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# HOLOCENE ENVIRONMENTAL HISTORY OF THE BOTTOMLESS LAKE (TĂUL FĂRĂ FUND) SPHAGNUM PEAT BOG IN BĂGĂU, ROMANIA

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**Abstract:**
This work focuses on the paleoenvironmental and palaeoclimatological history of the undisturbed core sequence of 8.6 m extracted from the Bottomless Lake (Tăul fără fund) sphagnum peat bog located in Băgău, Romania, which covers the last 8,600 years based on radiocarbon dating. By comparing results of archaeological and palaeoenvironmental investigations carried out so far in the area, results of the loss on ignition analyses and the data of the chronological analyses, it was possible to reconstruct climatic factors and anthropogenic impacts on the local environment. The undisturbed core sequence has above 86% organic matter content all along excluding the erosion horizons. Anthropogenic effects (building, woodcutting, pasturage, husbandry, farming) and changes in the local climate, vegetation, and environment increased the rate of the erosion and decreased the rate of the accumulation.

**Key words:** Romania, Holocene, peat bog, environmental history

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## INTRODUCTION

The Hungarian Academy of Sciences Institute of Archaeology and the Hungarian Peat Research Society, founded at the University of Szeged, examined peatlands both in Hungary and Transylvania, Romania. The most important aim of the study was to determine the conditions under which the peat areas and peat layers were formed and transformed at the end of the quarter. These peatlands carry important historical environmental and paleoclimatic information about the end of the Quaternary.

The chronological analysis of the development of peat layers was based entirely on radiocarbon (AMS = Accelerator Mass Spectrometry) measurements. By comparing the results of the archaeological and paleoenvironmental investigations carried out so far in the field, the results of the loss on ignition analyses, and the data of the chronological analysis, we outlined the environmental history of the peatland in the last 8,600 years BP and reconstructed the climatic and anthropogenic effects on the local environment.

## MATERIALS

### Localization

The Bottomless Lake (Tăul fără fund, Feneketlen-tó) is located in Romania (Fig. 1), in the central part of Transylvania, more accurately in the Lopadei Hills (Podişul Lopadei, Magyarlapádi-dombság), which is a part of the Târnava Mică Hills (Dealurile Târnavei Mici, Kis-Küküllő-menti dombság). It lies between the Mureş River (Maros) and the Târnava Mică River (Râul Târnava Mică, Kis-Küküllő folyó).

### History of the village

Written sources from the Early and High Middle Ages confirm that there were no human settlements in the immediate vicinity of the peat bog. The first village that was mentioned was Băgău in 1296 after the Mongol invasion in Europe as Bogo and its previous name was Perech.

**Fig. 1.** Map of Romania with the location of Băgău, edited by Tamás Zsolt Vári (base image: https://www.mapsland.com/europe/romania/large-detailed-relief-map-of-romania).

After that it was mentioned as Bogou in 1319, Bogov in 1332, Bagow in 1376, Bogo in 1390 and 1600 (Lestyán, 2000).

### Geology of the area

The peat bog covers 2.5–3 ha, but it can extend to 5–6 ha during wet periods (László, 2006). Romanian corings in the middle of the bog reached 4–5 m of peat but based on our coring it can be up to 8 m. The bedrock of the area consists of Miocene marls and clayey and silty inland sea sediments with dacite tuff (Stefanescu *et al.*, 2006). The area is covered with Holocene peat and the soil consist of histosol, cambisol and anthrosol.

### Climate of the area

The continental effect makes the summer dry and hot, while the Subcarpathian effect provides wet conditions (rain, snow) and results a cool winter. The requirements of the peat accumulation are present in all vegetational periods. A closed canopy forest maintains high humidity and protects the area. The peat bog has rich and diverse vegetation with 6 plant associations. It is a member of the Natura 2000 European Commission.

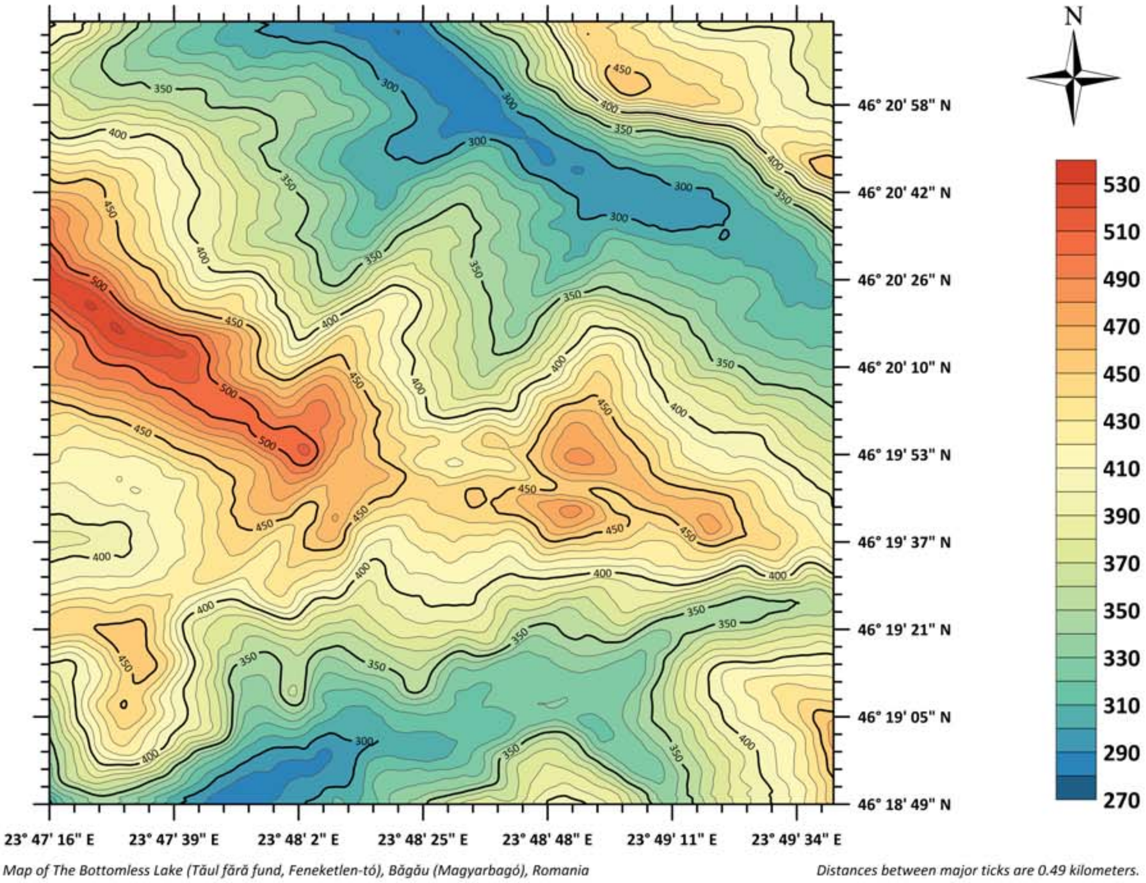
### Study site

The peatland was developed in the deepest part of a regressive valley, as there is a watershed in the area (Fig. 2). The stream travels from the drainage to the Bottomless Lake, where the fall of the valley ceases. As a result, a protrusion and retraction could have taken place at the end of the ice age, at the beginning of the Holocene, and then it slowed down. Correspondingly on the bog side of the valley, the stream got obstructed. Displacement was caused by mass movement, and the valley closed due to the slope movement of the sea sediments forming the valley side (Fig. 2).

## METHODS

### Field sampling

The 860-cm long peat core was collected using a Russian peat corer (90 cm long and 5 cm in diameter) with overlapping method (Aaby and Diegerfeld, 1986) in September 2015 at 439 m a.s.l., coordinates of the coring: N 46°19’51.57»E 23°48’32.45». The 45-cm long peat and sediment sections were placed in a plastic foil, then aluminium foil and properly stored under dark and cold conditions (4 ºC). Detailed sedimentological description of the peat cores (Table 1) follows the system described by Troels-Smith (1955), the co-



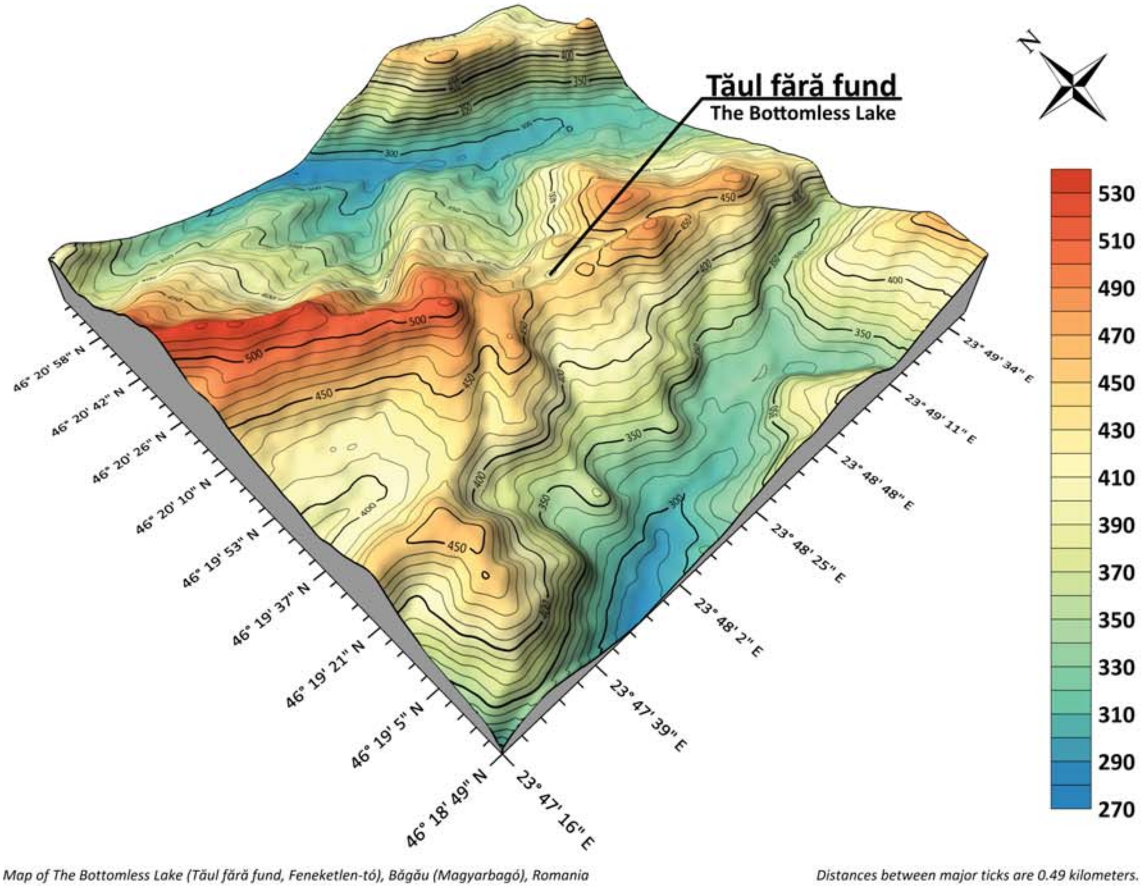


**Fig. 2.** Map of the Bottomless Lake (Tăul fără fund, Feneketlen-tó), Băgău (Magyarbagó), Romania. Distances between major ticks are 0.49 km.

lours of sediment layers were described using the Munsell Color Chart (Munsell Color, 1954).

Field team members were: University of Szeged, Hungary: Prof. Dr. Pál Sümegi, head of a department, Balázs Pál Sümegi institute engineer, János Rovó, engineer at the department; University of Sapientia, Romania: Attila Tóth, PhD student.

### Radiocarbon dating

The preparation of the samples for AMS dating and the actual steps of the measurement followed the methods of Hertelendi *et al.* (1989, 1995) and Molnár *et al.* (2013). Conventional radiocarbon ages were converted to calendar ages using the most recent Intcal13 calibration curve (Reimer *et al.*, 2013). Calibrated ages are reported as age ranges and mean age ±1SD at the 2-sigma confidence level (95.4%). The samples were measured in DirectAMS, Seattle, USA and in HEKAL, Debrecen, Hungary.

### Loss on ignition

The examinations of the organic matter and carbonate content were executed by the loss on ignition (LOI) method (Dean, 1974).

## RESULTS

### Radiocarbon dating

According to the radiocarbon results, the formation of the peat bog is estimated about 8,500 years ago. The filling of the biogenous remains and peat formation are present to this day. During about 8,500 cal yrs BP years approximately 860 cm of sediments accumulated, meaning that the average sedimentation rate was about 1 mm/year. However, based on the radiocarbon age data, the average sedimentation rate showed significant changes, fluctuating between approximately 0.24 mm/year and

Table 1. Detailed sedimentological description of the peat cores with Troels-Smith (1955) sediment description and Munsell (1954) color description.

| Depth (cm) | Zones | Troels-Smith symbols | Sediment types | Sediment colour codes (Munsell) | Sediment colours |
|---|---|---|---|---|---|
| 20–0 | Zone 6 | Tb3 As1 | sphagnum peat with clayey silt material | 10 YR 5/3 | greyish green |
| 88–20 | | Tb4 | sphagnum peat | 10 YR 4/3 | greyish brown |
| 100–88 | | Water layer | water layer | – | – |
| 160–100 | | Tb4 | sphagnum peat | 10 YR 3/2 | dark brown |
| 230–160 | | Th4 and Th2As2 | cyclic reed peat-laminated clayey silt | 10 YR 4/4 and 10 YR 4/1 | light brown and brownish grey |
| 404–230 | Zone 5 | Tb4 | sphagnum peat | 10 YR 3/2 | dark brown |
| 450–404 | | Water layer | water layer | – | – |
| 460–450 | | Tb1As3 | inwashed sediment | 10 YR 4/2 | brownish grey |
| 540–460 | Zone 4 | Tb4 | sphagnum peat | 10 YR 3/2 | dark brown |
| 550–540 | | Tb1As3 | inwashed sediment | 10 YR 4/2 | brownish grey |
| 650–550 | Zone 3 | Tb4 | sphagnum peat | 10 YR 3/2 | dark brown |
| 670–650 | | As2Ag1Tb1 | inwashed sediment | 10 YR 4/2 | brownish grey |
| 740–670 | Zone 2 | Tb4 | sphagnum peat | 10 YR 3/2 | dark brown |
| 760–740 | | As2Tb1Th1 | cyclic reed peat-laminated clayey silt | 10 YR 4/4 and 10 YR 4/1 | light brown and brownish grey |
| 820–760 | Zone 1 | Tb3Th1 | sphagnum peat | 10 YR 3/2 | dark brown |
| 860–820 | | Ga1Ag1As2 | re-deposited base-rock | 10 YR 5/2 | light grey |

Table 2. Calibrated and uncalibrated radiocarbon data table with calibrated BC-AD years and sedimentation rate (SR).

| Cm | Uncal BP | Sigma | Cal BP | Sigma | Cal BC-AD years | Cal BC-AD | Sigma | Laboratory | SR (mm/1 year) | SR (year/10 mm) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 100 % + 0.4 pM | | 5 | 5 | 1950–1960 AD | 1955 AD | 5 | HEKAL-2017 | 1.46 | 6.85 |
| 60 | 368 | 57 | 408 | 100 | 1443–1642 AD | 1543 AD | 100 | D-AMS-2016 | 1.05 | 9.54 |
| 255 | 2286 | 29 | 2268 | 104 | 403–215 BC | 314 BC | 99 | D-AMS-2016 | 1.05 | 9.51 |
| 360 | 3069 | 32 | 3263 | 101 | 1415–1233 BC | 1324 BC | 91 | D-AMS-2016 | 1.16 | 8.63 |
| 460 | 3800 | 20 | 4169 | 74 | 2293–2146 BC | 2367 BC | 74 | D-AMS-2016 | 1.60 | 6.25 |
| 559 | 4144 | 24 | 4700 | 121 | 2630–2872 BC | 2751 BC | 121 | D-AMS-2016 | 0.58 | 17.39 |
| 658 | 5665 | 49 | 6456 | 142 | 4649–4365 BC | 4507 BC | 142 | D-AMS-2016 | 1.79 | 5.58 |
| 829 | 6443 | 38 | 7358 | 70 | 5479–5339 BC | 5439 BC | 70 | D-AMS-2016 | 0.24 | 42.22 |
| 846 | 7709 | 44 | 8498 | 83 | 6631–6466 BC | 6547 BC | 83 | D-AMS-2017 | – | – |

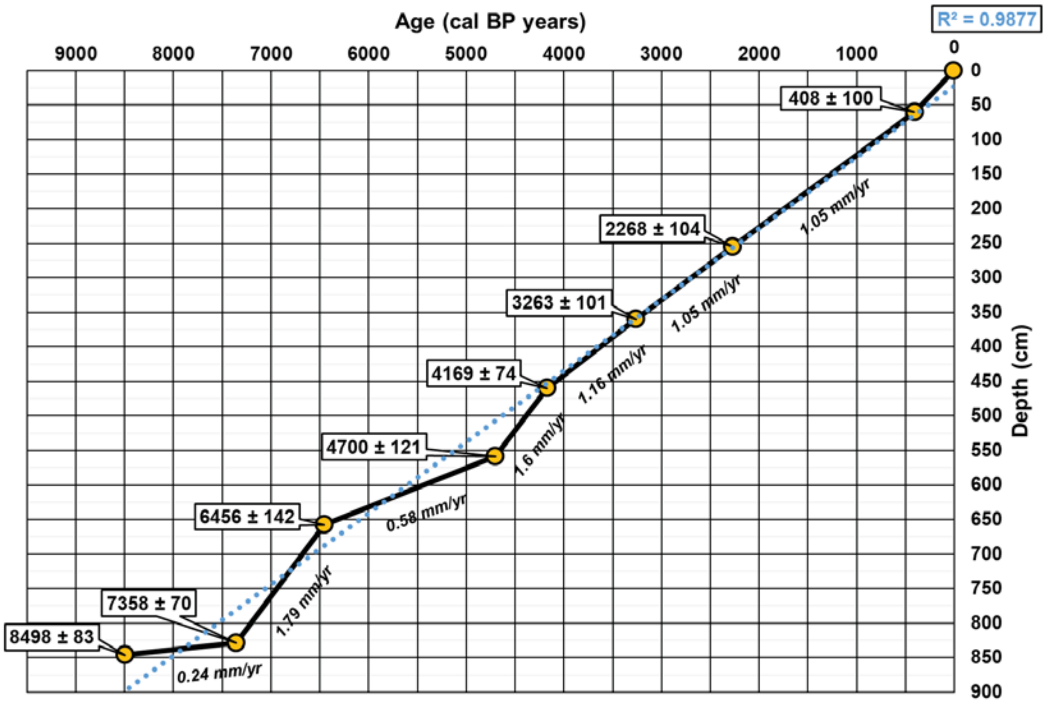


**Fig. 3.** Age (cal BP years), depth (cm) and sedimentation rate (mm/year) model of the Bottomless Lake core sequence.

1.79 mm/year, but in most of the section exceeded 1.0 mm/year (Table 2).

There is correlation a very close correlation between depth and age, based on polynomial fitting ($R^2$ = 0.9889), but the correlation between the linear settling rate was also very close ($R^2$ = 0.9877) between the layer and the line of origin. The sedimentation rate between 8,500 and 4,500 cal yrs BP years showed significant fluctuations. However, practically from the end of the Copper Age, and from the beginning of the Bronze Age, about 4,500 cal yrs BP, the evolution of the sedimentation rate was quite even (Fig. 3).

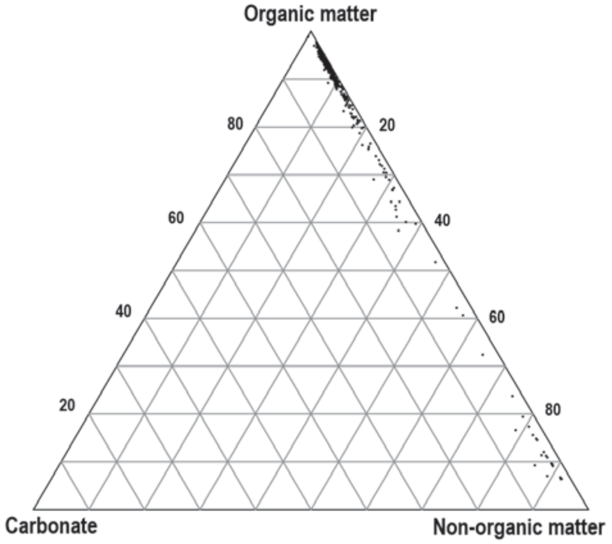


**Fig. 4.** Carbonate, organic and non-organic matter content shown on a triangle diagram for each sample.

## Loss on ignition

By sampling every 2 cm, we were able to investigate the development history of the peat bog and its environment, which enabled us to infer decadal breakdown and fluctuations in the sedimentological cycles.

On the average there is 86% organic matter, 13% non-organic matter and 1% carbonate content in the sequence. It consists mainly of sphagnum peat moss, with non-organic clayey silt in washed sediments (Fig. 4 and Table 1). Changes in the percentage of organic matter – non-organic matter content showed a different tendency in the profile (Fig. 5). At the same time, the increase in carbonate content is always related to the growth of non-organic matter. Thus, the change in the content of organic matter and the ratio of carbonate + non-organic matter is in contradiction (Fig. 5). The connection between the carbonate content and non-organic matter content is not accidental, as the Băgău Hills, such as the Bottomless Lake and the valley sides surrounding the mire, are made up of Miocene marls and clayey and silty inland sea sediments (Stefanescu *et al.*, 2006).

## ZONES

The sequence is built upon a re-deposited base rock and is followed by sphagnum peat and inorganic sediment depositions (Table 1). That is why we based our zoning on the deposition type changes. Every zone starts with inorganic sediment deposition and they end up with sphagnum peat formation.

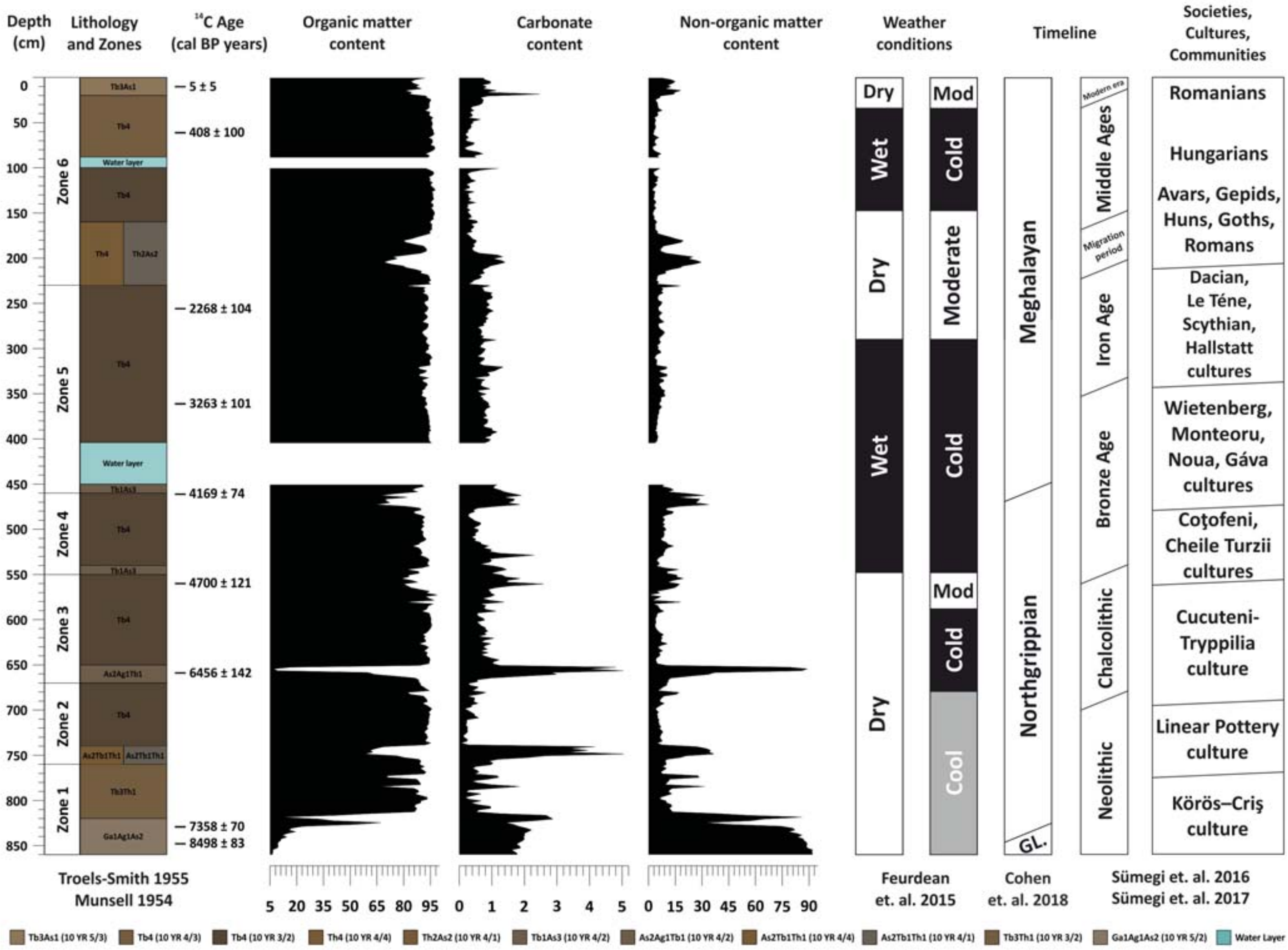


**Fig. 5.** The undisturbed core sequence of the Bottomless Lake with Troels-Smith (1955) sediment categories, Munsell (1954) soil colours, calibrated radiocarbon data, changes in organic, carbonate and non-organic matter content, Transylvanian holocene paleoclimatological data (Feurdean *et al.,* 2015), chronostratigraphical data (Cohen *et al*., 2018), archeostratigraphic data and cultures, cultural groups, communities (Sümegi *et al*., 2016, 2017).

### Zone 1 (860–760 cm)

The formation of the bog started about 8,500 cal yrs BP (6,500 yrs BC) years ago and first gyttja formed (Parris, 2001), which is a lacustrine mud containing abundant organic material, followed by peat from 8,000 cal yrs BP years. Starting from 860 cm (92%), the non-organic content gradually decreases and suddenly drops to 35% between 830–820 cm.

At the beginning of the formation of the peat, traces of slightly fossilized, but not burnt tree trunk remains were found in a so-called degradofuzinite state (Szőőr, 2000) mixed with bedrock sediment. It is likely that soil mixed with bedrock sediment slipped down on the slope bringing vegetation to the catchment basin. The sloping processes mixed the sediment with the vegetation from the former slopes, hillsides and valley sides. At that time, the peat sequence we examined did not developed yet. It is likely that about 8,500–9,000 cal yrs BP slope processes were able to close the examined valley and the valley lost its runoff.

### Zone 2 (760–670 cm)

The first remarkable washed in deposition developed during the Middle Neolithic period, during the establishment of the Linear Pottery Culture about 7,000 cal yrs BP (5,000 yrs BC). Based on the data so far, settlements and human productions had a significant effect in Transylvania's forested areas at this archaeological level at the time of the establishment of this culture. From the erosion level of the Middle Neolithic, a peat layer and an organic matter content were completely regenerated, and a powerful peat-moss layer developed until the end of the Neolithic that is the beginning of the Copper Age.

### Zone 3 (670–550 cm)

At the end of the Transylvanian Neolithic, at the beginning of the Copper Age, between 670–650 cm (6,500–6,400 cal yrs BP or 4,500–4,400 yrs BC), in the horizon of the Cucuten Culture an extremely powerful erosion developed.

**Fig. 6.** At the end of the Neolithic, at the beginning of the Copper Age, during the settling of the Cucuteni-Tripolye cultures the peat formation stopped because of the increased erosion and clayey silty sediment got deposited (640–660 cm).

The effects of human production and farming were so strong at this level that peat formation was completely interrupted and a sedimentary layer rich in silt and clay formed (Fig. 6). Thereafter, peat and peat layer were completely regenerated and the organic matter content of the layer exceeded 90%.

### Zone 4 (550–460 cm)

At the end of the Copper Age, during the establishment of the Tripolye Culture and because of production and environmental changing activity, there was another erosion level around 550–540 cm (4,500–4,700 cal yrs BP or 2,500–2,700 yrs BC), although the human impact was much smaller than commonly during the Copper Age. Thereafter, the peat formation started again, the peat regenerated and a layer of peat containing more than 90% of organic matter developed again.

### Zone 5 (460–230 cm)

There is an erosion level at 460–450 cm, which can be dated at the beginning of the Middle Bronze Age, between 4,100–4,200 cal yrs BP (2,100–2,200 yrs BC), at the time of the establishment of the Coţofen and Wietenberg cultures. For this period, we must mention the 4.2 ka BP aridification event, which is the beginning of the Meghalayan Stage in the Holocene (Cohen *et al.*, 2013). Researches suppose that this event played a significant role in the decline of several Neolithic communities, such as the Mesopotamian Akaddian Empire, the Liangzhu culture and the cultures nearby the Yangtze River, as well as the Indus Valley Civilisation (Li *et al.*, 2018; Gibbons, 1993; Staubwasser *et al.*, 2003). However, evidence of the European (UK, Ireland) 4.2 kyr event is ambiguous, suggesting that the origin and impact of the event are spatially complex (Roland *et al.,* 2014).

After the erosion, the peat layer did not regenerate, but during cool and wet climatic conditions the lake extended in the middle of the bog forming a water layer (450–405 cm). The formation of the peat started again with a considerable time and phase delay. It is likely that first a floating mat or floating island formed on the surface of the lake (Balogh, 2000a, b, 2001) at the end of the Middle Bronze Age. Until the end of the Iron Age, a peat moss layer with organic matter content of over 90% was formed with minimal inorganic material and carbonate content. According to our environmental history data based on our results and analyses, from the end of the Middle Bronze Age to the end of the Iron Age and beginning of the Migration Period, no major erosions were present and there was only a slight fluctuation in the data. This means no anthropogenic impact in the immediate vicinity of the Bottomless Lake peat bog at this time, which resulted a continuous accumulation.

### Zone 6 (230–0 cm)

During the rule of the Roman Empire and during the Migration Period, a double peak of erosion and consequently, a double peak of carbonate and non-organic matter developed in the peat layer (197–213 and 177–185 cm). It is likely that the migration and the establishment of Roman and Gothic settlements and their constructing and producing activity formed this double, human-related erosion and non-organic matter accumulation peak.

During the Middle Ages, there could have been a significant human impact in the area. At the end of the rule of the Árpád dynasty, the lake environment extended, and the formation of peat was interrupted again. At 100–88 cm depth we have set up two possible scenarios. The first is the same that happened in the Bronze Age. The second is that nearby cultures intervened and formed an artificial lake for fishing or other purposes. Either way, the peat accumulation commenced by developing a new floating mat on the lake surface. The formation of the peat layer was interrupted last in the modern era resulting from human impact and increased participation of silty clayey carbonate rich sediments derived from bedrock and soil.

Meanwhile it was possible to alter the environment. According to our data, the settled Hungarians and the Medieval settlement network did not directly touch the valley and hills surrounding the peat bog. This is also supported by the Medieval written source as the settlements were in the Küküllő and Maros river valleys surrounding the hills of Băgău. It also includes the village of Magyarbagó, called Bogo in the Medieval era, which was first mentioned in 1291, after the Mongol invasion of Europe, just before the end of the Árpád dynasty, mentioning that its original name was Perech in the Kingdom of Hungary (Léstyán, 2000).

## DISCUSSION

The sedimentation rate, on one hand, shows a correlation with the biogenous accumulation of the bog, and the biogenous accumulation with the climate, above all the local humidity. However, on the other hand, the formation and development of the peat bog is fully in line with the emergence and development of farming in Transylvania. Transylvanian farming started in the early Neolithic between 8,000–8,500 cal yrs BP (6000–6500 BC) with the Criș culture (Banner, 1937; Kutzián, 1944; Trogmayer, 1966; Kalicz, 1970; Raczky, 1976).

Thus, the accumulation in the peat bog depends on climatic and anthropogenic effects, above all on the disruption of the forest vegetation that substantially influences humidity, along with sediments entering the catchment basin, furthermore the interruption of biogenous accumulation. The technical standards of different cultures, number of communities, distance from their settlements and the technical and social solutions related to the forest affect development of the peat bog.

It was clear that the last 4,500 cal yrs BP had steady, high precipitation and relatively lower temperature, which resulted in constant high humidity. Under these climatic conditions and based on the sedimentation rate in the last 4,500 years, the bog could have been heavily biogenous, above all, sphagnum-like peat formation, with low or even no anthropogenic interventions (Fig. 3). Due to the climatic conditions of the peat bog, we can assume that vegetation periods were extremely humid, cool and rainy.

The peat and moss accumulation has been regressed and the organic matter content has been decreased due to intense erosive events when sediments were washed into the catchment basin or onto the surface of the mire. These sediments originate from erosion of the bedrock or parent material. The dynamics of erosion are controlled by climatic changes, anthropogenic effects and natural events (fires and storms destroying the forests surrounding the mire) (Longman *et al*., 2017). However, apart from the Holocene environmental-climatic conditions (Feurdean *et al*., 2015), and apart from the extraordinary events (lightning caused by forest fires, forest destruction caused by a storm), such a dry and hot climate did not develop in the examined region, which could dry out the trees on the north-facing hillside in the valley and replace it with herbaceous steppe-forest steppe vegetation.

Therefore, we assume that increased erosion could be caused by human activity: deforestation, farming, woodcutting, pasturage, husbandry, field cultivation, settlements, building and road construction (Longman *et al*., 2017). These erosion effects could be intensified, especially during rainy periods and combination of these two effects could slowdown a peat formation and decreased organic matter content (Fig. 5). That is why we compared the sedimentological parameters, organic matter, carbonate and non-organic matter content changes with the Transylvanian archaeostratigraphical levels described in literature and with the establishment of different cultures and cultural groups of different human communities (Sümegi *et al*., 2015, 2016, 2017). As a result, we linked the anthropogenic effects associated with individual human communities and archaeological periods and the development of erosion levels (Sümegi, 1998; Willis *et al*., 1998). It is clear, that the decrease of the effect of human production and the resulting erosion is indicated by the undisturbed peat formation, the increase in organic matter content and the 94% and above organic matter content ratios (Fig. 5).

In addition, it is significant that the peat formation of the bog has been interrupted twice when cold and wet climatic conditions were combined, and water layers were formed. At 450–405 cm depth (Fig. 5) these conditions of the Bronze Age were accompanied by lower temperature combined with lower evaporation and higher precipitation, leading to expansion of the lake in the middle of the bog. Due to this expansion the bog surface was covered by water causing interruption in the peat growth. A formation of peat continued by creating a floating mat on the water surface.

During the Middle Ages, at the end of the Árpád dynasty, at 100–90 cm depth we have set up two possible scenarios. The first is the same that happened in the Bronze Age: the lake extended and the peat formation commenced on top of the lake surface. The second is that nearby cultures intervened and formed an artificial lake for fishing or other purposes.

Based on the changes in carbonate, organic matter and non-organic matter content, we have been able to distinguish these segments that are characterized by the intensification of the anthropogenic effects.

## CONCLUSIONS

The accumulation in the peat bog depends both on climatic effects and on human activity in the vicinity, especially in the forest vegetation cover, which essentially influences the humidity. It also depends on the amount and type of biogenous matters and different sediments entering the catchment basin. The sedimentation rate shows a correlation with the biogenous accumulation of the peat bog. The biogenous accumulation correlates with the climatic conditions, above all with the local humidity. In addition, the formation and development of the peat sequence fully coincide with the formation and development of farming and production in Transylvania.

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