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CONSIDERATIONS ON THE AGE OF THE "GLIMEE" IN TRANSYLVANIA

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Abstract: The paper is a synthesis of the palynological studies that have addressed the age of landslides in Transylvania. We discuss the configuration of the paleo-vegetation in the respective areas, but also the probable factors, abiotic or biotic, which promoted the landslides and the relative period when they occurred in Transylvania. The analysis indicates two major periods of onset for landslides, the Pleistocene and Holocene.

Key words: Landslides, Palynological Analyses, Pleistocene, Holocene, Paleoclimate.

Introduction

Glimee type landslides (massive, deep landslides on slopes) are specific to the Transylvanian Plain, Târnavelor Plateau, Someşan Plateau, Moldavian Plateau, Getic Plateau and in some regions of the Subcarpathians.

It is generally accepted that the development of the *glimee* was favoured by the climatic conditions of the Late Pleistocene - Early Holocene, respectively the Preboreal and Boreal ages. However, even under current climatic conditions, the periods with exceptional rainfall have shown that the landslides continue to evolve, with numerous reactivations.

The most important factors that trigger *glimee* are variations in the volume and humidity of rock masses, torrential rainfall, earthquakes, human impact – such as cutting down trees on slopes, etc. Most of them occur after prolonged wet periods (spring, autumn), torrential summer rains or after a long period of drought on highly fragmented terrain [14].

The aim of this work is to estimate the relative period when most of the *glimee* occurred in Transylvania, and to discuss their probable trigger factors and the significance of these insights in the wider context of climate change.

Among the published works that have presented palynological analysis results from the Transylvanian area we have selected those which, through their geographical location and the age of their peat deposits, provide evidence regarding landslides in Transylvania. These data were checked against other works regarding the age of landslides in the study area and some recent works discussing the *glimee* in the Moldavian Plateau.

Results and Discussions

The analyzed palynological sites are presented in Table 1, while their geographical distribution as well as the location of the most important *glimee* in the Transylvanian Depression are shown in Figure 1.

The *glimee* are very typical for the landscape of the Transylvanian Depression and play an important role in the evolution of the Transylvanian landscape by resizing the slopes [32]. Due to the extensive areas that they have affected, they are considered "catastrophic moments in the evolution of the slopes" [15]. The *glimee* evolution is influenced by slope, aspect, lithology and land use [20]. A slope affected by landslides continues to evolve by forming new landslide bodies that overlap the old ones [32].

Several studies have addressed the relative age of landslides [12, 23, 24, 35]. Surdeanu *et al.* [33] consider that the C14 dating and also the recording of large-scale movements on the slopes of the Transylvanian Plain support a new interpretation of the age established by spore-pollen analyses. If the genesis of some *glimee* is related to mass movement processes, others are generated by erosive processes. Surdeanu *et al.* [33] consider, regarding the lithological structure, that *"the presence of sands is what gives a certain direction to the evolution"*. Roșian [29], shares the opinion of Jakab [15] that it is not possible to state a general age for all *glimee*, these being triggered, both in the Pleistocene and in the Holocene, by certain favourable conditions, specific to particular moments and not periods.

Nevertheless, given the scarcity of C14 datings, palynological analyses remain a useful resource that needs to be considered in determining the age of landslides, including the *glimee*.

G. Pop [28] attributes a Subatlantic age to certain landslides in Transylvania, based on the pollen diagram from Sălicea [26], although E. Pop supported the Atlantic age of the swamp. The author concludes that the general process of landslides in Transylvania is connected to the main wet period of the Postglacial, the Subatlantic.

However, Lupșa [18] resumes and completes the palynological analysis of the mesotrophic swamp at Sălicea, published by Pop in 1932; the diagram reflects the most representative hornbeam phase from the SE Carpathian area, attesting to the relatively old, Atlantic age of the swamp. In a previous work [23] Morariu indicates a glacial age for many of the landslide's areas from Transylvania.

Also, as Morariu *et al.* [24] observe, the age of landslides is related to the processes that trigger them. They note a correlation between the area of landslides and the area occupied by Sarmatian formations, where intercalations of sands, sandstones and conglomerates are common, between layers of marl and limestone, producing the necessary conditions for large-scale landslides. Also, according to the authors, the monoclinal or slightly wrinkled structure also promotes the formation of landslides. The authors discuss the situation of landslides at Bozieș, Șaeș, Dracășviz, Movile and Sălicea, but also refer to other sites from Transylvania, and quote related studies that support the age of landslides. The five areas included in the palynological research indicate different ages for the sedimentation process: Late Glacial-Preboreal at Dracășviz and Boreal-Atlantic at Șaeș, Bozieș, Sălicea, and Movile. Based on the pollen diagrams, the authors conclude the existence of several "*phases*" of landslides: an older phase in the Pleistocene-Preboreal, reflected in the pollen diagram from Dracașviz, and another in the Boreal, but without excluding the possibility of new phases in the wet periods of the Postglacial, particularly in the Subatlantic.

Partially replicating these studies, Tanțău and Fărcaș [35] perform palynological analyses at Dracășviz, more detailed than their predecessors, revealing, albeit lacunar, the vegetation history in the Dracășviz region starting with the end of the Late Glacial / Preboreal until the Subatlantic, with the 5 phases of vegetation described by E. Pop [26] for the lower altitude areas from the territory of Romania: the pine phase (*Pinus*), the pine-spruce transition phase (*Pinus- Picea*), the phase of mixed oaks, with spruce and hazel (*Quercetum mixtum-Picea-Corylus*), the hornbeam phase (*Carpinus*) and the beech phase (*Fagus*). There is an evident continuity of mixed oak forests in the area, from the Boreal to the historical period, up to the present day. According to the authors, "*the hypothesis of Pleistocene landslides in this geographical region was confirmed, given the pre-Boreal age of the peat bog, formed in a pre-existing depression that had developed due to the landslide*".

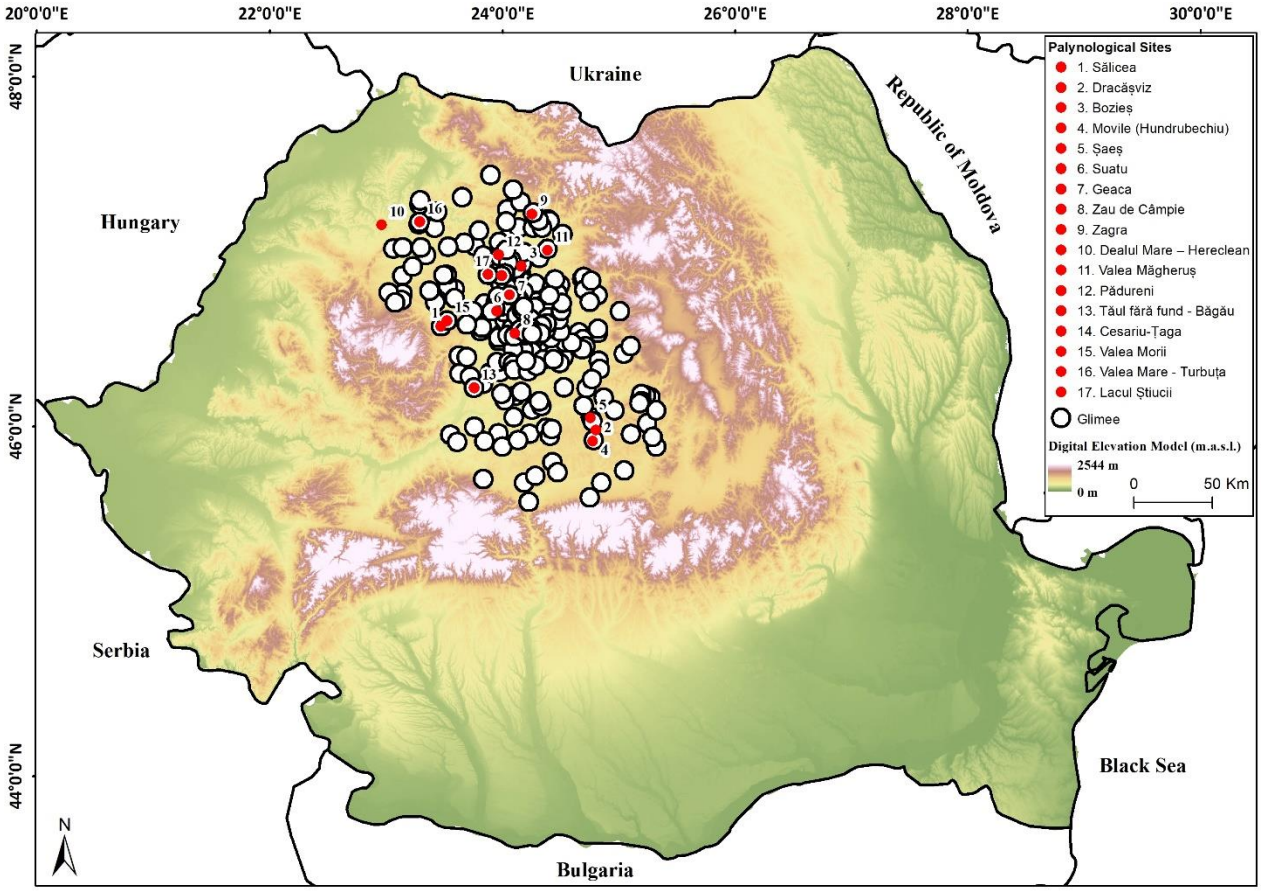

Fig. 1: The geographical location of the analyzed palynological sites and the distribution of the most important *glimee* in the Transylvanian Depression.

In 1964, Sandulache *et al.* discusses the origin of lakes in the Transylvanian Plain, taking into account the statements of Morariu [23] who considers both lakes and landslides as Periglacial and respectively Pop [28] who concludes that both morphogenetic phenomena – landslides and lakes in valleys – occurred in the last Postglacial period, in the Subatlantic or even earlier. To clarify this issue, the authors performed palynological analyses in the lakes of Suatu, Geaca and Zau de Cîmpie. Based on the pollen spectra obtained, they conclude that the freshwater lakes in the Transylvanian Plain are old, having formed in the Boreal-Atlantic, 7000-8000 yr BP, while the

dams that reflect anthropogenic activity are much more recent. These results, we believe, are consistent with the hypothesis of the existence of several "*phases*" of landslides [24].

Another "*lake*" that aroused interest both from a floristic [27] but also palynological [17] perspective is the Zagra Lake from the landslide area south of the Țibleș Mountains. Also called Tăul lui Alac, this landslide-dammed lake is located on Dealul Comorii, near the village of Zagra, Bistrița-Năsăud county. According to the author, the swampy lake was a clogged stage of a dam lake, formed in the depression that resulted between the slope and the slidden soil mass. At that time the "*lake*" itself was represented by two deep bodies of water, surrounded by a swamp. Possibly, it is the area known today as the Zagra Lake Reserve, with an aquatic ecosystem surface of *c.* 1.8 ha.

Following the palynological analyses, Lupșa reconstructed the history of the vegetation in the region starting with the end of the pine phase, at the passage between Late Glacial and Postglacial. The abundance of rainfall from the Subatlantic led to the formation of a deep water table, as well as the establishment of a *Sphagnum* peat bog. According to Morariu [22], "*the geological disturbance that determined the landslides, the sinking and the appearance of the lake, according to analysis of the pollen and sediments, may have taken place before or during the Quaternary Glaciation, when man had not yet entered this valley*."

In the area of *glimee* from Dealul Mare - Hereclean, near Zalău, Șuteu *et al.* [34] investigated the vegetation history in the marshy pools formed at an altitude of *c*. 210 m. The authors state that the foundation of these swamps is represented by an alternation of sandy marls with sands, which were, in a colder and wetter climatic period (Subatlantic) prone to massive landslides. Palynological spectra confirm this hypothesis, reflecting the composition of Subatlantic forests in the region: mixed oaks (*Quercetum mixtum* = 28–45%), composed of sessile and pedunculate oaks, limes, maples, ashes, but also beech (*Fagus* = 20–30%), and at higher altitudes spruce (*Picea*) and even fir (*Abies*). The overrepresentation of alder (*Alnus*) in the pollen spectra also suggests a humid edaphon, favored by the humid and colder climate.

Also, Diaconeasa and Mitroescu [7] obtained interesting results by analyzing the pollen of a sequence extracted from the „*Tăul fără fund*" swamp in Băgău, a clogging lake, formed behind an older landslide. The basal part of the sag pond formed by the landslide is covered with clay material of variable thickness (7.4–10 m), which turned out to contain both Tertiary and Quaternary pollen. Peat was deposited over the basal clay, its age estimated by the authors on the basis of pollen spectra, in the absence of C14 dating, as Boreal-Atlantic. The authors also note, over the entire range of analyses, the predominance of forest over grassland ecosystems.

Near Cluj-Napoca, at Valea Morii, Tanțău and Fărcaș [36] analysed two palynological sequences, following the evolution of vegetation in the region starting with the end of the Late Glacial. They revealed the continuous and dominant presence of hill-belt forests throughout the whole Holocene period. Sedimentation was slow in the first part of the Holocene, registering two hiatuses, the first during the Preboreal and the second during the Boreal. The sedimentation rate strongly increased during the Subatlantic, where, however, sterile horizons were also recorded, reflecting the change in sedimentation conditions.

At the north-western limit of the Transylvanian Depression, on Valea Mare, at Turbuța, the pollen, micro-charcoal and total carbon analyses performed by Feurdean *et al.* [11] reveal the environmental changes from the Younger Dryas to the Middle Holocene. The results indicate the presence of open pine (*Pinus*) and birch (*Betula*) forests with patches of spruce, elm, alder and

willow (*Picea, Ulmus, Alnus* and *Salix*) before 12,000 cal. yr BP. A rather sudden replacement of the dominant species by *Ulmus* at approx. 11,900 cal. yr BP reflects the effect of competition caused by global warming in the early Holocene. Up to 11,000 cal. yr BP, forests were increasingly diverse and dense, with the expansion of *Quercus, Fraxinus* and *Tilia* (oak, ash and lime), the emergence of *Corylus* (hazel) and the decline of herbaceous taxa.

The marked expansion of *Quercus* accompanied by *Tilia* between 10,500 and 8000 cal. yr BP could indicate low humidity, associated with both the low altitude of the site and a regional shift to a drier climate. At 10,000 cal. yr BP, *Corylus* spread throughout the region, and at 8000 cal. yr BP it replaced *Quercus* as the dominant forest component. The hornbeam (*Carpinus*) settled in the area at around 5500 cal. yr BP. The results of this study indicate that during that period the forests in the lowlands of Turbuța have never been closed.

The sediments of the paleolake from Valea Măgheruș provided new data on the development of the Romanian paleo-environment during the Late-Glacial [16]. The studied sediments accumulated after the damming of a small river valley, following a series of events that happened during the de-glaciation period. A continuous sediment sequence belonging to the former lake has been preserved on the banks of the creek and contains evidence of the environmental changes associated with the Late Glacial Interstadial (Bølling-Allerød) and the Late Glacial Stage (Younger Dryas).

These climatic events are reflected by the vegetation dynamics in the region. The Late Glacial Interstadial was warmer and wetter, as shown by the increased organic matter content of the lake, decreased basin erosion, the development of marsh plant communities, and the expansion of *Picea* during the Allerød interstadial. The Late Glacial Stadial was colder and drier, as indicated by the low content of organic sediments, an increase in erosion markers and a decrease in spruce and its replacement with birch. The landscape was more open, since the herbaceous species expanded during this period. Based on the interpolation of C14 datings performed on charcoal and wood fragments, the authors concluded that the lake sequence was deposited between a. 15,280 ± 475 and 12,490 ± 450 cal. yr BP.

These studies partially confirm those carried out previously by Diaconeasa [4], which, based on the pollen spectra obtained, and in the absence of C14 dating, frames the sequence studied from Valea Măgheruș in a cold period of the Late Glacial, the accumulation of sediments ending in the Dryas I c (in the Bølling-Allerød Interstadial). The author highlights a pine phase, with several forest episodes: pine, pine-spruce, pine and pine-birch and the absolute dominance of forest vegetation during that period.

Following studies conducted at Lacul Știucii, while trying to elucidate the origin of the forested steppe in Transylvania, Feurdean *et al.* [9, 10] provided the first indisputable evidence for the existence of coniferous forests in this region since the last MIS 3 glacial cycle. The chronological results indicate that the basin of Lacul Știucii is recording the environmental conditions since about 55,000 cal. yr BP (Full Glacial) with probable erosive events between 38,000 and 13,000 cal. yr BP. However, according to the authors, the accumulation of sediments in the last 12,000 cal. yr BP was continuous. These forests endured during MIS 2 and 1, and even predominated before 3700 cal. yr BP, challenging the hypothesis that the lowlands of Transylvania were not forested after the last glaciation. However, these forests were never completely "*closed*", reflecting the climatic conditions (warming) and natural fires, but also the anthropogenic impact, all these factors favouring the persistence of grasslands throughout the Holocene.

Gârbacea *et al.* [12] state that the *glimee* played an important role in the evolution of the Transylvanian landscape. The authors studied the landslides from Pădureni, at the Unguraș Hills, in the N-W part of the Transylvanian Depression. In a longitudinal depression between the first rows of these landslides, an oval-shaped peat bog called "*Tăul Fără Fund*" formed, with a thickness of about 300 cm. They used a sample taken from the lower part of the sequence (295 cm deep), from the failure plane, at the boundary between peat and the basal clay. The entire sequence is 310 cm long. The lowest part (10 cm) consists of lacustrine clay, over which they found 5 cm of organic clay (depth of 300–295 cm). Most of the sequence (295–0 cm) is represented by *Sphagnum* peat.

For a better understanding of the paleoenvironment and vegetation type around the site during the landslides period, a palynological analysis on a sample from the boundary between peat and basal clay was performed. The results show an "open" forest type of vegetation around the site at that time, composed of 59% trees and 41% herbaceous plants and ferns (*Pterydophyta*) and *Sphagnum* moss (*Bryophyta*). The forest vegetation was dominated by *Fagus sylvatica* (52%) and *Carpinus betulus* (23%). *Quercus, Alnus, Ulmus* and *Betula* were also present with lower percentages.

By C14 dating of the basal layer, the age of landslides was established for the first time in Romania (min. 1820 ± 30 yr BP, 1694-1825 cal. yr BP). The analysis of the pollen from this layer indicates that the landslide from Pădureni (Transylvania Depression) occurred in the Subatlantic. During this period the vegetation of the studied area consisted of open forests dominated by *Fagus sylvatica*. The results could indicate a possible period of deforestation that promoted the landslides.

In (probably) the same site, from Pădureni-Țop, in the absence of C14 datings, in an older paper, Diaconeasa [5] considers that the landslide process started before the end of the Subboreal swamping, interpreting the high percentages of hornbeam pollen (40%) as belonging to the Subboreal, although in later works [6] he remarks the so-called "*revertence*" process, i.e. the rebound of hornbeam percentages in Subatlantic, thus placing the age of the swamping in Subatlantic. In fact, Buz *et al.* [1], following palynological analyzes, reconsider the age of the landslide, stating that the landslide process was related to "*the appearance of a wet ecotope, triggered, with sufficient probability, by the Subatlantic climate in its initial phase*".

At *c*. 15 km from Pădureni, in the palynological profile from Cesariu-Țaga, Diaconeasa & Mitroescu [8] deduce, based on the pollen spectrum (14C datings lacking), an old date for the swamping, late Late Glacial to early Preboreal. The area was characterized at that time by a cold climate, being dominated by pine forests (*Pinus* 91%), sporadically accompanied by spruce (*Picea* 6%), birch (*Betula* 1.5%) and alder (*Alnus* 1.5%). Within this profile, sterile layers, respectively hiatuses or interruptions in the sedimentation process are noticeable, due to changes in the evolution of the paleoenvironment, having multiple possible causes.

In Romania, the forests dominated by *Fagus sylvatica* are characteristic of the Subatlantic period (about 2600 cal. yr BP up to the present day) and have been identified in sequences from different areas of the Transylvanian Depression [13, 37, 38]. Where large percentages of *Carpinus* pollen have been identified in the Subatlantic, they correspond to hornbeam *revertence* from the Subatlantic period, when, at lower altitudes, mixed forests of hornbeam with oak and/or beech were formed [6, 37, 38]. Also, the high percentages of mixed oaks in certain palynological sequences are due to the lower altitude of the respective sites and the greater distance from the beech formations located at higher altitudes.

Assessing the chronological sequence of landslide activity during the Holocene can help to better frame their distribution in the wider context of climate change and better define the danger of landslides in order to take appropriate mitigation measures, as stated by Niculiță *et al.* [25]. The authors classified landslides as very old, old and recent, depending on their morphological appearance and correlation with the studied archaeological sites, and created a model of landslide evolution during the Holocene for the Moldavian Plateau. Based on the data collected, they did not exclude the Pleistocene period for some very old landslides (about 12,000 years ago), while the rest of the landslides took place during the Holocene: the old ones after 6550 BP and up to few centuries ago, while the latest occurred in recent centuries.

The analysis of landslide inventories in the Moldavian Plateau showed a decrease in the size of landslides over time. The more recent landslides tend to be reactivations of older landslides, partially remobilizing their deposits and especially causing the retreat of their escarpments, according to Niculiță *et al.* [25]. The authors note an evolutionary trend, spatial and dimensional, of Holocene landslide activity in response to climate change.

Table 1: Palynological sites studied in Transylvania

No.	Site name	Climate period	Geographical Coordinates	Alt. (m)	Reference
1	Sălicea	Atlantic	46°40'N, 23°31'E	700	Pop E. 1932; Pop G. 1961; Morariu et al. 1964; Lupșa 1981
2	Dracășviz	Late Glacial/Preboreal	~ 46°08'N, 24°47'E	428	Morariu et al. 1964; Tanțău & Fărcaș 1997
3	Bozieș	Boreal-Atlantic	~ 47°01'N, 24°11'E	435	Morariu et al. 1964
4	Movile (Hundrubechiu)	Boreal-Atlantic	~ 46°01'N, 24°47'E	±510	Morariu et al. 1964
5	Șaeș	Boreal-Atlantic	~ 46°09'N, 24°46'E	415	Morariu et al. 1964
6	Suatu	Boreal-Atlantic	46°45'35"N, 23°58'47"E	±343	Săndulache et al. 1964
7	Geaca	Boreal-Atlantic	46°51'08"N, 24°05'07"E	±289	Săndulache et al. 1964
8	Zau de Cîmpie	Boreal-Atlantic	46°38'N, 24°08'E	±295	Săndulache et al. 1964
9	Zagra	Late Glacial/Preboreal	47°19'N, 24°16'E	420	Pop 1960; Lupșa 1972; Morariu 1974
10	Dealul Mare – Hereclean	Subatlantic	47°14'21"N, 23°0'05"E	210	Șuteu et al. 1978
11	Valea Măgheruș	Late Glacial	47°05′94"N, 24°23′61"E	345	Diaconeasa 1979; Lascu et al. 2015
12	Pădurenii	Subatlantic	47º04′52"N, 23º59′21"E	420	Diaconeasa 1985; Buz et al. 1986; Garbacea et al. 2015
13	Tăul fără fund - Băgău	Boreal-Atlantic	46°19'N, 23°48'E	430	Diaconeasa & Mitroescu 1987
14	Cesariu-Țaga	Late Glacial/Preboreal	46°57'43"N, 24°01'09"E	250	Diaconeasa & Mitroescu 1988
15	Valea Morii	Late Glacial	46°42′N, 23°34′E	620	Tanțău & Fărcaș 2001
16	Valea Mare - Turbuța	Late Glacial	47°15′44"N, 23°18′71"E	275	Feurdean et al. 2007
17	Lacul Știucii	Full Glacial	46°58′04"N, 23°54′10"E	239	Feurdean et al. 2013; 2015

The reactivation of *glimee*-type landslides triggered by the increased rainfall in the years 1970 and 1975, and the catastrophic effects they had on the morphology and dynamics of the slopes, highlighted the importance of geological and climatic factors, confirming the possibility of *glimee* development in the current period [21].

Woody vegetation prevents landslides through its buffer role in the water circuit. Cocean *et al.* [2] emphasize the major role of vegetation, particularly forests, in rainwater retention and in

fixing soil and slope materials, and that the mechanical balance of slopes is normally ensured by the shaping action of slope erosion and surface processes. In their view, destabilization occurs as a result of dynamic factors with major potential, such as heavy and prolonged rainfall.

Where the displaced material is covered by forests, geomorphological processes are limited. However, where grasslands are the dominant vegetation type, due to massive deforestation and the inclusion of land in the agricultural circuit, soil erosion processes and torrential runoff are increasing.

On the other hand, the specific geomorphological character of the *glimee* can indicate a high biodiversity conservation value in the physical-geographical context of the Transylvanian Depression [30]. The vegetation types that develop on the slidden soil mass are often different from the original vegetation of the unaffected slope, certain plant communities being known to have an affinity for landslides [19]. The *glimee* often provide conditions for particular plant communities, which may represent relics developed during past paleo-environmental conditions, such as the steppe vegetation developed during the Pleistocene [3].

Conclusions

The analysis of the works that considered this subject indicates two large periods of landslide occurrence, the Pleistocene and the Holocene. It can also be concluded that the landslides did not occur only in the early Holocene, but they are manifesting in Transylvania even during the current Subatlantic period. The factors that trigger them are both abiotic and biotic, among the most important being abundant rainfall alternating with periods of drought, and respectively the intense anthropogenic intervention on the landscape in different ways. Further studies could interconnect these insights and correlate them with the current climate change, to direct the evolution of relief and vegetation in the future.

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CONSIDERAȚII ASUPRA VÂRSTEI GLIMEELOR DIN TRANSILVANIA

(Rezumat)

Lucrarea constituie o sinteză asupra studiilor palinologice care au abordat problema vechimii alunecărilor de teren din Transilvania. Se prezintă configurația paleo-vegetației din zonele respective, dar și factorii probabili, abiotici sau biotici, care au determinat alunecările de teren. Se evidențiază perioada de timp relativă în care au avut loc aceste alunecări de teren în Transilvania. Analiza efectuată indică două mari perioade de declanșare a acestui fenomen, Pleistocenul și Holocenul.

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