	1	1	1			1	
Sphyradium doliolum			1	4	1				
Truncatellina cylindrica				1					
Vallonia pulchella			1						
Vallonia costata		1	2	17					
Chondrula tridens			2	1					
Cochlodina laminata			4	3	7	1	1		
Cochlodina cerata	35	52	0	2	6	1	1		
Clausilia dubia	2	2	1	2					12
Clausilia pumila		17	1	16	10	1	2	1	
Iphigena ventricosa					2				
Iphigena plicatula				1	1				
Laciniaria plicata		1	3	4	18	1	2	1	
Laciniaria biplicata					5			1	
Balea cana									4
Ruthenica filograna			3	19	6				16
Clausilia sp.	10	75	27	150	37	2	1	9	56
Vitrea crystallina		1		6					
Vitrea contracta				1					
Vitrea diaphana					1				
Aegopinella minor			1	5	5				
Aegopinella pura				4					
Oxychilus glaber				8					
Oxychilus orientalis				1	4	1	1		
Oxychilus depressus					1				

Table 5. *Cont.*

Sample Number [13]	**12**	**11**	**10**	**9**	**13**	**8**	**7**	**6**	**5**
Nesovitrea hammonis		3		1					
Zonitidae		4	2	21					
Euconulus fulvus				1					
Daudebardia rufa				4					
Limax maximus					11	2	1	8	
Limacidae									4
Discus ruderatus		1		7				1	
Discus rotundatus			2	1	2				
Discus perspectivus		1							
Bradybaena fruticum	1				2				
Euomphalia strigella	1	3				1	1		
Trichia unidentata				1					
Perforatella incarnata				2	1				
Isognomostoma isognomostoma				1					
Helicigona faustina				3	1				
Helicodonta obvoluta			1		2			1	
Helix pomatia			1	3	2	1	1		4
Helicidae		2	4	5	1				4
SUMMA	49	168	57	307	128	11	11	23	100

The first malacological zone developed between 220 and 180 cm, between 15,000 and 14,000 cal BP years. European and Central European forest species [28] are absolutely dominant at this late-glacial horizon, especially *Cochlodina cerata*. Cold-tolerant Mollusca species are represented only by *Discus ruderatus*, while warm-tolerant species (*Bradybaena fruticum*, *Euomphalia strigella*, *Granaria frumentum*) have also been found in this section.

The next malacological horizon developed between 180 and 140 cm, i.e., between 11,200 and 9900 cal BP. The number of *Cochlodina cerata*, the dominant species of the late-glacial horizon, has declined but persists in the section. Several character elements of the Early Holocene faunal evolution of the Pre-Carpathian region, such as *Acicula polita*, *Ruthenica filograna*, *Sphyradium doliolum*, *Aegopinella minor*, *Oxychilus glaber*, *Trichia unidentata*, *Helicigona faustina* and *Helicodonta obvoluta* appeared (Table 5 and Figure 5).

In the next malacological horizon, between 140 and 60 cm (cc. 6500–4600 cal BP), the number of individuals declined strongly, the proportion of closed forest species declined and the ratio of species preferring more open forest environments (*Helix pomatia*) increased. The number of hygrophilous malacofauna elements (*Iphigena ventricosa*) was higher. In this horizon, prehistoric pottery was found in all of the samples, so it can be assumed that there was significant human disturbance and vegetation conversion (wood harvesting for fuel and building material) in the area around the rock shelter. We have named this locally important malacological horizon the *Iphigena ventricosa—Helix pomatia* horizon.

Human impact may have diminished in the study area at the beginning of the Iron Age (60–0 cm), as Mollusca species preferring open areas declined and *Clausilia* species became the absolute dominant elements in the near-surface horizon. *Balea cana* species appeared only in this horizon, which is the eponymous Mollusca species of this depth (Figure 5).

The determination of the malacological material was verified and accepted by Endre Krolopp, who then requested the return of the material after the radiocarbon analysis. By his will, the remaining malacological assemblage was deposited in the collection of the Mátra Museum.

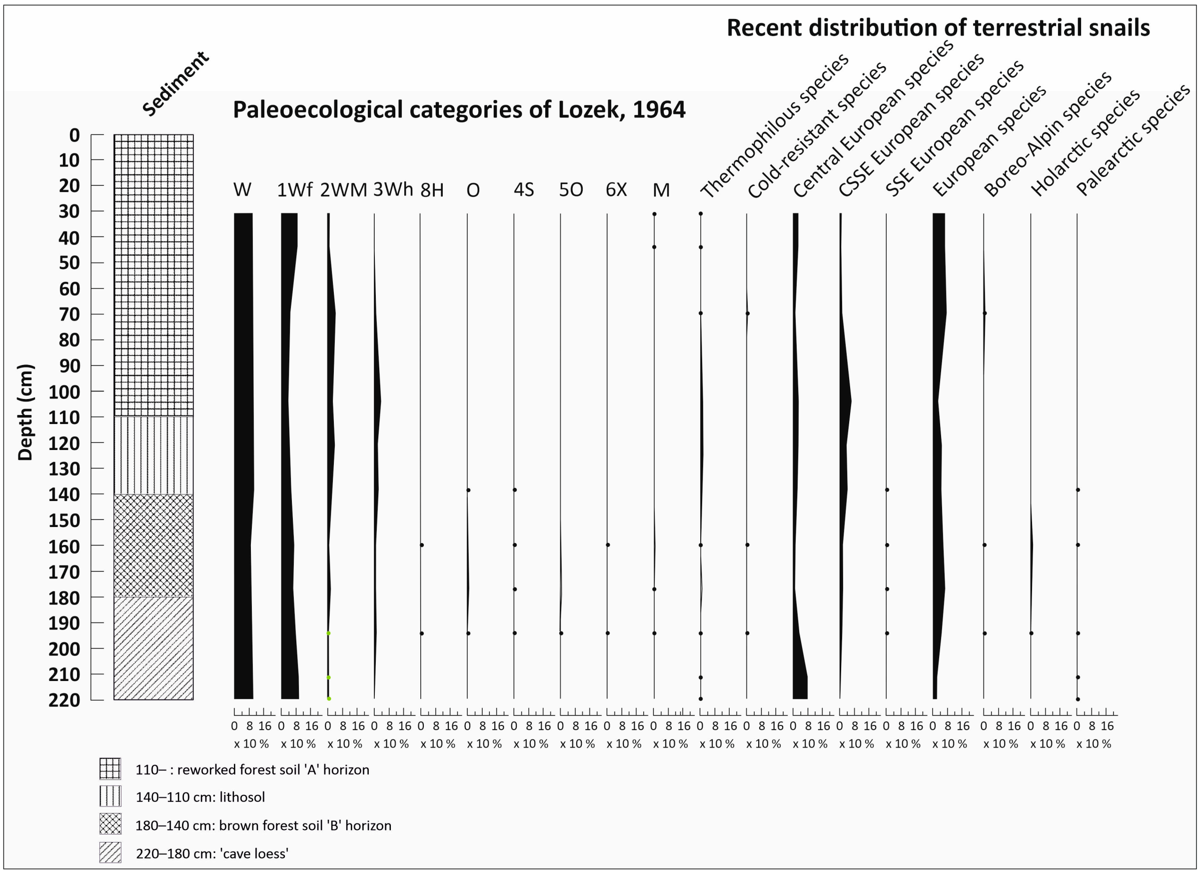

Figure 5. Malacological results based on the palaeoecological categories of Ložek [29] and recent distribution data [28]. Paleoecological categories of Ložek [29]: W = Woodland, locally open habitat species; 1Wf = Woodland species; 2WM = Mesophilous forests species; 3Wh = Wet forest species (gallery forest); 8H = Hygrophilous species; O = Open habitat species; 4S = Warm steppe species; 5O = Open woodland species; 6X = Xero-thermophilous species; M = Mesophilous species.

3.5. Vertebrate Analysis

The analysis is based entirely on the results of previously and extensively published vertebrate fauna analysis [3,12–15].

In the horizon between 220 and 180 cm ptarmigan species (*Lagopus mutus/muta*, *Lagopus lagopus*), western capercaillie (*Tetrao urogallus*), black grouse (*Lyrurus tetrix*), and hazel grouse (*Tetrastes bonasia*) were present. This is supported by the composition of the vole fauna. Birch mice (*Sicista*), narrow-headed vole (*Microtus gregalis*), European snow vole (*Chionomys nivalis/Microtus nivalis*) and tundra vole (*Microtus oeconomus*) which are widespread in the Boreal-Alpine region characterized by humid-cool climate, have been found together with species indicating milder climate, such as small rodents (*Arvicola*, *Pitymys subterraenus*, *Myoides glareolus*, *Apodemus silvaticus*), European fat dormouse (*Glis glis*), hazel dormouse (*Muscardinus avellanarius*), snakes (*Ophidia*), amphibians (*Bufo*) and reptiles (*Lacerta*) in this horizon (Figure 6).

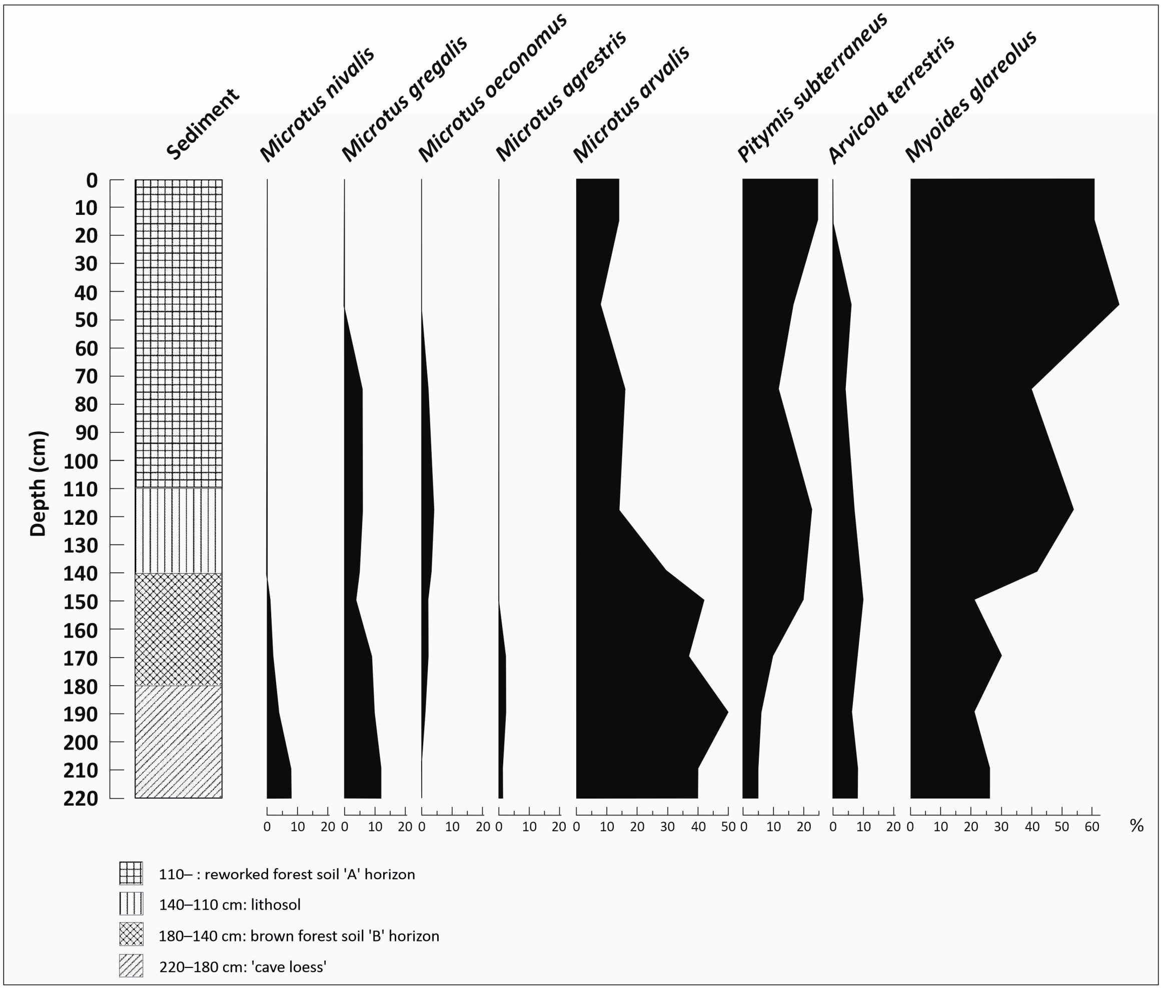

Figure 6. Dominance change of the microvertebrata assemblage (selected taxa) [12,13,15]. Dark blue color = Cryophilous species; Light blue color = Cold-resistanat species; Green color = Euryok species; Red color = Thermophilous species.

In the next horizon between 180 and 140 cm, i.e., between 11,200 and 9900 cal BP, the typical fauna elements of the Late Pleistocene disappear, such as ptarmigan species (*Lagopus mutus/muta, Lagopus lagopus*), European snow vole (*Chionomys* nivalis/*Microtus nivalis*), while others recede, such as narrow-headed vole (*Microtus gregalis*) and tundra vole (*Microtus oeconomus*). The ratio of birch mice (*Sicista*) and pika (*Ochotona*) remained significant, and the finds of bison (*Bison*) appeared. The presence of reindeer (*Rangifer*) [3,12,13] suggests that perhaps reindeer populations did not completely disappear from the Carpathian Basin during the last glacial as previously modelled [30]. The proportion of faunal elements, that were dispersing during the Holocene, such as European fat dormouse (*Glis glis*), hazel dormouse (*Muscardinus avellanarius*), snakes (*Ophidia*), amphibians (*Bufo*), lizards and European pine vole (*Pitymys subterraneus/Microtus subterraneus*), bank vole (*Myoides glareolus*) and wood mouse (*Apodemus sylvaticus*) increased, while wild boar (*Sus scrofa*) and squirrel (*Sciurus vulgaris*) appeared.

In the next vertebrate fauna horizon, from 140 cm to 60 cm (6500–4600 cal BP, from the Late Neolithic to the Early Bronze Age) the remains of narrow-headed vole (*Microtus gregalis*), European snow vole (*Chionomys nivalis/Microtus nivalis*) and tundra vole suggest that cold-tolerant elements persisted until historical times. From the Late Neolithic onwards, the ratio of forest species (*Pitymys subterraenus, Myoides glareolus, Apodemus silvaticus*) increased sharply, while the proportion of common vole (*Microtus arvalis*) declined (Figure 6).

4. Discussion

Based on the radiocarbon data, the accumulation processes may have started at the end of the Late Glacial, during the last glaciation, in the younger Dryas cooling (stadial) horizon. This horizon, known as the Nahanagan Stadial in Ireland [31] and the Loch Lomond Stadial in England [32], may have caused significant cooling and recurrence of dust accumulation in the North Atlantic region. The development of this cooling event was limited in the Carpathian Basin [33], as evidenced by the clay content of this layer, which indicates a more pronounced weathering, i.e., a milder and wetter climate. Sediment accumulation ceased between approximately 14,000 and 11,200 cal BP (Table 2) and coarse rock debris had fallen into the rock shelter. It is interesting to note that this occurred at a time when dust accumulation was drastically reduced in the Carpathian Basin and the temperature increased, when poorly developed litho and podzol soil developed in the study area [8,33,34]. This phenomenon is not unique in caves in Hungary; in other cases, the lack of sediment accumulation and the change in sedimentation was observed between 14,000 and 11,200 cal BP years. During the same period, a significant increase in slope processes was observed [35] and the accumulation of coarse rock debris accelerated in the mid-mountain zones, including the Pre-Carpathian region. Probably the permafrost layer in the mid-mountain zone was melted as a local environmental projection of the global warming that started at the end of the Pleistocene, and this caused the changes in the sedimentation process.

However, the amount of anthracological material does not reach the minimum number for statistical analysis in these days (Table 4, [24] in both the Rejtek [4,5] and the Petényi cave [4,5,36]); yet these data were completely unique in the 1950s, even though the local presence of trees had been known for several decades based on the analyses of charcoal remains by Hollendonner [37,38], Greguss [39] and Sárkány and Stieber [40] in the Carpathian Basin during glacials.

At the same time, the local presence of woody (especially coniferous) elements in the glacial and late-glacial vegetation has been suggested by pollen samples [41,42] and woodpecker bones [12,15]. However, the novelty (and the complete rejection of these new data) was caused by the detection of the local presence of broad-leaved thermo-mesophilous (*Quercus* sp., *Ulmus* sp., *Acer* sp., *Carpinus* sp., *Fagus* sp.) trees in the Late Glacial horizon, the existence of a deciduous refugia [4–6,38] in northern Hungary.

Anthracological data indicate that a mixed taiga forest with deciduous elements, such as beech (*Fagus* sp.), oak (*Quercus* sp.), ash (*Fraxinus* sp.), elm (*Ulmus* sp.) and maple (*Acer* sp.) trees was already present in the local vegetation at the end of the Pleistocene [4–6].

The Late Pleistocene charred wood remains clearly demonstrate that thermo-mesophillous wood species, already locally assumed in the 1990s on the basis of pollen analysis [7–9], were indeed present in the Carpathian foreland in the Late Pleistocene vegetation in the appropriate microclimatic and microenvironmental oases [9].

The composition of charcoal is primarily used to reconstruct the composition of former forests [43]. As a result, mixed spruce-pine (Picea—Pinus) taxa dominated with scattered thermo-mesophilous deciduous forest (oak (*Quercus* sp.), elm (*Ulmus* sp.), ash (*Fraxinus* sp.), linden (*Tilia* sp.), beech (*Fagus* sp.), hornbeam (*Carpinus* sp.)) species [4–6,34]. Based on the anthracological results, the hypothesis of József Stieber was right. His results preceded palynological studies in Hungary by almost 40 years and proved that coniferous and thermo-mesophilous (broad-leaved) deciduous trees were already present in the Carpathian Basin vegetation at the end of the Pleistocene. In other words, the area was not a cold tundra desert zone, but due to microenvironmental factors, a mosaic vegetation developed during the last glacial [33,34].

The most surprising was the local presence of beech (*Fagus* sp.) (Table 4, Figure 4) in this mixed forest canopy at the end of the Pleistocene [5]. Namely, several pollen analytical models [44–48] have modelled the distribution of beech in the Carpathian foothills, gradually spreading from a beech refugium in Slovenia (Figure 7), where the age of the oldest beech pollen was around 8500 BP years (7500–7600 BC) [44–46]. According to pollen models [49], beech (*Fagus* sp.) may have spread in the Transdanubian region between 8000 and 7300 cal BP years, in the North Hungarian Mountains between 6300 and 5500 cal BP years, and in the Great Hungarian Plain between 4500 and 4000 cal BP years. In contrast, anthracological data indicate that beech (*Fagus* sp.) was already present in the study area during the Late Glacial (Rejtek) and Early Holocene (Bátorliget) (Figure 7).

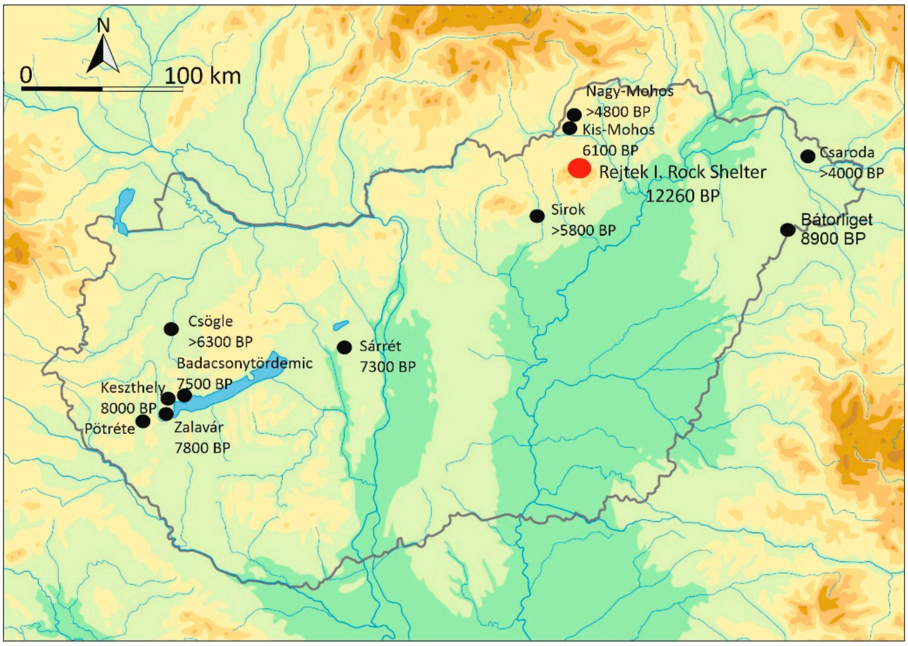

Figure 7. Reconstruction of *Fagus* (beech) tree distribution based on beech pollen and radiocarbon dated *Fagus* (beech) charcoal remains (Rejtek (study site: red dot), Bátorliget) (modified after Magyari [49]).

The presence of beech (*Fagus* sp.) charcoal in Rejtek indicates that beech dispersal could not have started only from the Quaternary beech refugium in Slovenia [44–50]. According to the Rejtek site and data from Bátorliget, several relict areas of beech may have developed on the periphery of the Carpathian Basin, in the mountain ranges surrounding the basin (Transylvania, Northern Carpathians, Czech Basin, possibly the Transdanubian Central Mountains), so the spread of beech, its colonization in the Carpathian Basin, may have been a multi-directional process, or may have occurred from several directions in the Carpathian Basin. The anthracological analysis of the Rejtek section [4–6] shows that in the deciduous forest formed during the Early Holocene, the scattered stands of pine forest elements (Figure 4) retreated in the relict as the temperature rose.

A very similar process could be modelled from Bátorliget [7–9] and the Nyíres Lake of Csaroda [34]. The process whereby thermo-mesophilous species persist in an area during cooling, and cold-tolerant species preserve during warming periods has been termed the double refugial effect in previous works [7,9]. Anthracological results demonstrated that the pine forest—deciduous forest transition—outlined in previous palynological works [7–9,33]—was also taking place in this area at the Pleistocene/Holocene boundary. At the same time, the composition of the charcoal assemblage also suggests that the vertical structure of vegetation was already established in the area at the beginning of the Holocene.

The composition and dominance changes of the species-rich Mollusca fauna of the Rejtek I. Rock Shelter raise many questions (Table 5). The results of the radiocarbon measurements and their correlative comparison with the Mollusca fauna have fundamentally changed the previously described ideas about the evolution of the Mollusca fauna of the Bükk Mountains [51–53].

Forest species (Ložek's forest taxa: Wf category: [29]) dominated throughout the profile, mainly European and Central European forest species (Figure 5). The composition of the malacofauna showed similar results to the anthracological results. The co-presence of *Discus perspectivus* and *Discus ruderatus*, which are now widespread in beech and coniferous forests, and the dominance of *Cochlodina cerata* support the development of the double refugial effect. In addition, the Pleistocene residual elements and the Holocene elements, i.e., the cold-tolerant and cryophylous Pleistocene and the thermophilous Holocene malacofauna, coexisted in the Bátorliget bog [7], which support this hypothesis [33]. The name of the Late Glacial horizon is the *Cochlodina cerata* zone, which is a locally evolved ecozone (Figure 8). In addition, bird species typical of both boreal-alpine regions and deciduous forests were present in the Late Glacial sedimentary horizon. The co-presence of cold-tolerant and milder climate preferring species in the Late Glacial vertebrate fauna is similar to the above discussed malacological and vegetation development. The composition of the Rejtek fauna is thus very similar to the composition of vegetation at the Late Glacial and confirms the ideas described for forest refugium vegetation evolution.

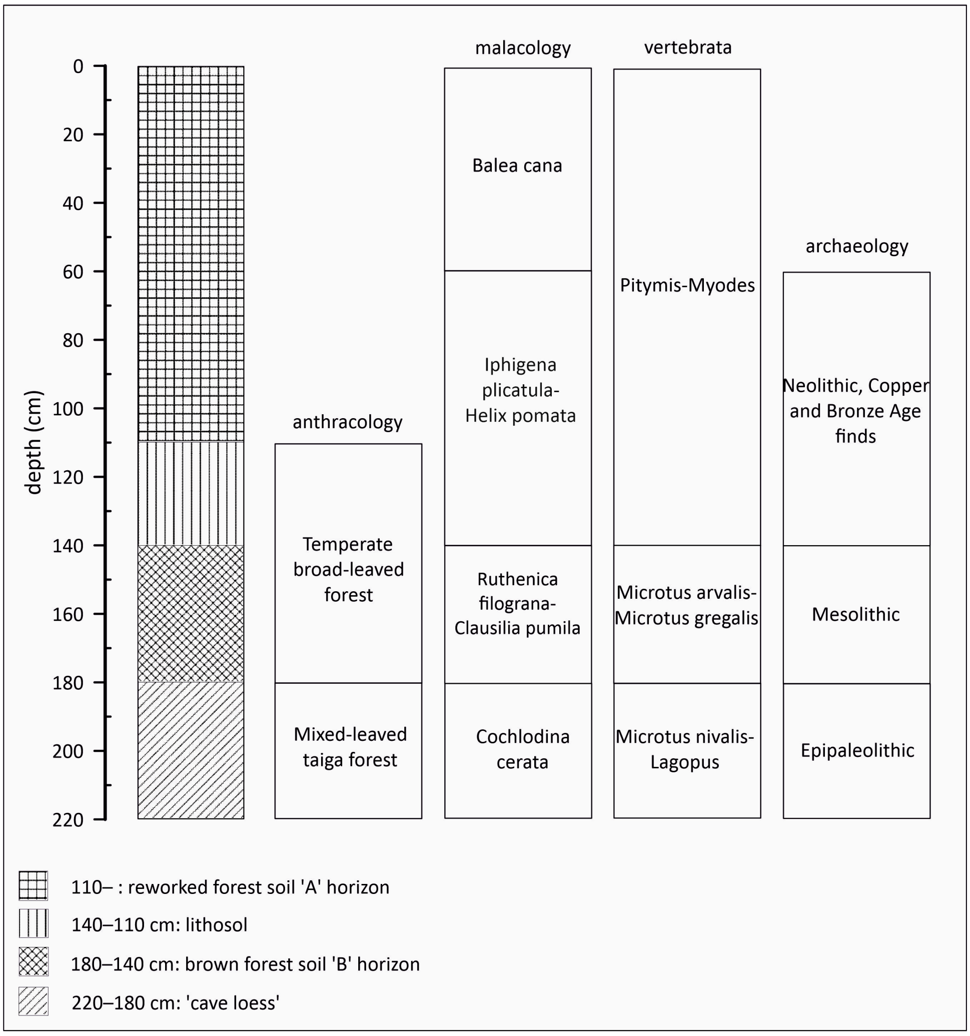

Figure 8. Antracological [5,36], malacological, vertebrate [12,13,15] and archaeological [11,25] ecozones, and vegetation type reconstruction.

The continuous presence of *Cochlodina cerata* (which spread at higher elevations in the mountainous region nowadays), *Cochlodina laminata, Clausilia dubia, Clausilia pumila, Laciniaria plicata* species throughout the Late Pleistocene and Early Holocene, and the Late Glacial presence of the *Discus perspectivus* species is of particular importance. As a result, it is clear that in addition to the previous cold steppe/warm steppe faunal variation model [51–53], a forest/forest-like faunal composition change associated with parallel vegetation evolution has also developed in the Bükk Mountains. The faunal composition shows significant similarities with the Early Holocene malacofauna of the Bátorliget bog [33] and the Carpathian region [54–56]. At the same time, there are also differences, as forest elements originating from the Balkan gene centre [28] were not found in the Rejtek section. The distribution of Central European—European species is similar [57] in the Early Holocene section of the Bátorliget bog. On the other hand, species with a Carpathian distribution did not occur in the same proportion as it was observed in the Rejtek section.

The composition of the Early Holocene malacofauna of Rejtek indicates that the forest environment was already established at the beginning of the Early Holocene without the interposition of a major steppe phase.

However, the Early Holocene presence of the Boreo-Alpine *Discus ruderatus* species (as in the case of the Bátorliget section) is very significant evidence of a double refugial effect. This malacological horizon is called the *Ruthenica filograna-Clausilia pumila* horizon. The presence of *Acicula polita* and *Helicigona faustina* in the Early Holocene and their records from about 11,200 and 9900 cal BP years (confirming our earlier statements [33]) clearly make it meaningless to postulate the *Helicigona faustina*—*Acicula polita* biozone to the Late Holocene. This Early Holocene biozone can only be interpreted as a local ecozone.

The presence of *Clausilia* species and the persistence of *Discus ruderatus* suggest that the study site is suitable for a long-term temperate (deciduous) forest refugium, which could and can survive the climatic cycles of the Quaternary and perhaps also the anthropogenic industrial influences, and, therefore, has outstanding conservation importance in the temperate zone both in Europe and globally.

The upper horizon of the profile (140–80 cm) indicates that the ratio of coniferous trees decreased and the number of deciduous trees has become dominant. This change coincided with the settlement of productive farming communities and the emergence of ceramic finds. In these ceramic-rich horizons, a greater proportion of south-eastern European mollusc species preferring open forests were distributed. Thus, we can assume that the composition of the Early Holocene forest changed due to human impact during the Middle Neolithic. It is noticeable that the spread of hornbeam (*Carpinus* sp.) can be attributed to anthropogenic influences, although the spread of this tree species has also been linked to climatic changes [47]. Nevertheless, based on previous data [8,34], we maintain that human influences (selective logging, burning, copper smelting) have played a role in the rapid spread of hornbeam (and perhaps beech) in the Middle Holocene.

5. Conclusions

Radiocarbon data indicate that the profile spans the end of the Pleistocene to the entire Holocene; thus, it is suitable for exploring the environmental background of Quaternary cultures and the local appearance of individual cultures, for answering questions of archaeostratigraphy, litho-, biostratigraphy and chronostratigraphy, and for establishing a unified geochronology. The comparative radiocarbon analyses on shells [58–63] show correct geochronological data and therefore proved to be suitable for the characterization of the sedimentary sequence accumulated in the Rejtek I. Rock Shelter. This is supported by new radiocarbon analyses carried out 10 years after our radiocarbon survey, in which the data showed a completely similar trend with the most recent analyses on bones recovered from the profile [21]. This seems to be supported by the charcoal, the radiocarbon data from the snail shells, the archaeological finds from the sedimentary assemblage, the post-lithostratigraphic classification of the section and the biostratigraphic classification of the excavated vertebrate material [3,12,13,15] (Table 2).

Based on chronological investigations, the section probably begins with the Late Glacial horizon of the end of the Pleistocene between 15,000 and 14,000 cal BP years. Loess-like sediment has accumulated in the rock shelter. Based on the composition of the bioindicator groups, the Pleistocene/Holocene boundary around the cave was strongly humid and forested, but it can be assumed that the forest was not closed on the hillsides, possibly alternating between steppe and forest mosaics. This can only explain why the local anthracological and malacological assemblages allow us to reconstruct a closed and mixed pine forest in the area of the study site.

This is confirmed by the composition of the vertebrate fauna, but the presence and proportion of cold steppe and tundra species confirm the presence of more open vegetation patches. If we consider the important role that owl droppings may have played in the accumulation of vertebrate material in the rock shelter [12], it can be assumed that the action radius of the owls in the area [64] determined the origin of the small mammal remains in Rejtek. This allows us to conclude not only about the immediate surroundings of the rock shelter, but also about its background and wider environment in the Bükk Mountains. The anthracological, malacological and vertebrate material thus reflects different distances of dispersal, different sizes of vegetation cover and environmental conditions in the section, so differences between them are to be expected. In the immediate vicinity of the rock shelter, epipaleolithic communities (Figure 8) lived and exploited its features in the mixed canopy of thermo-mesophilous temperate deciduous trees, and a mixed taiga woodland with possibly more open patches in the background. The evolution of the epipalaeolithic horizon [11] suggests that Late Pleistocene epipalaeolithic groups preserving Palaeolithic traditions were still present in the study area at the end of the Pleistocene, between 15,000 and 14,000 cal BP years.

There is a sediment hiatus of about 2000 years, the beginning of the Early Holocene between the 14th and 12th millennia BP. Environment historical analysis of continuous, radiocarbon dated sections from different study sites shows that the sedimentation process, the vegetation cover and the nature of the weathering changed fundamentally within this period. It can be assumed that this change could have caused the stratigraphic hiatus in the sequence of the rock shelter.

During the Early Holocene a deciduous forest existed in the vicinity of the rock shelter, but cold-tolerant relict elements were also preserved. This species-rich, closed forest containing coniferous trees may have already been inhabited by Mesolithic communities, and the trapezoidal blades found in the Rejtek Rock Shelter suggest that Mesolithic Tardonasien groups lived in or in the vicinity of the study site. According to the Rejtek section, the emergence and spread of the Mesolithic population and the retreat of epipaleolithic groups were also influenced by the environmental alterations generated by climate change, the establishment and spread of a new deciduous forest environment.

Prehistoric pottery finds from the Neolithic to the Bronze age were revealed; however, sediment hiatus occurred throughout the Neolithic horizon of the profile according to radiocarbon data (Table 3).

At the end of the Neolithic and beginning of the Copper age the deciduous forest environment subsisted in the vicinity of the cave, with species-rich shrub and crown canopy, where beech (*Fagus* sp.), hornbeam (*Carpinus* sp.), oak (*Quercus* sp.) and hazel (*Corylus* sp.) trees and shrub vegetation spread over the area. This is supported by the mollusc fauna that indicate open forest. Probably the exposure of the hillsides, the higher humidity of the valley in the foreground of the rock shelter had a fundamental influence on the vegetation, similar to what we can observe today in the south-facing valleys of the Bükk Mountains, so parallel vegetation development could have occurred. As a result, lithophyte vegetation, steppes, oak (*Quercus* sp.) forests with a rich shrub layer, linden (*Tilia* sp.) forest, beech (*Fagus* sp.) forest mixed with hornbeam (*Carpinus* sp.) and maple (*Acer* sp.) trees, similar to what we can observe today in the Imókő area [65], may have developed side by side on open steep faces. It can be assumed that this mosaic vegetation, which is contingent on local exposure and humidity, was already established during the Late Glacial and that this may have allowed the thermophilic deciduous forest species to persist in the coniferous forest during the Last Glacial. This mosaic nature may also have characterized the deciduous forest environment that evolved during the Early Holocene, when coniferous forest species receded into refugial locations with cooler, more humid microclimates and deciduous forest species spread from the former milder relict patches.

Probably, this change can be linked to human impact; according to the pottery finds [25] the area was inhabited from the Late Neolithic, and the significant anthropogenic disturbance (trampling, building and fuel extraction) affected the structure of the vegetation.

From the Iron age the expansion of forests was related to the depopulation of the area around the rock shelter, as neither archaeological finds, nor charred wood fragments were found. A very similar process could be observed and linked to the decline of human influence in the surroundings of the Mohos bog at Kelemér in the 8th century BC [8].

The study site appears to be particularly valuable for long-term forest refugia because the forest environment has been able to survive major climatic changes and human impact. At the same time, the sedimentological profile, although it is not continuous, contains archaeological finds, palaeobotanical, malacological and vertebrate palaeontological remains that are some of the most valuable environmental and stratigraphic data in Hungary for the Late Pleistocene and Holocene.

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