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A radiocarbon-dated cave sequence and the Pleistocene/Holocene transition in Hungary

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Abstract: The Petény Cave located on the Hungarian Highlands yielded one of the most well-documented vertebrate fauna of the Late Pleistocene and Holocene in Hungary. In addition to the vertebrate remains, considerable numbers of mollusc shells and charcoals were retrieved from the profile of the rock shelter. Furthermore, a pollen sequence close to the cave was also evaluated in order to reconstruct the flora of the region. A new radiocarbon analysis of samples from the Petény Cave was used to correlate data of different methods and to correct the earlier outcomes. The cave sequence exposes layers from 15.180 cal BP to 483 cal BP. Nevertheless, based on our new radiocarbon data, the sequence is incomplete and layers corresponding to the Pleistocene/Holocene boundary are missing from the profile.

The results of our radiocarbon analysis clearly support considerable amounts of thermo-mesophylous gastropod species appearing as early as 15.180 cal BP. The appearance of deciduous woodlands in the Carpathian Basin along with the concomitant mollusc elements is much earlier than previously assumed, supporting the presence of temperate woodland refugia in the study area.

Keywords: Radiocarbon analysis; vertebrata fauna; malacology; cave; NE Hungary

1 Introduction

The Petényi Cave (Peskő II rock shelter) was one of the most important sites of Hungarian Holocene research. Archaeological finds as well as vertebrate, charcoal, pollen and mollusc remains occurred in the profile of the cave [1–6]. Decades of environmental, historical and archaeological research in Hungary have examined issues of environmental changes and determined when these changes occurred in the Carpathian Basin during the last 15.000 years, mainly during the Pleistocene/Holocene transition.

This profile is highly important in understanding the palaeoenvironmental changes and the chronological appearance of different cultures in the Carpathian Basin during the Quaternary. Previously, the analyses and the palaeoecological and stratigraphic evaluations of the profile were based mainly on vertebrate remains [5, 6]. Additionally, neither at the time of the original investigations in the 1960s nor later was an attempt made to develop the precise chronological classification of the profile and carry out radiocarbon tests. Local vegetation zones and local environmental zones were not taken into account, despite the fact that they were established by that time and were known to not be equal to the Holocene chronozones [7]. It was thought that the same environmental historical events took place in the layers of Petényi Cave that were observed all over the Carpathian Basin. The full reconstruction of the profile was based on pollen zones that were originally described in the southern Scandinavian Peninsula [8], which were adopted and expanded to Central European pollen zones [9, 10]. Stratigraphic levels and vertebrate stratigraphic units were classified into chronozones such as Late Glacial, Preboreal, Boreal, Atlantic, Subatlantic, and Subboreal, but due to this approach and the lack of radiocarbon data, disagreement and opposing views have evolved among researchers. For example, József Stieber, who analysed charred wood remains from the cave [3, 4] that indicate local vegetation changes, did not accept the stratigraphic classification and chronological scale, so he published his results [3, 4] separately from the archaeologists [1, 2, 5, 6].

The Petény Cave (Peskő II rock shelter) found on the Hungarian Highlands yielded one of the most well-documented transition vertebrate fauna of the Pleistocene/Holocene boundary in Hungary [1–6]. Besides vertebrate remains, a considerable number of mollusc shells was retrieved from the sequence of the rock shelter. Furthermore, samples were taken from these layers for

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pollen analysis, which is highly remarkable in Hungarian palaeoenvironmental research, since this was not a usual procedure in the investigation of cave sequences. The numerous artifacts retrieved during the archaeological excavations were dated from 15.180–14.529 cal BP to 316–483 cal BP. The biggest palaeoecological problem of this important profile is that the whole material of the cave was extracted and the excavators did not leave a profile behind. Therefore, reconstruction of the sediments is only possible by the former notes and sediment descriptions and some poor quality photos.

In addition to the findings of the cave sequence, we carried out detailed sedimentological, palynological and geochemical studies on a complete peatland and lacustrine sequence from the peat-bog of Kis-Mohos, just north of the Peskő II rock shelter, corresponding to the past 15.000 years. Since the profile of the cave is an extremely important starting point for research projects in terms of the Holocene, we first aimed to carry out radiocarbon tests and to analyse and evaluate the aforementioned mollusc material from the earlier analyses. Our aim was to expand our radiocarbon-based chronological and environmental historical analysis series to Late Pleistocene and Holocene profiles in the Carpathian Basin for the last 30–40.000 years [11].

In this study we aim to present: 1) the results of the new radiocarbon and malacological analysis, 2) a comparative investigation of the earlier palaeontological and archaeological research and 3) a chronological analysis of the profile. The high-resolution radiocarbon-dated peatland sequence revealed an evolutionary history completely contradictory to the former ideas and reconstructions for the Hungarian Uplands for the Pleistocene/Holocene boundary, both in a chronological and thematical sense [1–6].

These findings successively indicate the need for detailed radiocarbon analysis of material retrieved from caves and rock shelters in the future, which are key elements from both environmental historical and archaeological points of view. These analyses will eventually allow for a comparison of environmental histories for the Pleistocene/Holocene boundary. In order to meet these demands, we carried out a detailed radiocarbon study of samples from the Petény Cave (Peskő II rock shelter).

2 Site location

Our study samples are from the Petény rock shelter (Figure 1), situated adjacent to the Peskő Cave on the western fringe of the Nagyfennsík ("Great Highland") of the Bükk Mountains, NE Hungary. The Petény (Peskő II) rock shelter, found at an elevation of 735 m a.s.l., was formed in Triassic limestone, with dimensions of 12–13 m in the north to south directions and 3–8 m in the east to west directions (Figure 2). The maximum height of the shelter is around 3.5 m, the lower 2.2–2.5 m section having sedimentary infill. The accumulated layers were excavated in 1955 by László Vértes and Dénes Jánossy. The two researchers created a profile exposing six visually identifiable layers within the rock shelter, to a depth of about 2.2–2.5 m (Figure 3). All layers yielded considerable amounts of artifacts, charcoal, vertebrate and mollusc remains [1–6]. The samples derived from each stratigraphic unit were subjected to detailed sedimentological, micromineralogical, vertebrate palaeoecological, and anthraconomical analyses [1, 2]. Furthermore, pollen analysis was also carried out, which was outstanding as it was very rarely done in cave sequence samples at the time in Hungary.

3 Methods

3.1 Radiocarbon analysis

Isotope-geochemical (radiocarbon) analysis was not previously conducted. In this study, five mollusc shells were subjected to detailed AMS radiocarbon analysis in accordance with the standards of the Radioisotope Laboratory of the Silesian University of Technology, Poland. The radiocarbon analysis of two Mollusc shells was carried out in the DirectAMS laboratory in Seattle (USA). The seven resulting radiocarbon dates were calibrated using Calib700 programs from Reimer *et al.* [12].

It must be noted here that according to several researchers, mollusc shells are not suitable for radiocarbon analysis yielding incorrect dates compared to charcoals retrieved from the same layer [13–15]. In order to minimize or eliminate the bias derived from the presence of inactive carbonates, only herbivorous gastropod shells [16, 17], primarily those of herbivore molluscs have been utilized in this study, in accordance with Preece [18].

3.2 Mollusc analysis

The mollusc material collected during the excavation, along with detailed documentation of the sampled profile was provided to us for further investigations and publication by Endre Krolopp, a senior researcher of the Hungar-

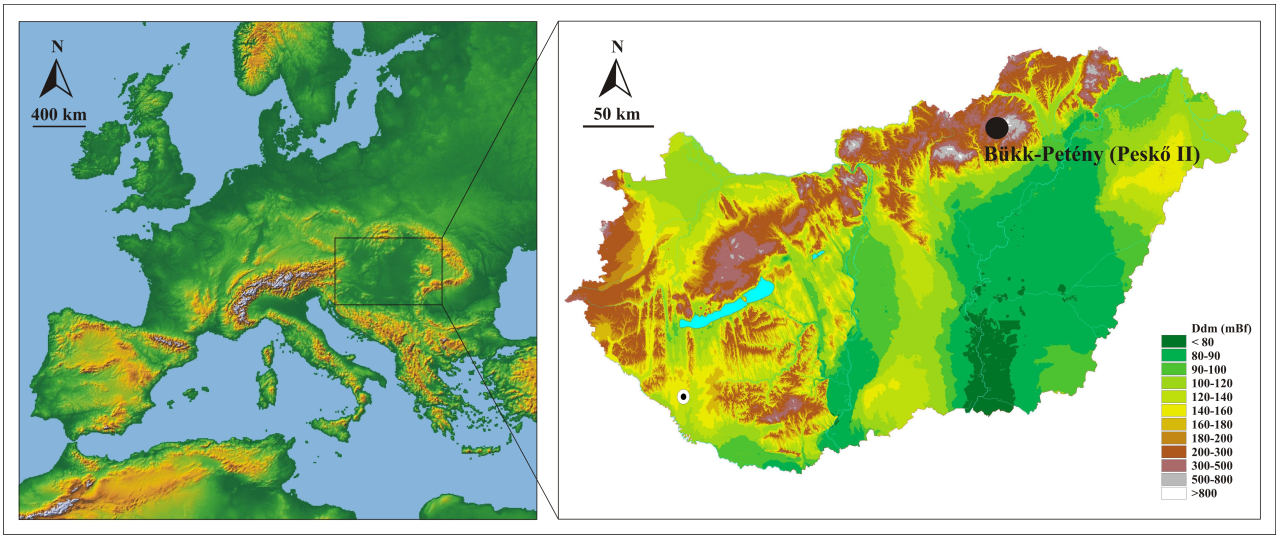

Figure 1: The location of the study site of Petény (Peskő II) rock shelter.

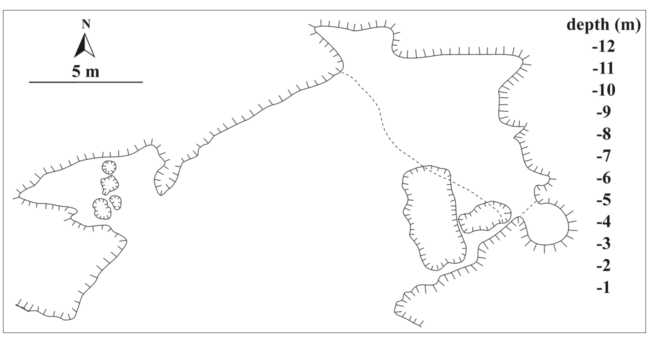

Figure 2: Map of the Petény (Peskő II) rock shelter.

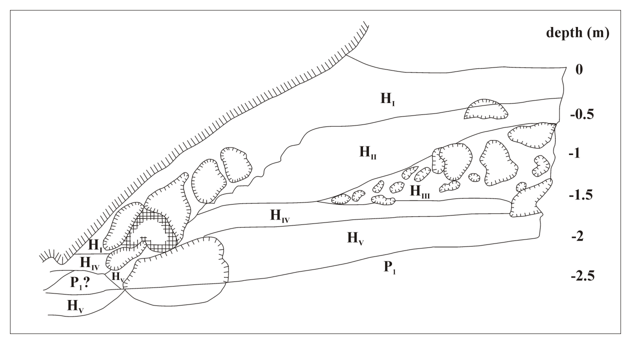

Figure 3: Geological cross-section of the Petény (Peskő II) rock shelter within original numbers of the excavated layers.

ian Geological Institute. All samples available to us had associated stratigraphic data (Table 1). Sample P_1 contained a single fragment of *Cochlodina cerata*. The single fragment of the sample H_{IV} was not suitable for taxonomic determination. Naturally, these shells were fully consumed during the process of the AMS radiocarbon analysis.

The course of the analyses was as follows: Shells were leached in hot distilled water and washed in a 0.5 diameter sieve several times in order to clear the surface of the shells. The cleared shells were then identified. The obtained mollusk material was classified by taxon and layers. Table 1 shows the layers from P_1 to H_I. All identifications were checked by the Quartermalacological reference collection of the Hungarian Geological Institute and Department of Geology and Paleontology, University of Szeged. Different publications from Europe and Hungary were used to check the identified species and shell fragments [19–25].

We used the names of terrestrial snail species from the work of Kerney *et al.* [22]. In addition to the identification, the number of individuals was checked and supplemented with the recognized fragment parts [20, 23, 27]. According to these works, only the apexes or the apertures of the fragments were taken into consideration in the determination of number of individuals.

4 Results and discussion

4.1 Radiocarbon analysis

As mentioned in the methods section, mollusc shells are not always suitable for radiocarbon analysis. The main reason for this is the presence of carbonate in the substrate, which yields significant amounts of inactive carbon. This can be then either built into the mollusc shells or precipitated on the surface of the shells [28–31]. Brennan and Quade [32] analyzed a number of small terrestrial gastropod taxa and found that small shells generally

Table 1: Archaeological layers, depth, chronological phase and Mollusc shells used for AMS radiocarbon dating.

Layers	Depth (cm)	Sediment layers	Original phases	Chronological phases	Mollusc shells for ^{14}C data
H_I	0–30	Blackish-brown soil	Recent	Subatlantic	*Balea cana*
H_{I-II}	30–60	Blackish-brown soil within limestone fragments	Alföld phase	Subatlantic	*Clausilia pumila*
H_{II}	60–90	Blackish-brown clayey silt	Kőhát phase	Subatlantic	*Clausilia pumila*
H_{III}	90–120	Blackish-brown clayey silt within stone fragments	Bükk phase	Epi-Atlantic/Subboreal	*Clausilia dubia*
H_{IV}	120–140	Reddish-brown silty clay	Kőrös phase	Atlantic	Clausilidae fragment
H_V	140–170	Yellowish-brown clayey fine silt	Bajót phase	Boreal	*Cochlodina cerata*
P_1	170–200	Yellowish-brown course silt with high clay content		Late Glacial	*Cochlodina cerata*

yielded reliable ^{14}C ages for late-Pleistocene palaeowetland deposits in the American Southwest. Pigati *et al.* [33] followed by measuring the ^{14}C activities of a suite of small gastropods living in alluvium dominated by Palaeozoic carbonate rocks in Arizona and Nevada and found that while some of the small gastropods did incorporate dead carbon from limestone when building their shells, others did not. Nevertheless, several scientists [34–40] used radiocarbon dates determined from mollusc shells in their works, sometimes verified and compared by dates retrieved from charcoals of the same horizon. Radiocarbon dates determined from charcoal and mollusc shells from the same sediment layers tended to display minimal difference (between 300 and 80 years) [18] for samples aged between 11.000 and 30.000 ^{14}C yr BP.

The cave sequence exposes layers from 15.180–14.529 cal BP to 316–483 cal BP (Table 2). As the profile spans the terminal Pleistocene and the major part of the Holocene as well, it can be used to reconstruct the palaeoevironmental change over a relatively long chronologic sequence. Besides, it may help us in resolving the possible conflicts of litho-, bio- and chronostratigraphical interpretations for the area. The former archaeological, lithostratigraphic and vertebrate biostratigraphic results of the profile [5, 6, 41] also also help to clarify the litho-, bio- and chronostratigraphy of the profile.

Radiocarbon analyses were not performed in Hungary in the 1960s and hence not in the case of the Petényi cave. The excavated layers were mainly classified into biostratigraphic levels on the basis of the vertebrate fauna composition (Table 1, original phases) [5, 6, 42, 43] and on the basis of stratigraphic analysis of vertebrata fauna of the Jankovich cave [44–46], 150–200 km away from the Petény cave. This vertebrate biostratigraphical theory remained until now, in spite of the fact that time-transgression processes that affect biostratigraphical results, and the significance and limits of local environment and local biostratigraphic units were revealed several decades ago [7]. Only a few radiocarbon measurements were carried out in recent years, mainly on vertebrate remains from loess layers of archaeological sites [47]. A series of radiocarbon measurements was also conducted on Late Quaternary vertebrate sites [48].

Thus, the radiocarbon results presented here are considered to be the first series of radiocarbon measurements, which provide an opportunity to clarify the change of a fauna composition in a cave sequence during the Late Pleistocene and Early Holocene.

Based on the radiocarbon data (Table 2), several inconsistencies with the original ideas can be detected (Table 1 and 3). In our analysis, the bedrock (P_1) was formed during Pleistocene (15.180–14.529 cal BP), but at this level it does not correspond to the Allerod phase as it was originally published [1, 2], nor with the Dryas II, Preboral-Boreal phase as it was later believed [6]. It instead corresponds to the early Late Glacial, Dryas I phase or the oldest Dryas horizon [49]. Although different chronological data of this stadial level is known from different ar-

Table 2: The results of the new AMS radiocarbon analysis of samples from the Petény (Peskő II) rock shelter with the original names of the layers and corresponding depths in cm, plus the received and calibrated radiocarbon dates [12].

Layers	Depth (cm)	BP years	±	σ (13C)	Cal BP years (2σ)	BC/AD years (2σ)	Lab code
H_I	30–0	346	21	−12,9	316–483	1467–1634 AD	D-MAS-002118
H_{II-I}	6030	1735	30	−7,6	1710–1565	240–385 AD	GdA-587
H_{II}	60–90	2824	30	−5,6	3142–2929	1193–901 BC	D-MAS-005124
H_{III}	90–120	5025	35	−7,1	5892–5661	3943–3712 BC	GdA-586
H_{IV}	k120–140	6605	35	−7,2	7565–7436	5611–5487 BC	GdA-588
H_V	140–170	8170	50	−7,6	9267–9010	7318–7061 BC	GdA-585
P_1	170–200	12580	60	−4,6	15.180–14.529	13.231–12.580 BC	GdA-584

eas of the world [49], it is clear that the horizon between 15.180 and 14.529 cal BP corresponds with the oldest Dryas level [50], or with the G2 stadial level [51]. This stadial horizon was observed in the Carpathian basin on the basis of radiocarbon-dated Quartermalacological analysis [52–54] and was denominated a *Pupilla sterri* zonula [54, 55]. In this horizon, cryophilous species occurred last in a large number in the centre of the Carpathian Basin [52–55].

The original sampling method involved retrieving samples from the 2.2–2.5 m high profile at 20–30 cm intervals. Perhaps this is why it contains major temporal hiatuses. However, the new radiocarbon results corroborate the presence of a non-continuous sedimentary sequence, interrupted by depositionary hiatuses. It was noted even during the course of the excavations that a part of the shelter's ceiling must have suffered erosion, hampering the unambiguous separation of the first Holocene layer (H_V) from the underlying lowermost Pleistocene layer (P_1) [1, 2]. The considerable amount of rock debris present in the sequence likely posed further problems in the determination of the accurate stratigraphy. According to the new results, there is a depositionary hiatus between 14.529 and 9267 cal BP (Table 2). This might be attributed to either a later erosion of the layers corresponding to this period, or the accumulation of considerable rock debris derived from the walls of the shelter, which could inhibit the deposition of finer sedimentary components on the bottom of the cave. Suprisingly, the period of the aforementioned depositionary hiatus is coeval with a major drop in aerial dust accumulation in the Carpathian Basin, leading to the evolution of lithosoils, then podsolic and finally brown forest palaeosol horizons in the study area [56–59].

The observed depositionary hiatus is by no means a unique phenomenon restricted to this particular rock shelter alone, as a transformation in the sedimentary facies or the development of a sedimentary hiatus between the terminal Pleistocene and the Early Holocene was observed in several other Hungarian cave sequences as well.

On the basis of sedimentological data and observations and electronmicroscopic photos of quartz from sediments of the Late Pleistocene and Early Holocene, the melting of the discontinuous permafrost layer occurred in the Late Glacial/Postglacial transition period [57, 59] so freeze-thaw and water-flow processes were more intensive. As a result, mass movements such as creep became more intensive in the mountainous zone at the beginning of the Holocene [60]. In the hollows and blocked valleys, which formed as a result of the landslides, lacustrine environments evolved at the beginning of the Holocene. Previous research associated this with the melting of the discontinuous permafrost layer [53, 57, 59, 61, 62]. Data and radiocarbon-dated sedimentological analysis of other sites in the Bükk Mountains [63] [Sümegi 2012] indicate that the breaking off of the walls of rock shelters and smaller caves became more intensive during Late Glacial and early Holocene times.

It seems to us that there was a significant increase in mass wasting leading to the accumulation of considerable amounts of rock debris in the areas of the mid-mountains in Hungary during Late Glacial and early Holocene [64]. Most likely, as a local outcome of global warming of the climate at the terminal Pleistocene, the permafrost layer melted in the zone of the mid-mountains, leading to alterations in the accumulation of sediments.

4.2 The findings of lithological studies in light of the new radiocarbon results

According to the reports of the original investigations, the cave sequence was composed of the following layers:

P_1 horizon (between 200–170 cm): slightly calcareous, yellowish-brown clayey silt with a considerable coarse silt fraction and a few limestone fragments. After the removal of the carbonate content, the ratio of the clay, fine and coarse silt fraction in the sediment sample was equally around 30%. On the basis of its lithological characteristics, this type of sediment can be taken as the counterpart of the surficial loess, termed “cave loess” [69], which formed via slight weathering and mixing of the dust accumulating at the bottom of the cave with the original rock material. The accumulation of this sediment type can be dated to the final young Dryas stadial of the terminal part of the Late Glacial. On the basis of radiocarbon data, the loess-like bedrock sediment accumulated between 15.180–14.529 cal BP, during the later Dryas phase (Table 3).

H_V horizon (between 170–140 cm): slightly humic, yellowish-brown clayey silt with a considerable amount of larger (> 0.5 mm) limestone fragments. The clay content is above 40% in this horizon, and thus it can be interpreted as either a weathered counterpart of the bedrock, a less developed palaeosol, or an inwashed palaeosol layer. The numerous large limestone blocks in the sediment indicate an intensification of rock fall from the walls and ceiling of the rock shelter during the formation of this horizon. This horizon must have formed during the beginning of the Holocene, the Boreal period, between 9267–9010 cal BP, as was shown by the radiocarbon results (Table 3). On the basis of radiocarbon data, there is a 5000-6000–year-long hiatus between the sediments of the older Dryas phase and the following Holocene layers.

H_{IV} horizon (between 140–120 cm): Strongly limonithic, humic, reddish-brown silty clay with minimal carbonate and coarse silt content. This horizon can be interpreted as a reworked brown forest palaeosol, pointing to increased weathering and considerable vegetation cover during the time of its formation. Mass wasting was not so important here as shown by the major drop in the amount of limestone fragments. This layer formed at the beginning of the Atlantic period, 7500 cal BP. This level is greatly important, since on the basis of archaeostratigraphic data [70, 71] the first Neolithic population settled down in the Sub-Carpathian region during this time and the Neolithic Bükk culture in the study area that had a significant effect on the environment. There are more known Neolithic colonizations in the region [72–75]. It is likely that as a result of deforestation, soil erosion became more intensive and the organic material content of the sediment accumulating in the cave became higher.

H_{III} horizon (between 120–90 cm): This part of the section yielded the highest ratio of coarse silt fraction with limestone blocks as large as 50 cm as well. The matrix of the rock fragments is blackish-brown, non-fossiliferous, carbonate and organic-rich clayey silt, representing either a reworked, slightly developed lithosoil formed on a carbonate parent material, or a highly disturbed forest soil. The sedimentological parameters of this horizon point to intensified weathering and pedogenesis accompanying a decreased vegetation cover, and/or intensive disturbances either natural or artificial in nature (*e.g.* forest fire, logging). The Neolithic pottery fragments retrieved from the layer point to human influences related to the appearance of agricultural production. The numerous individual stone blocks in the layer represent a collapse of the major part of the cave ceiling. This considerable rock fall must have resulted in the development of a depositionary hiatus and angular unconformity between the H_{III} and the overlying H_{II} horizons. The formation of the unit can be dated to the second part of the Atlantic Period, 5892–5661 cal BP that corresponds to the Copper Age and not to the Late Bronze Age as was originally published.

H_{II} horizon (between 90–60 cm): blackish-brown, organic-rich, clayey silt with a significantly decreased carbonate content and reduced amount of stone fragments and blocks. The clay content exceeds 30%, which, along with the other general sedimentological parameters of the horizon, indicates intensified weathering and pedogenesis under lush vegetation during the Subatlantic Period. This horizon developed between 3142–2929 cal BP, at the end of the Bronze Age and beginning of the Iron Age (Table 1–3). By that time, earthen forts and hoarding castles were established by the communities of the Kyjatice culture [76–78]. Soil erosion became more intensive due to deforestation [73].

H_{I-II} horizon (between 60–30 cm): this unit is largely similar to the previous one, when visually observed. However, the significant drop in the clay and organic content as well as a considerable increase in the amount of limestone debris in the material points to an alteration of sedimentation. This unit seems to represent a transition between the surficial and the underlying horizons. This level corresponds to 1710–1565 cal BP.

H_I horizon (between 0–30 cm): This blackish-brown, humic, clayey silt horizon mixed with rock fragments represents a reworked lithosoil that developed between 316–483 cal BP.

4.3 Archaeological interpretations made in light of the new radiocarbon results

Many problems occurred with the initial archaeological investigations and interpretations. For example, new cultures were thought to have been found on the basis of unsuitable ceramic fragments, which are completely unknown in this region until now. Later interpretations [6, 65] deleted the archaeological data that were unambiguous in the original archaeological publications [1, 2]. So we

Table 3: The individual stratigraphic units of the cave sequence with their original archaeological classification based on the retrieved artifacts [1], plus the new calibrated radiocarbon results and their archaeostratigraphical classification based on a system developed for Hungary using radiocarbon results [68].

Layers	BC/AD years	Archaeological remains from the Petény sequence based on original works [1]	Hungarian Archaeological Periods and Cultures based on ^{14}C data [35]
H_I	1467–1634 AD	Middle Age	Middle Age and Ottoman Age
			Magyar Culture
H_{I-II}	240–385 AD	Imperial Age	Imperial Age
			Barbarian Groups
H_{II}	1193–901 BC	Iron Age	Late Bronze - Early Iron Age
		Hallstatt Culture	Kyjatice and Mezőcsát Cultures
H_{III}	3943–3712 BC	Late Copper Age	Middle Copper Age
		Baden Culture	Ludanice Group
H_{IV}	5611–5487 BC	Neolithic Age	Neolithic Age
		Bükk Culture	Bükk Culture
H_V	7318–7061 BC	Mesolithic Age?	Mesolithic Age
			Tardonasian
P_1	13231–12580 BC	Epipalaeolithic?	Epipalaeolithic Age

decided to supplement the archaeological analysis with archaeostratigraphic data used today, especially with regard to the Late Glacial (15.180–14.529 cal BP) and Early Holocene (9267–9010 cal BP) [1, 2] because we have little accurate radiocarbon data in Hungary concerning these archaeological levels [64, 66].

As shown by the evaluation of the formerly retrieved artifacts [1, 2], plus the new radiocarbon results, the sequence corresponds to the time of the Late Glacial (15.180–14.529 cal BP, Epipalaeolithic) and Early Holocene (9267–9010 cal BP, Mesolithic) cultural groups in the area. The clear separation of the tools corresponding to these two cultures was not without problems, similar to the delineation of the layers representing the Late Glacial and Early Holocene, as was mentioned before. The horizon marked as H_V was originally identified as representing the Allerödian of the Epipalaeolithic, on the basis of the numerous atypical silex blades and non-retouched microblades retrieved from this unit [1, 2]. However, Vértes [1, 2] also recognized ambiguous Mesolithic-type tools as well. Conversely, based on the analysis of charcoal pieces retrieved from the same horizon, the H_V horizon was assigned into the Mesolithic by Stieber [3]. Although the H_V layer is overlying the lowermost P_1 layer, their accurate delineation is not without problems due to the presence of an angular unconformity or depositionary hiatus between them. Both the P_1 and H_V horizons yielded atypical blades, part of which was identified to Epipalaeolithic, with the remaining part assigned to be questionably Mesolithic in age [6]. The questionably Mesolithic blades were restricted to the H_V horizon. According to the new AMS radiocarbon results, the Epipalaeolithic tools derive from the layer P_1 (15.180–14.529 cal BP) whereas those of ambiguous Mesolithic age derive from the layer H_V (9267–9010 cal BP) (Table 3).

The younger Holocene layers yielded artifacts corresponding to the Neolithic, Copper and Iron Ages. However, in several places the layers seems to have suffered mixing, as the older horizons often contained artifacts of younger cultures assigned to the Iron Age Kyjatice Culture as well [1]. Moreover, the younger Iron Age layers often yielded pottery fragments assigned to the Copper and Neolithic Cultural Groups as well [1]. This mixed nature of the artifacts and pottery fragments could have been the result of the non-precise, univocal delineation of the stratigraphic horizons in the cave sequence. Alternatively, it could simply represent the outcome of the various taphonomic processes characteristic of cave sedimentary systems, like the syngenetic inwash of surficial sediments into the cave or postgenetic mixing caused by humans or the soil-dwelling fauna [67].

According to the new radiocarbon dates for the mollusc samples retrieved from the identified horizons of the profile, the Pleistocene bedrock (P_1) corresponds to the Epipalaeolithic (15.180–14.529 cal BP), the horizon H_V to the Mesolithic (9267–9010 cal BP), the horizon H_{IV} to the Neolithic (7535–7436 cal BP), the horizon H_{III} to the Middle Copper Age (5892–5661 cal BP), the horizon H_{II} to the Late Bronze-Early Iron Age (3142–2929 cal BP), the horizon H_{I-II}

to the Imperial Age (1710–1565 cal BP) while the final unit of H_I represents the Middle Age (316–483 cal BP) (Table 3).

According to the new radiocarbon results, we see successively younger layers from the bedrock towards the top of the studied cave sequence. With the help of these data, the absolute age and correct place of the formerly identified horizons could have been accurately determined in the archaeostratigraphical system established via the collective use of radiocarbon and historical data by Vaday [68] for Hungary. Nevertheless, according to the original archaeological descriptions, these horizons contained mixed artifacts of different archaeological periods, which must be attributed to postgenetic disturbances and mixing. Furthermore, the possibility of erroneous determinations can not be fully excluded either.

4.4 The findings of palaeobotanical studies in light of the new radiocarbon results

The results of the palaeobotanical analysis caused the most debate among the members of the original research team. The analyser of charcoal material, József Stieber, was the first in Hungary to state that pollen-based vegetation reconstructions relate to a larger area (regional), while charred wood remains are suitable for the reconstruction of local forests [3]. Therefore, there can be huge differences between the results of the methods. Thus, the fomer arboreal vegetation composition and the pollen-based stratigraphic levels of Pleistocene and Holocene were questioned on the basis of anthracological data [3, 4]. Our chronological analysis was able to resolve this scientific debate that started 60 years ago.

The palaeobotanical interpretations are based on the analysis of charcoal [3] and pollen particles retrieved from the samples of the individual horizons (Miháltzné Faragó Mária in [1]).

The first palaeobotanical unit or zone corresponds to the horizon embedding Epipalaeolithic tools [2]. This zone is characterized by a univocal dominance of coniferous trees (*Pinus, Pinus silvestris, Picea*) with a ratio over 90% between 15180–14529 cal BP. More than 64% of the charcoal pieces belonged to the taxon of spruce (*Picea*), while Scotch pine (*Pinus sylvestris*) comprised only 18% of the studied material. In addition, numerous charcoal fragments of the so-called thermomesophylic deciduous trees were identified in the sample, pointing to the development of a mixed taiga containing locally such deciduous elements as oak (*Quercus*) and maple (*Acer*), for example. These Late Glacial charcoal pieces serve as clear evidence for the local presence of thermomesophylous deciduous arboreal elements in the Late Glacial woodland vegetation of the Carpathian foreland, corroborating the findings of former palynological and malacological studies, which indicated the presence of thermomesophylous woodland refugia in the southern foothills of the Subcarpathian region of the Carpathians [57–59, 79–85].

The next palaeobotanical unit or zone corresponds to the H_V horizon assigned to the Mesolithic. The ratio of coniferous AP (Arboreal Pollen) (*Pinus*) in this zone was below 10%, with a concomitant dominance of deciduous AP (over 85%) including such species as birch (*Betula*), lime (*Tilia*) and alder (*Alnus*). The ratio of NAP (Non-Arboreal Pollen) including *Gramineae* was only minimal at this time [1, 2]. However, the ratio of birch pollen grains exceeded 60%. All this information seems to refer to a complete transformation of the vegetation in the vicinity of the rock shelter, where the mixed taiga was replaced by species-rich, deciduous woodland with wet undergrowth between 9267–9010 cal BP.

According to the latest palynological results for the Carpathian Basin, the coniferous woodlands were replaced by decidous woodlands in the Subcarpathian region and the areas of the Hungarian Mid-Mountains around 9200–9000 cal BP [59]. The first step of this transition included the advent of birch to the areas of the retreating pine woodlands [59], either as a result of climatic change and/or extensive forest fires as shown by the palynological results of the sequence of the Kis-Mohos mire of Kelemér. The findings of the Petény cave section, presented here, seem to corroborate this model, pointing to the replacement of the Late Glacial mixed taiga woodlands by birch-dominated deciduous woodlands by the beginning of the Holocene, or more precisely, the opening of the Boreal period.

The third palaeobotanical zone corresponds to the H_{IV} horizon yielding Neolithic pottery fragments [2]. This unit yielded a single charcoal piece of yew (*Taxus baccata*) and numerous charcoal pieces of deciduous trees and bushes (hazel - *Corylus*, hornbeam - *Carpinus betulus*, ash - *Fraxinus*, oak - *Quercus*) [3]. The ratio of oak (*Quercus*) and hornbeam (*Carpinus*) among the charcoal pieces was above 30–30% each According to the palaeobotanical results, the beginning of the Neolithic witnessed the evolution and presence of hornbeam–oak (*Caprinus–Quercus*) woodland. Other palaeobotanical results show scattered ash (*Fraxinus*) and a bush horizon composed of dominantly hazelnut (*Corylus*). Later on, as shown by the findings for the fourth palaeobotanical zone, there was an expansion of oak (*Quercus*) woodlands in the area. However, the possibility that the advent of oak (*Quercus*) might be attributed to the selective exploitation of trees in the surroundings of the cave by the newly settled human cultural groups cannot be fully excluded.

In our opinion, the radiocarbon-dated palaeobotanical results are highly important and we can prove the original theory [3, 4] by these new data; the refugium model of local temperate trees is realistic on the basis of charred wood remains.

4.5 The findings of malacological studies in light of the new radiocarbon results

All samples yielded fragments of mollusc shells suitable for study. Each horizon is dominated by species that are today found in association with woodlands. The appearance of the rock-dweller *Chondrina clienta* (Table 4) marks an opening in the vegetation restricted to H_{IV} corresponding to 7565–7436 cal BP. The appearance of the Central European, Carpathian forest-dweller *Cochlodina cerata* in the horizon represents the terminal stage of the Pleistocene (P_1). It may indicate that the area served as a potential refugium for woodland floral and mollusc elements as well, corroborating the ideas on the presence of woodland refugia in this region as stated above. This was the second Late Glacial specimen of *Cochlodina cerata* identified in the zone of the mid-mountains in Hungary whose presence is supported by radiocarbon results.

Cochlodina cerata spread throughout the Northern and Northeastern part of the Carpathians [86, 87] and lived in closed forests, especially on wet rocks under trees and shrubs [24]. The appearance of *Cochlodina cerata* is higly important between 15.180 and 14.529 cal BP because this species lives in temperate forests of the Carpathians today. Therefore, during the oldest Dryas phase, temperate forests might have been present in the study area. As a result, it can be assumed that a refugia of temperate forest existed in the analysed region. These data support the earlier palaeoecological and biogeographic analyses [37, 56, 58, 59, 79, 80, 84, 88] that more refugia existed in the southern border of the Northern Carpathians where temperate forest habitat and taxon survived the coldest stages of the Pleistocene.

The Early Holocene (H_V) layers are characterized by a species-rich woodland mollusc fauna with a dominance of *Clausilia pumila*, which exist in forested hill slopes in Central Europe and also serve as an index fossil because the Late Pleistocene occurrence of this species in unknown.

The collective appearance of *Cochlodina cerata, Cochlodina laminata, Clausilia dubia, Clausilia pumila* and *Helicigona faustina* is also highly useful, as they indicate the development of a closed deciduous woodland in the area during 9267–9010 cal BP. The general composition of this mollusc fauna closely resembles the Early Holocene mollusc fauna of Bátorliget marshland [82], which is one of the most important radiocarbon-dated Holocene type sections in Hungary [57]. The mollusc fauna found in the Petény Cave points to the development of deciduous woodlands during the Early Holocene without a preceding steppe phase in the study area. Therefore, the Mesolithic human population must have lived in a woodland setting in the vicinity of the rock shelter. All of the species that occurred in this level of the profile (Early Holocene) live in temperate closed forests today and therefore serve as forest habitat markers [9, 21, 23, 87, 89, 90].

There is a major drop in the species and specimen numbers of the successive horizons compared to H_{IV}. This indicates a general retreat of woodland elements. Some open-area and rock-dweller elements like *Orcula dolium* and *Chondrina clienta* also turn up. The appearance of these two species might be linked to an intensive deforestation connected to the agricultural activities of the first productive Neolithic groups in the area.

Unfortunately the number of specimens was low, which did not allow for statistical analysis of samples. Nevertheless, the change of fauna composition clearly indicates the change of the environment, the opening up of the forest canopy and the formation of open areas. This is supported by the appearance of *Orcula dolium*, which lives in sunny rock walls in forest environments [91, 92], as well as *Chondrina client*, which also prefers rock habitats [23, 93, 94]. The appearance of these two species that prefer open areas and the disappearance of *Clausilia pumila* and *Cochlodina cerata* during the early Holocene indicate the opening up of the closed forest. This level corresponds to the Neolithic in the study area according to the radiocarbon data of horizon H_{IV}. Moreover, the presence of ceramic fragments [1, 3] indicates the existence of the Neolithic Bükk culture. This open environment also characterizes the next horizon (H_{III}), which corresponds to 5892–5661 cal BP (Copper age).

After the horizon of H_{II} there is another significant rise in the proportions of woodland elements in the layers corresponding to the H_{I-II} horizon. Furthermore, the younger historical layers (H_I horizon, the terminal phase of the Medieval Age and Ottoman Period [95]) are also characterized by the dominance of closed woodland elements. The appearance of *Balea cana* in the surfacial layer is also notable as this species in the cave sequences of the Bükk Mountains is generally recognized to mark the time of 316–483 cal BP (H_I) [95]. It seems that at the end of the Medieval Age and beginning of the Modern history the area

Table 4: The distribution of the identified mollusc species in the sequence with their palaeoecological classification.

Species	Palaeoecological group	H_I 1467–1634 AD	H_{I-II} 240–385 AD years	H_{II} 1193–901 BC	H_{III} 3943–3712 BC years	H_{IV} 5611–5487 BC years	H_V 7318–7061 BC years	P_1 13231–12580 BC years
Chondrina clienta	Rock-dweller	-	-	-	+	+	-	-
Orcula dolium	Rock-dweller	-	-	-	+	+	-	-
Cochlodina cerata	Woodland	+	+	-	-	-	+	+
Cochlodina laminata	Woodland	+	+	+	+	-	+	-
Clausilia dubia	Woodland	-	-	-	+	-	+	-
Clausilia pumila	Woodland	-	+	+	-	-	+	-
Laciniaria plicata	Woodland	-	-	-	-	-	+	-
Laciniaria biplicata	Woodland	-	-	+	+	-	-	-
Balea cana	Woodland	+	-	-	-	-	-	-
Clausilia sp. indet	Woodland	-	-	-	-	+	-	-
Aegopinella minor	Woodland	-	-	-	-	+	+	-
Oxychilus glaber	Woodland	-	-	+	-	-	-	-
Euomphalia strigella	Forest-steppe	-	-	-	-	-	+	-
Helicigona faustina	Woodland	-	-	-	-	-	+	-

was desolated, supported by written historical data and other palaeoecological studies in the area [96, 97].

4.6 The findings of vertebrate studies in light of the new radiocarbon results

The interpretations presented in this section are solely based on formerly published results [5, 6, 41]. Nevertheless, it is important to present the results of vertebrate fauna analyses in a separate chapter, because on the basis of the new radiocarbon analyses we can refine the original stratigraphic theories and rephrase the environment reconstructions of the original chronological levels. Significant time differences were detected in comparison with the previous analysis of vertebrate fauna, and the temporal appearance and survival of species were clarified.

In the horizon of P_1, the following representatives turn up collectively: *Rana mehelyi*, which becomes extinct at the end of the Pleistocene; the cold-resistant, Boreo-Alpine willow ptarmigan (*Lagopus lagopus*); rock ptarmigan (*Lagopus mutus*); common vole (*Microtus arvalis*); snow vole (*Microtus nivalis*); root vole (*Microtus oeconomus*); narrow-skulled vole (*Microtus gregalis*); cave bear (*Ursus spelaeus*); pikas (species cannot be determined, but it belong to the *Ochotona* genus); chamois (*Rupicarpa rupicarpa*) and mountain hare (*Lepus timidus*). The species dwelled in deciduous woodlands and preferred humid, temperate climatic conditions, much like the Birkhuhn black grouse (*Lyrurus tetrix*), bank vole (*Myodes glareolus*), and woodmouse (*Apodemus sylvaticus*). The composition of the vertebrate fauna is congruent with the findings of palaeobotanical studies, also pointing to the development of a transitional flora and fauna in the area, which developed via the mixing of the Late Pleistocene cold taxa and Early Holocene warm taxa. The appearance of the Birkhuhn black grouse (*Lyrurus tetrix*), bank vole (*Myodes glareolus*) and woodmouse (*Apodemus sylvaticus*) species that live in closed, temperate forests today prove that temperate species lived in the study area during the oldest Dryas phase, between 15.180 and 14.529 cal BP. Therefore, besides charcoals and molluscs, the vertebrate fauna composition demonstrates the existence of late Pleistocene temperate woodland in the study site.

In the next H_V horizon the cold-resistant, Boreo-Alpine elements undergo a major retreat, with only a few specimens of some Pleistocene remnant species surviving (*Lagopus, Ochotona, Microtus oeconomus*). The representatives of the warm taxa, like the Birkhuhn black grouse (*Lyrurus tetrix*), the bank vole (*Myodes glareolus*) and the woodmouse (*Apodemus sylvaticus*), which had a subordinate relict role in the Late Glacial fauna, experience a sudden advancement, becoming decisive dominant elements of the new fauna. Among the Holocene index fossils of the Carpathian Basin, such species as the common dormouse (*Muscardianus avellanius*), the woodland vole

(*Pitymys subterraenus*) and the hare (*Lepus europeus*) also turn up here.

The composition of this temperate-forest-preferring vertebrate fauna is completely in agreement with the composition of the mollusc fauna, corroborating the theory of dual refugia postulated earlier on the basis of palaeobotanical studies for the Carpathian Basin [79]. Therefore, it seems that the Subcarpathian region acted as some sort of dual refugia, offering shelter for the so-called warmth-loving species [79] during the glacials and to the so-called cold-resistant elements [79] during the warm periods. These refugial patches must have existed side by side, forming a mosaic that harbored species of different ecological needs in the area [80]. Of course, this issue is more complicated than just simple temperature changes because all ecological factors affect specimens and competition between species and competition within species is also present. However, the fauna composition indicates that sporadic deciduous forest patches existed in the conifer woodland [79, 80], so a mosaic taiga forest may have existed in the Late Pleistocene. In this environment, cold-resistant elements dominated, but warmth-loving trees and deciduous forest species may have subsisted. In these deciduous forest patches, vertebrate species favouring deciduous forest environments could survive. Mixed taiga forests with deciduous forest patches are known from the Altai Mountains today [58, 66, 98, 99]. At the end of the Pleistocene, both global and local warming [100] had transformed the environment of the Sub-Carpathian region [59]. Cold-resistant elements were forced back into colder areas, while deciduous forest elements preferring milder climate spread from refugia and became dominant during the Early Holocene. This is supported by the presence of vertebrate fauna elements. Mosaic cold recesses existed in the deciduous forest environment, where cold-resistant species could survive warming during the Early Holocene. The presence of cold-resistant *Microtus oeconomus*, *M. gregalis*, *Lagopus* species during the early Holocene support this theory.

There is a depletion of the vertebrate fauna in horizon H_{IV} (Table 5) caused by the full disappearance of glacial relict taxa. This phenomenon is also observable in other Hungarian profiles of the same age [57, 82], implying that the appearance of a productive community (Neolithic), accompanied by intense human disturbances in the environment, eventually led to the complete disappearance of these cold relict spots and hence a transformation of the vertebrate fauna. From 7565 cal BP onwards the vertebrate fauna is more or less homogenous, showing no major changes in composition. The cold-resistant species that dominated during the Late Pleistocene disappeared from this level of the profile.

5 Conclusion

As was revealed by the final results, the cave sequence exposed layers from the Late Glacial, starting about 15.180–14.529 cal BP. However, layers corresponding to the Pleistocene/Holocene boundary (between 14.000 and 9500 BP years) are completely missing, hampering a direct environmental reconstruction for the period. The appearance of thermo-mesophylous gastropod species in considerable amounts as early as the Late Glacial is indicated by the results of the radiocarbon analysis. Results clearly indicate that the appearance of deciduous woodlands in the Carpathian Basin, along with the concomitant mollusc elements, occurred a lot earlier than previously assumed, corroborating the presence of temperate woodland refugia in the study area, as was formerly postulated by a British-Hungarian research team [59, 79, 80].

As shown by the composition of bioindicator elements (Figure 4) in the first stratigraphic horizon, the vicinity of the rock shelter was covered by humid woodlands between 12.000 and 14.000 BP years. The woodlands were likely replaced by forest steppe mosaics in the more distant background areas of the hill crests. Only this model explains the results of anthraconomical studies referring to the presence of the closed mixed taiga woodland locally at the site [59, 80]. The presence of some cold steppe and tundra elements in the vertebrate fauna points to the presence of open vegetation patches, probably at a larger distance from the study site.

However, there is an important taphonomic factor that should be taken into consideration during the analysis of the vertebrate fauna of cave sequences. A part of the accumulated rodent bones were hoarded by owls in Petény cave, according to recent analysis of bones accumulated in rock shelters [85], since they are ideal objects for owls to rest and digest. During digestion owls eject the indigestible parts, including bones, into the caves and rock shelters [101–103]. These owl sputums accumulate together with the sediment and preserve the bones collected and ejected by owls in the caves and rock shelters.

Thus, owls and owl pellets generally influence a major component of these sediments [5]. The actual extent of the hunting territory of owls fundamentally determines the origin of microvertebrates in the cave's fauna [104]. Therefore, not only the rodents' living area should be taking into account regarding the extent of the reconstructed area. We

Table 5: The distribution of the identified vertebrate fauna elements [6] in the sequence.

Species	H_I 1467–1634 AD	H_{I-II} 240–385 AD years	H_{II} 1193–901 BC	H_{III} 3943–3712 BC years	H_{IV} 5611–5487 BC years	H_V 7318–7061 BC years	P_1 13231–12580 BC years
Rana mehelyi	-	-	-	-	-	-	+
Lagopus mutus	-	-	-	-	-	+	+
Lagopus lagopus	-	-	-	-	-	+	+
Lyrurus tetrix	+	+	-	-	-	+	+
Myodes glareolus	+	+	+	+	-	+	+
Microtus arvalis	-	-	-	-	-	+	+
Pitymys subterraenus	+	-	-	+	-	+	-
Microtus nivalis	-	-	-	-	-	-	+
Microtus oeconomus	-	-	-	-	-	+	+
Microtus gregalis	-	-	-	-	-	+	+
Apodemus sylvaticus	+	+	+	+	+	+	+
Ursus spelaeus	-	-	-	-	-	-	+
Ochotona sp.	-	-	-	-	-	+	+
Lepus timidus	-	-	-	-	-	-	+
Lepus europeus	+	-	-	-	+	+	-

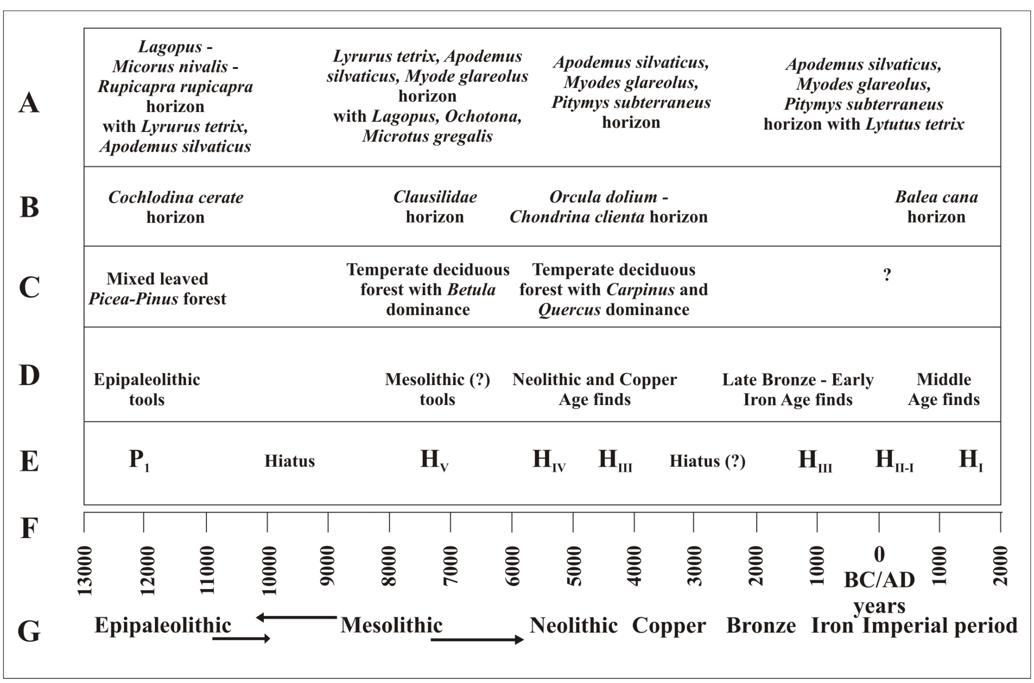

Figure 4: The radiocarbon dated palaeoecological data from Petény (Peskő II) rock shelter
A = Vertebrate horizons in the Petenyi rock shelter sequence
B = Malacological horizons in the Petenyi rock shelter sequence
C = Palaeobotanical horizons in the Petényi rock shelter sequence
D = Archaeological finds from the Petényi rock shelter sequence
E = Sedimentological horizons and depositionary hiatuses in the Petényi rock shelter sequence
F = Time scale (calibrated annual years)
G = Hungarian Archaeological Periods based on radiocarbon-dated archaeological finds and excavations [68]

have to consider the preying area of raptor birds, especially owls that use caves, as well [5]. Thus, the composition of the microinvertebrates reflects the environment of the wider surroundings of the cave as well. Birds collect snail shells [104], and even thicker snail shells, similar to gravel, are used for crushing [107]. So during digestion [106] characteristic signs of damage and solution can be observed in the calcium carbonate material of shells. Rodents collect snail shells as well and typical signs of bites can be observed on the surface of shells [107, 108]. Shells with traces of digestion of birds or rodent bites were not found in the malacological material of Petény cave. The majority of shells were washed into the cave from the immediate vicinity during the last 15.000–16.000 years.

The direct vicinity of the rock shelter, covered by mixed taiga woodlands with minor open patches, offered ideal conditions for the local Epipalaeolithic communities, which were present in the study area between 15.180–14.529 cal BP [2].

The next stratigraphical unit corresponds to the period of the Early Holocene, with the oldest Holocene layers missing. This horizon was dated to 9267–9010 cal BP. At that time, the fauna is dominated by deciduous woodland dwellers, with some cold-resistant relict elements reflecting a larger number of species. Deciduous woodland environments harbored some coniferous elements as well. The area was populated by Mesolithic communities at 9267–9010 cal BP. As was shown by the findings of the palaeoenvironmental analyses of the Rejtek cave profile, the retreat of the Epipalaeolithic (15.180–14.529 cal BP) and advancement of the Mesolithic (9267–9010 cal BP) group must be linked to some major climatic change leading to a transformation of the mixed taiga woodlands into extensive deciduous woodlands [109]. The presence of some glacial relict forms in the Early Holocene horizon implies a gradual transition between the Pleistocene/Holocene flora and fauna and not an abrupt biogeographic shift and extirpation of the older Pleistocene elements.

The succeeding stratigraphic unit corresponds to a time period from 7565–7436 cal BP. During this period of time, decidous woodlands, which were dominated by oak and alder, still existed in the vicinity of the rock shelter [3, 4]. In addition, hornbeam, lime, alder, maple and hazelnut occurred. The slopes of the valleys characterized by higher humidity must have harbored extensive rock steppes.

According to our findings, the study site might be important in the long-term persistence and evolution of woodland refugia. Despite the presence of some major depositionary hiatuses, the Petény profile contains key stratigraphical, chronological, palaeoecological and environmental historical elements for the understanding of the terminal Pleistocene and the Holocene events in Hungary. The new radiocarbon dates enabled an accurate temporal reconstruction of the cultural changes that took place around the site, along with the concomitant transformations in the environment.

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