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# ORIGIN AND EVOLUTION OF A PEAT BOG FROM NORTHEASTERN ROMANIA

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**Abstract**: Peatlands are highly sensitive ecosystems that respond to hydrological, climatic, and geomorphological changes. In this study, we investigate the origin and historical evolution of a peatland located in Northeastern Romania, on the Suceava plateau. Our approach includes the analysis of historical maps and physical characteristics of both the peat (grain size, LOI - loss on ignition) and water (pH, dissolved oxygen, electrical conductivity). Our findings suggest that the development of this peatland has been more prominent along the surface than the depth. The presence of gravel and sand at the base of the peat deposit, along with surface morphological evidence, supports the hypothesis that this peatland originated in an ancient paleomeander. pH analysis indicates that the peatland is mesotrophic, while granulometric and LOI analyses suggest a fluviogenic origin.The significant changes observed in the sedimentary structure of the peatland may be attributed to climate

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change, with potential anthropogenic influences over the past 50 years. Furthermore, our study contributes valuable insights to geomorphological research in the Suceava valley, revealing visible changes spanning the last 250 years.

**Key words**: peatland, lithostratigraphy, grain-size, LOI, Suceava Plateau, Northeastern Romania

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## INTRODUCTION

Peatlands serve as valuable archives of paleoenvironmental and paleoclimatic data, as they are highly sensitive ecosystems (Bragg & Tallis, 2001) influenced by hydrological, ecological, and geomorphological conditions (Evans & Warburton, 2007). Although they do not cover extensive surface areas, peatlands play a significant role in controlling $CO_2$ levels and thereby have a major impact on climate changes over time. As climate change becomes increasingly acute, there is a growing interest in the study of peatlands.

Due to their high organic matter content (comprising 20-30% of the total), which can exist in the form of decomposed or decomposing organic material (Myślińska, 2003), peat deposits provide valuable insights into past climates and environments. The formation of peat deposits is primarily influenced by hydrological, geomorphological, and ecological conditions (Evans, 2013). These three natural factors are critical in determining the size and typology of peatlands. In addition to these natural factors, anthropogenic influences have a negative impact.

The present study was triggered by the anthropogenic factor, specifically fire, particularly the burning of the marshland area in 2014. The prolonged duration of the fire, characterized as a smoldering soil burn, the persistent coal-like smell that lingered for three months, and the brownish-red remnants left from the burning, prompted a more detailed investigation of this area. In subsequent field investigations conducted in 2015, numerous snail shells were discovered, confirming the presence of a wetland area once. Additionally, a series of coring, each reaching a depth of 2 meters and located 200 meters away, were drilled in August 2016 in the immediate vicinity of the previously burned area. These boreholes intercepted various layers of snail shells at different depths, suggesting fluctuations in moisture levels over time.

The aim of this study is to identify the typology of the peatland in Părhăuți, as well as the factors contributing to the genesis, origin, and evolution of the peatland over time. The present study immediately draws attention, through its initial field investigations, to its significance within the context of recent climate fluctuations and their implicit impacts on the surrounding environment.

## STUDY AREA

The Părhăuți peatland is situated in the Suceava Plateau at ~ 300 m altitude, in northeastern Romania. Geomorphologically, it lies at the contact of the T 8-10m and T 10-12m terraces in the central section of the Suceava River (Figure 1). Administratively, this peatland falls within the boundaries of Părhăuți village, Todirești commune, Suceava county, spanning multiple parcels of privately-owned agricultural land. The area of the peat is 2.42 ha. The region's lithology predominantly comprises sedimentary rocks, including gravel, sands, and clayey marls. Detailed analysis of Quaternary deposits, especially the terrace deposits, has provided valuable insights into the lithological structure that facilitated the formation of the peat deposit in the territory of Todirești commune (refer to Figure 2).

Sediment core F1 reveals a gradual and slow transition into the T10 terrace deposits, featuring fine sedimentary deposits at the upper portion (sand and clay) and coarser deposits towards the base of the borehole (coarse sand and gravel). The climate in the area is temperate continental with Baltic influences, characterized by severe, cold winters and warm, dry summers. The average annual temperature stands at 8°C, with January recording a minimum of -6°C and a maximum of 18°C. The region receives annual precipitation of 565 mm/year (as reported by the Suceava Meteorological Station).

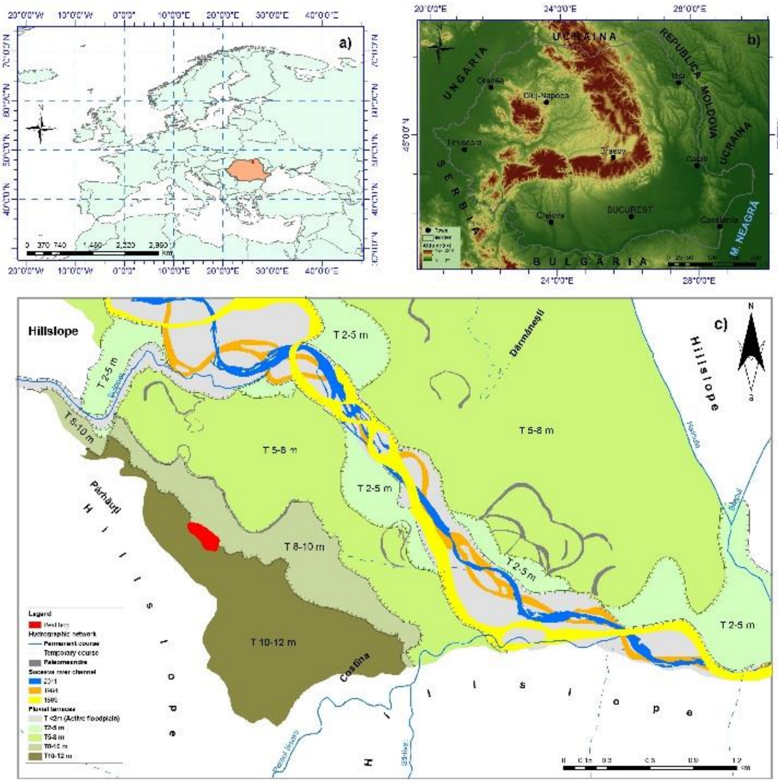


**Figure 1.** Location of the study site (red dot) in: a) Europe and b) Romania. The geomorphological map (c) show the position of the study area in relation to the Suceava and Solonet rivers. Fluvial terraces are labelled with "T" and their corresponding height range.

Groundwater plays a significant role in the formation of peat areas, alongside atmospheric precipitation, nurturing their development. In the study area, based on sediment cores, local wells, and existing drainage systems, it was determined that groundwater is typically found at depths ranging from 1.5 to 3 meters.

Visual and cartographic analysis places the study area within a zone characterized by marsh vegetation typical of wetlands, despite significant transformation into agricultural land due to surface drainages and underground artificial drainage systems. Consequently, on the relatively limited surface where the peatland has developed, hygrophilic species are found including: *Carex riparia*, *C. vulpina*, *Juncus effusus*, *Scirpus silvaticus*, *S. lacustris*, *Bolboschoenus maritimus*, *Phragmites communis*, *Typha latifolia*, *T. Angustifolia*, *Salix alba*, *Populus alba* and *Salix triandra*.

## METHODS

The identification of the study site became possible following a wildfire incident in the winter of 2013, which resulted in a smoldering surface and ground burn. This smoldering fire persisted for approximately four months before being extinguished, primarily through human intervention aimed at preventing its spread towards nearby populated areas. The scarcity of references to peatlands in the Suceava plateau (Olaru, 1965) area prompted the examination of various cartographic materials, including the first Austro-Hungarian military topographical survey dating back to 1765 and the second Austro-Hungarian military topographical survey from 1860. These historical maps were used to identify past land use patterns.

The main drilling activities were conducted in the immediate vicinity of the area affected by the fire in April, specifically on the 10m terrace adjacent to the Suceava River. During these drilling operations, it was confirmed that the extracted sediments were indeed peat. In the subsequent field campaign, a total of 21 cores were extracted using Edelman coring equipment, with coring points following a grid-type system at distances of approximately 40-50 meters apart. Geographical coordinates for these coring points were recorded using a Garmin GPS device. Following extraction, the cores were placed in PVC tubes, wrapped with polyethylene film, and stored at a temperature of 4°C until further analysis.

Additionally, for core number 17, a series of parameters related to water quality (pH, dissolved oxygen, electrical conductivity) were analysed using a multiparameter HQ40d Portable. These measurements were essential for characterizing the type of peat present in the core. A lithostratigraphic description of all cores was conducted based on sediment color and texture. Grain size analysis and the determination of organic and inorganic carbon content (loss on ignition; LOI) were carried out specifically for core F1 and F2 to provide a clearer understanding of the structure between the peat deposit and the underlying deposits on which this peat developed. For grain size analysis we used the protocol by Rădoane (Rădoane, Ichim, Rădoane, Dumitrecsu, & Ursu, 1996) and for LOI we applied the methodology by Heiri, (Heiri, Lotter, & Lemcke, 2001).

## RESULTS AND DISCUSSIONS

### STUDY AREA DELIMITATION AND CHARACTERISTICS

The delineation of the study area was conducted using a grid-based method, with borehole F1 located in the vicinity of the burned area serving as a starting point (Figure 2).

To define the study area, a total of 22 boreholes were drilled, each with dimensions ranging from 150 to 350 cm (Figure 2). The primary objectives of these boreholes were to outline the peat deposit, investigate its origin and evolution, and determine its thickness and maximum depth. Consequently, we identified the presence of peat starting from a depth of 25 cm in select cores (F2, F6, F21, and F22), with depths reaching 107-121 cm in boreholes F18 and F14 in the northern and northeastern areas, respectively. The deepest point at which peat was identified lies on the edge of the T 10m terrace, at a depth of 338 cm, where the peat layer also reached its maximum thickness of 290 cm.

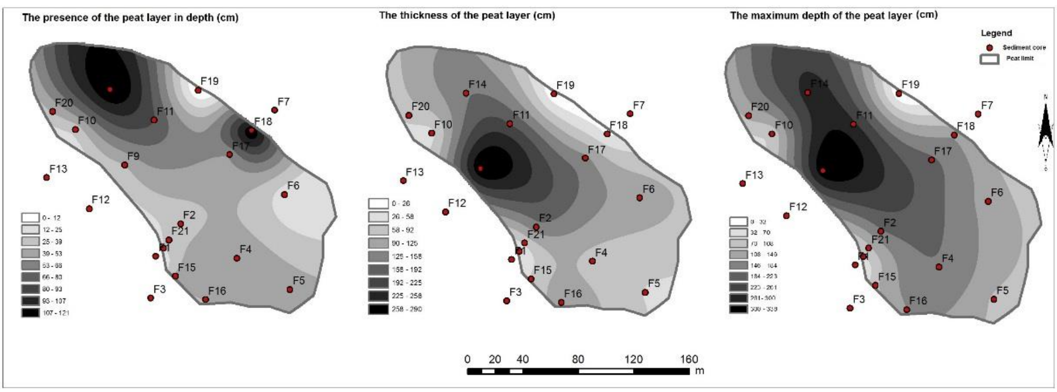


**Figure 2.** a) Presence, b) thickness and c) maximum depth of the peat layer

As depicted in Figure 2, the peat deposit exhibits its greatest thickness at the forefront of the terrace, as indicated by a concave interpolation. This leads us to speculate about the potential for its expansion, especially in areas where alterations in the hydrographic network may have occurred.

## ORIGIN AND EVOLUTION OF THE PEATLAND

To investigate the origin and evolution of the peatland, we established two longitudinal sections and two transverse sections. Out of the total of 22 boreholes, six of them were positioned in approximately parallel alignment along the contour line at 300 meters. These boreholes were arranged in a southeast to northwest direction at varying intervals.

The boreholes labeled F5, F4, F2, F9, F10, and F20 contributed to the creation of longitudinal profile A (Figure 3), which provides the most comprehensive and complex insights into the development of the peat deposit in the longitudinal direction. Along this southeast to northwest longitudinal section, we observed a sequence of peat layers with varying thicknesses developed in a continuous alignment. According to longitudinal profile A, , the peat layer exhibits progressive growth from the southeast to the northwest until reaching borehole F9, where it attains a thickness of 290 cm (the maximum inflection recorded). Subsequently, there is a significant reduction in peat thickness (F10, with a 50 cm peat layer), followed by a slight increase in the last borehole (85 cm of peat). The soil layer covering the peat also varies in thickness along the same longitudinal profile, with the southeastern part being thicker and relatively compacted, while in the northwest part, the soil layer thins, becoming less compact, and the soil-peat mixture becomes visible (refer to Figure 3). Below the peat layer, the transition predominantly leads to gray clay, which, with increasing depth, shifts into sandy clay, clayey sand, and further below, these sands with varying grain sizes merge with fine gravel. There are exceptions where the transition from peat directly to sand (with minimal clay content) occurs, along with coarse sand, and at the base of some boreholes, sand mixes with gravel (such as F2 and F20). Approximately 40 meters to the north, while maintaining the same alignment, four boreholes are unevenly spaced.

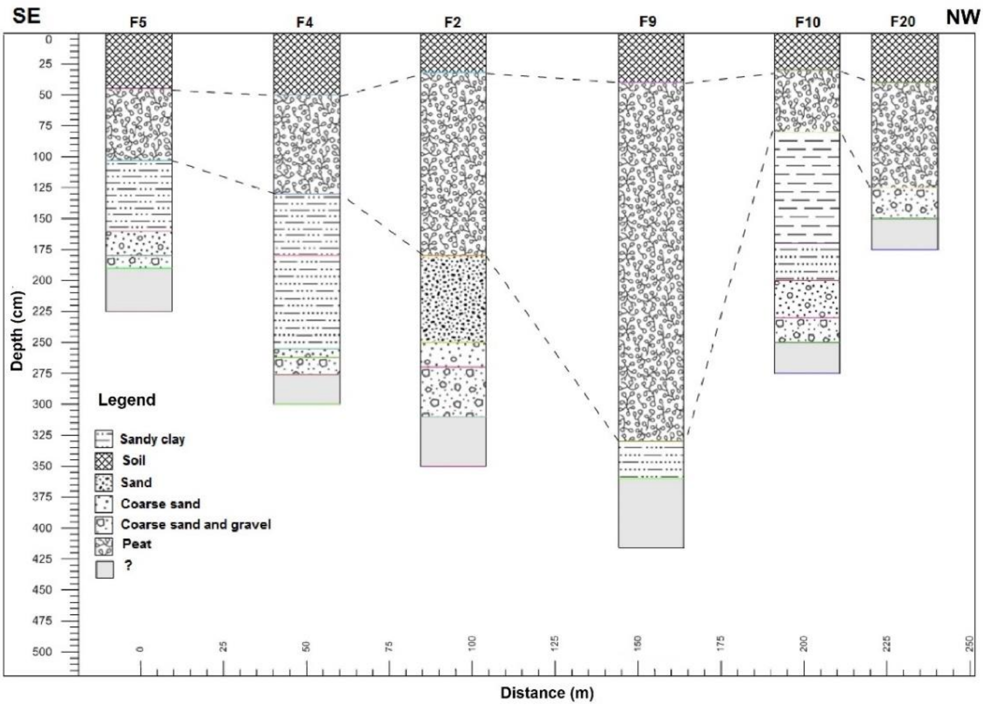


**Figure 3.** Longitudinal profile A in the SE – NW direction

Longitudinal profile B, which runs parallel to the direction of the first profile, provides additional insights into the peat layer's distribution. This profile reveals that the peat layer descends from the southeast (starting at F6 with a depth of 20 cm of peat) towards the northwest. In core F14, the peat layer is encountered at a depth of 120 cm beneath a layer of clay. The relatively consistent thickness of the peat layer, its depth orientation, and the presence of clay above the peat in borehole F14 suggest that the development of the peat deposit likely occurred from northwest to southeast, with subsequent coverage by clay.

From core F1, a series of six cores were drilled in the southwest to northeast direction, intersecting perpendicularly with the 300-meter contour line. This arrangement creates a transverse profile referred to as profile C (as shown in Figure 4.5). Transverse profile C spans a length of 95 meters, cutting across the front and a portion of the ridge of the T 10-12m terrace. This profile aids in delineating the positioning of sedimentary layers in which the peatland developed. Based on the data collected, it becomes evident that the peat deposit extends between boreholes F18 to F22, with the maximum thickness observed in core F2, which is located right on the edge of the T 10-12m terrace. At the base of the front of this terrace, peat was identified at a slightly greater depth (approximately 50 cm), with a development depth similar to that of the borehole positioned on the edge of the terrace. Notably, there is a significant change in peat layer thickness between cores F17 and F18, and the presence of sandy clay below the soil layer (which exhibits its maximum thickness in this section) raises the possibility of deposition-related changes. Additionally, the transition between terraces can be discerned by examining the arrangement of layers in a northwest-southeast direction, perpendicular to the front of the terrace.

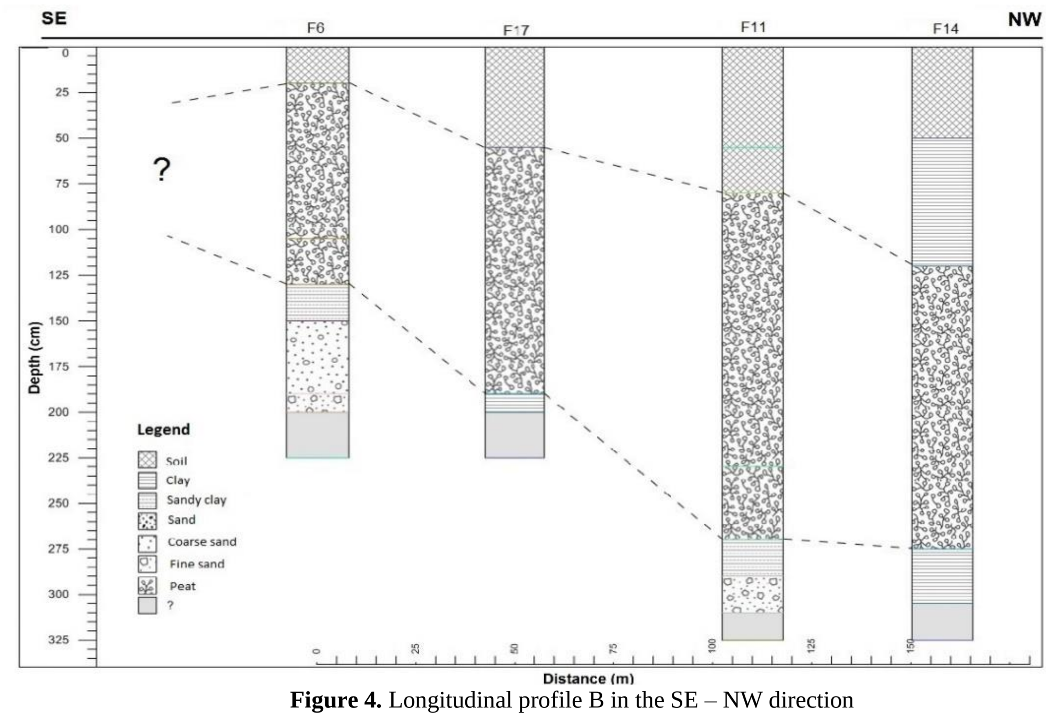


**Figure 4.** Longitudinal profile B in the SE – NW direction

Transverse profile D runs in a southwest to northeast direction, situated approximately 60 meters north of transverse profile C (as shown in Figure 5). This profile comprises four boreholes: F9, F11, F12, and F19. Much like transverse profile C (depicted in Figure 5), transverse profile D (illustrated in Figure 6) exhibits similar characteristics and a roughly equivalent layer arrangement. Specifically, boreholes F9 and F11 mirror the arrangement observed in boreholes F2 and F17. This observation suggests that the deposition of sediment began in the central portion, or the front of the terrace, and proceeded upward (toward the ridge of the terrace). Subsequently, due to erosion or drag processes, sediment was transported towards the T 8-10m and T 10-12m terraces.

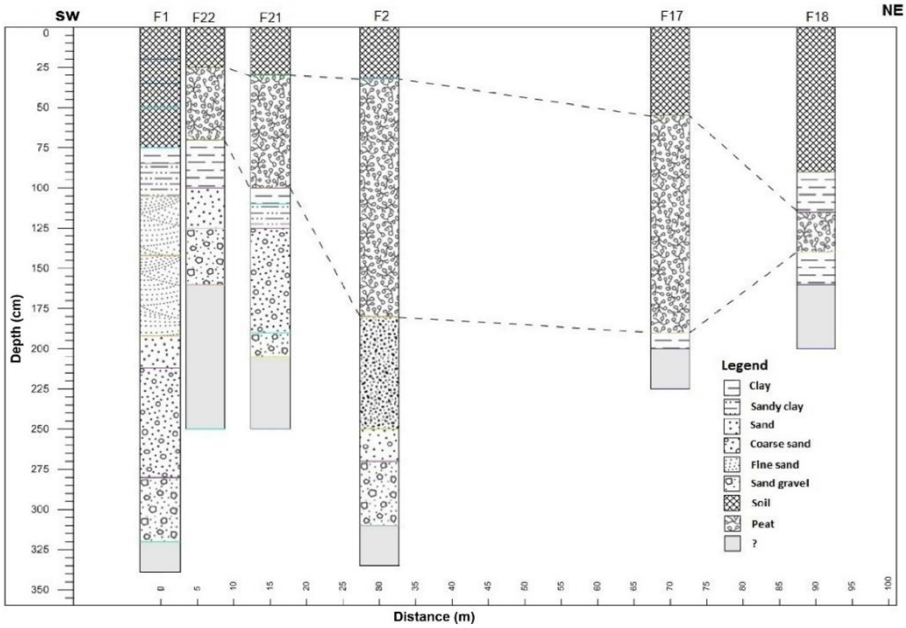


**Figure 5**. Transverse profile C in the SW – NE direction

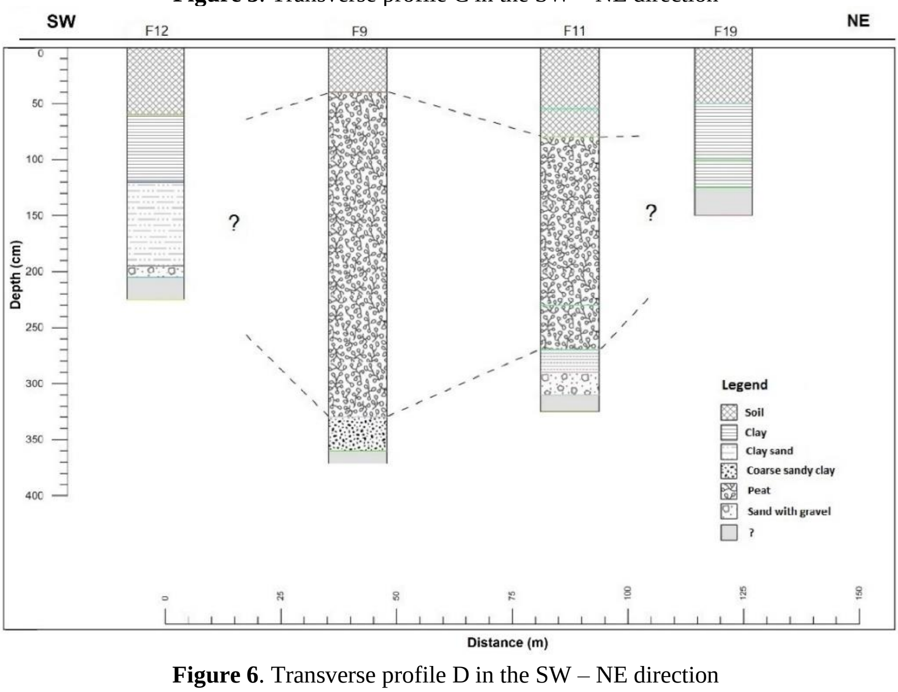


**Figure 6**. Transverse profile D in the SW – NE direction

## GRAIN SIZE AND LOI ANALYSIS

In order to obtain a clearer picture of the structural differences between the peat deposit and the sediments t on which this peat was developed, we analyzed two physical indicators, namely grain size and the analysis of the organic matter and carbonates content (LOI - loss by combustion method).

These parameters were analyzed based on the F1 borehole - necessary for the description of the sedimentary structure of the T 8-10m and the F2 borehole - for the peat deposit. For the present study we chose to correlate the median particle size (D50, the particle diameter at which 50% of the material is coarser, and 50% is finer) with the parameters analyzed through the LOI method.

In the case of the D50 (phi units), a relatively uniform distribution is observed in the first 2/3 of the F1 borehole and a sudden increase towards its base, where we identified the fine gravel (Figure 7). D50 values of the peat are lower, due to the much finer material of its composition, with higher values at the top of the profile and lower values at the bottom of the profile.

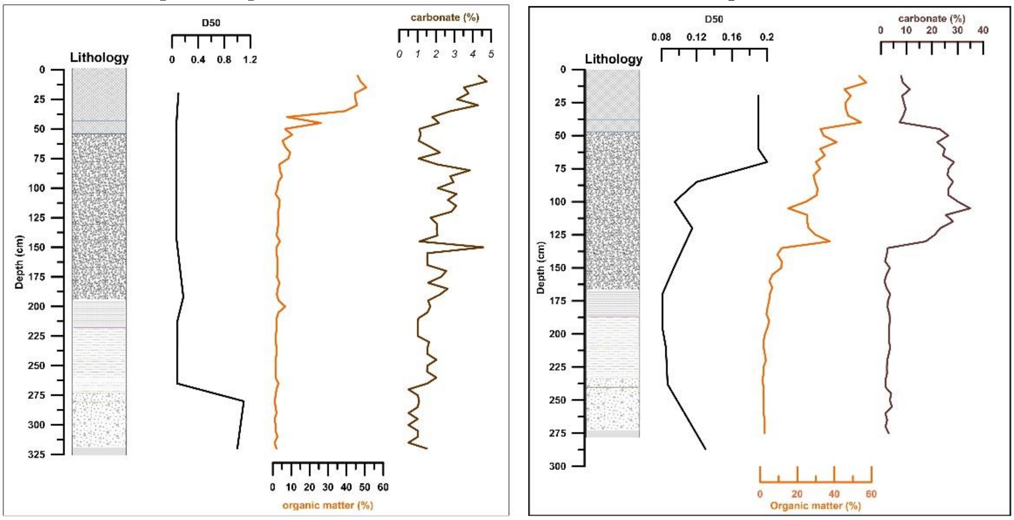


**Figure 7.** Particle size analysis and content of carbonate and organic matter in the borehole F1 (left) and F2 (right)

The results obtained by LOI method indicate the larges variation of carbonates in the sedimentary material extracted from F1, compared to the material from F2 (Figure 7), where a maximum of them is observed in the peat deposit, where the material is not very compacted (Figure 7). A much greater loss of carbonates is also observed in F2, compared to F1, which suggests that the accumulation of carbonates is much greater in the peat deposit than in the detrital sedimentary deposits stored in the T10-12 m.

## ORIGIN AND EVOLUTION OF THE PEAT

The formation of peat deposits is the result of a complex interplay of physical, chemical, and biological processes, all of which contribute to the distinct characteristics of such deposits.

These characteristics are reflected in the sedimentary layers, with the principle of superposition of layers being a fundamental concept in understanding their formation. This principle, first articulated by Nicholas Steno in 1669 (MacLeod, 2005), dictates that the lowermost layer is the oldest, while the topmost layer is the most recently accumulated, making it the youngest in terms of formation.

Over the past two decades, research has shed light on the significance of peat deposits as valuable environmental archives, offering the opportunity to reconstruct past climates and environments. Currently, peat bogs in the mountainous regions of Romania have been the focus of extensive study, with the most renowned archives located in the Eastern Carpathians. Notable examples include Tăul Mare Bardău (Fărcaş, Tanţău, Mîndrescu, & Hurdu, 2013) (Cristea, et al., 2014) and Cristina in the Maramureș Mountains, both of glacial origin and characterized as oligotrophic. Other significant peatlands in the region include those in the Rodna Mountains, such as Poiana Ştiol (Tanţău & Fărcaş, 2004) and Gărgălău (Tanţău, Geantă, Feurdean, & Tămaş, 2014).

Additionally, there are peatlands in the Moldo-Transylvanian Carpathians, including the Mohoş peat bog (Tanțău, et al., 2003) and Luci (Tanţău, Feurdean, De Beaulieu, Reille, & Fărcaş, 2014a), as well as in the Apuseni Mountains, such as Padiș, Molhaşul Mare, Călineasa, Ic Ponor, and Pietrele Onachii (Feurdean & Willis, 2009) and Meridionali Carpathians (Longman, et al., 2021), among others. While in most cases in Romania, peat deposits are of an oligotrophic nature, with origins related to glacial, limnological, or ombrogenous processes, in the case of the Părhăuți peatland, it has a fluvial origin. This hypothesis is based on the identification of detrital sedimentary rocks - sand and fine gravel in all 20 boreholes within the peatland area, which have been directly related to cartographic materials from the past three centuries. The analysis of the transverse profile along the Suceava Valley, the location of the peatland on the front and ridge of the T 8-10 m terrace, and the immediate part of the T 10-12 m terrace (Figure 5), the identification of a watercourse called Solonica B (Figure 8 – Phase I), and the possibility of the existence of an ancient paleo-meander (Figure 8) where water stagnated for an extended period can explain the formation of the peat deposit in this area. Furthermore, old cartographic materials highlight a marshy area that favoured the development of this peat deposit.

The development and expansion of the peat deposit (Figure 8) are represented by a model adapted and modified after (Łajczak, 2013) and are based on three distinct stages:

I. The first stage or Phase III (Figure 8) in which the accumulation of the peat deposit occurs from the paleo-meander, located on the T 8-10 m terrace towards the front of the T 10-12 m terrace, with a more pronounced development along the x-axis and less along the y-axis.

II. The second stage or Phase IV (Figure 8 shows that the peat deposit expands along both axes, reaching an equilibrium. This lengthwise expansion may be due to surface water runoff in the opposite direction of the maximum peat deposit development, a process that can lead to deposition by drag. During this stage, it can be assumed that the material was deposited in an anaerobic environment, due to the existence of a marsh developed on the former paleo-meander. This is explained by the presence of the peat deposit starting from a depth of 107-121 cm and with reduced thickness (0-25 cm) in the eastern part of the peat deposit, observations indicated by the stratigraphy of boreholes F18 and F19.

III. The third stage or Phase V (Figure 8) represents the final deposition phase in which accumulation has reached its maximum extent. This maximum expansion of the peatland may be attributed to hydrological modifications, as these deposits are directly linked to the atmosphere (Chamber, Daniell, & Members, 2010), and its formation is based on climatic, hydrological, geological, geomorphological conditions (Charman, 2002) that give it a specific, unique character.

To establish the typology of the Părhăuți peatland, consideration was given to its physical and chemical properties: temperature, color, structure, pH, salinity, and organic matter content (Table 1).

**Tabel 1**. Physico-chemical properties of the peat from Părhăuți (sediment core F15)

| Water T(˚C) | pH (units) | NaCl (mS/cm) | Dissolved oxygen(mg/l) | Color | Structure |
|---|---|---|---|---|---|
| 15.4 | 8.16 | 2.25 | 2.01 | brown -black | fibrous-grassy |

From a geological perspective (Giulescu, 1996), peat deposits can be classified as reserves when their thickness exceeds 30 or 50 cm.

Considering the pH measurement result, with a value of 8.16 in borehole F15 (Table 1), we can categorize the peatland as mesotrophic, referred to as 'transitional marshes,' which still have nutrient salts with a mitigating acidic reaction. Due to the lack of age determinations for the deposit, a direct correlation with recent climate changes cannot be established. The only information that can provide a chronological context are the radiocarbon ages of elm tree trunks from the minor bed of the Suceava River, which are approximately 6300 years BP in Ițcani and 3600 years BP in Milișăuți (Kern & Popa, 2016). In addition to these determinations, we can also consider the ages of oak tree trunks from the Siret River, located on the T 5-7 m terrace, which are 5300 years BP old (Rădoane, et al., 2015), as well as those from the Moldova River, situated on the T 1-2 m terrace with an age of approximately 3000 years BP (Chiriloaei, Rădoane, Perşoiu, & Popa, 2012). Taking into account the ages of tree determinations found in sedimentary material related to the T 5-7 m terrace of the Siret River (5300 years BP), it can be estimated that the age of the T 10-12 m terrace of the Suceava River is much older, possibly exceeding 6300 years BP, as indicated by the study by (Kern & Popa, 2016).

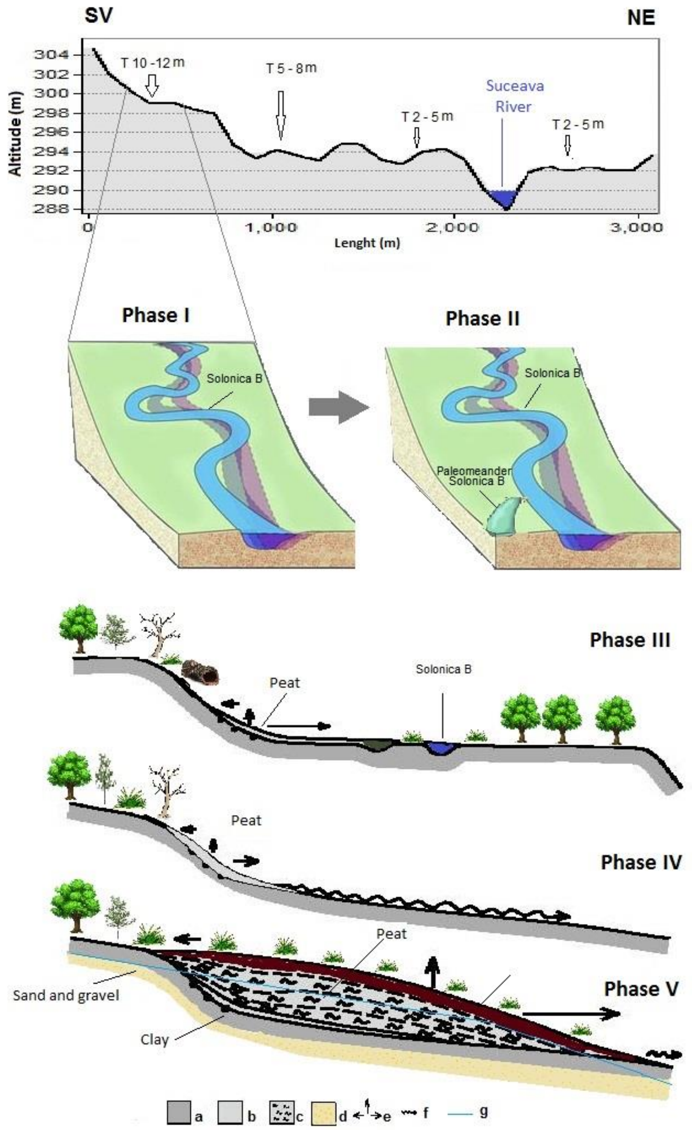


**Figure 8.** The development model of the Părhăuți peatland, in which is represented: a) the cross-sectional profile of the Suceava valley in the right of the peatland; b) the evolution of the hydrographic network – Phase I and Phase II and c) the peatland development scheme – Phases III, IV, V. (after Łajczak, 2013, with modifications) The legend signifies the following elements: a – the clay layer; b – the first layer of peat; c – the peat deposit; d – the layer of sand and gravel; e – the development direction of the peat deposit; f-surface water runoff; g-ground water level.

The evolution of the Părhăuți peatland is based on four sets of topographic maps and a satellite image (Figure 9), from which the following changes in land use within the peatland's vicinity were identified:

i) A marshland area in the period 1773-1776 (Figure 9a), with the possibility of the peatland expanding into a marshy environment, reflected by the abundance of palustrine plant remains, especially roots, in most of the boreholes where the peat layer was identified.

ii) The mid-19th century witnessed a significant change in vegetation attributed to hydrological and climatic modifications. During this period, the peatland transitioned from a marsh to an area with softwood vegetation, typical of high-moisture terrains. In this period, the existence of a Soloneț River branch, called Solonica B, can also be observed, which may have served as drainage for the marshy area noted in the 18th century.

iii) The transformation of the studied area into agricultural land in the 20th and 21st centuries is evident on the topographic map from 1984 and the satellite image from 2023. Therefore, all these changes over the past three centuries are attributed to human activities, particularly those related to land reclamation and drainage for the expansion of arable land (Bădăluţă, Bistricean, & Nagavciuc, 2013), with less influence from external forces (climatic, hydrological, or tectonic).

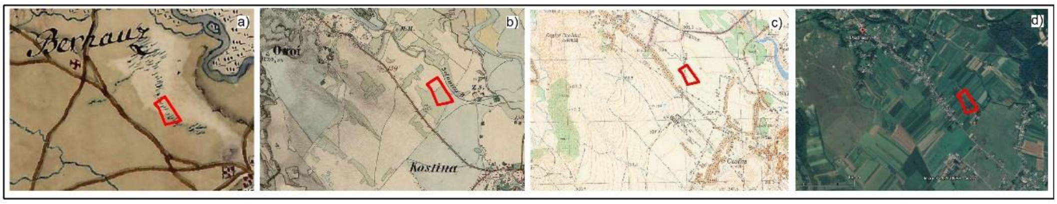


**Figure 9.** Evolution of peatland based on: a) First Military Survey Map of the Habsburg Empire (conducted between 1773 and 1776), b) First Military Survey Map of the Habsburg Empire (conducted between 1861 and 1864), c) topographic map from 1984 and d) satelite image from 2023.
(Source: for images a) and b) https://maps.arcanum.com/en , c) topographic military map, scale 1:25.000, edition 1974/'75 and d) GoogleEarth)

## CONCLUSIONS

This paper focuses on two major aspects, namely the origin and evolution of the Părhăuți peatland. Based on 22 boreholes, its dimensions, both horizontally and vertically, were determined. The data generated reveal that this peatland developed more along the x-axis than the y-axis.

Moreover, the intersection of fluvial gravel and sand at the base of the peat deposit and the morphological indications on the surface argue for the formation of this peatland in an ancient paleomeander, at the contact between the T 8-10m and T 10-12m terraces. pH analysis demonstrates that the Părhăuți peatland is of mesotrophic type, while grain size analysis and LOI analysis determine its fluviogenic origin. Regarding the evolution of the peat deposit, successive cartographic sets covering the last three centuries indicate a transition from a marshy area (1773-1776) to one with arboreal vegetation (mid-19th century), and finally, to agricultural land (20th and 21st centuries). All these changes were primarily caused by human actions, especially deforestation (after the Austro-Hungarian occupation: 1773) and area drainage (during the communist period: 1970).

This paper provides new contributions to geomorphological studies in the Suceava Valley and highlights a series of visible modifications over the past approximately 250 years.

## AUTHOR CONTRIBUTIONS

G.B. designed the study. G.B. and C.A.B. performed the fieldwork. G.B. performed the grain size and L.O.I., C.A.B. and G.B. performing the evolution model. M.M., D.I. and B.I.N. analysed evolution of the peat based on maps. C.A.B. and G.B. prepared the paper with contributions and input from all authors.

**COMPETING INTERESTS**

The authors declare that they have no conflict of interest.

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